TAMPEREEN TEKNILLINEN YLIOPISTO
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UTILIZING VISUALIZATION TO SUPPORT MANAGEMENT AND PROCESS FLOW

Master of Science thesis

Examiner: prof. Minna Lanz
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TIIVISTELMÄ

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Tämä diplomityö on kirjoitettu Metso Mineralsin tehtaan uuden tuotantolinjan kehitysprojektin layoutin suunnittelusta ja toiminnan visualisoinnista. Tuotannon ja toimintojen visuaalinen virtaus on tavoitteena useille valmistavan teollisuuden yrityksille. Virtaava prosessi parantaa tuotannon tehokkuutta ja hallittavuutta. Layoutin optimaalinen suunnittelu ja lean ajattelutavan sisäistäminen ovat tärkeitä osia virtauksen luomisessa.

Diplomityön tarkoituksena oli luoda uusi tuotannon layout joka tukee prosessin virtausta ja mahdollistaa tarvittavat toimenpiteet tahtiajan saavuttamiseksi. Tämän lisäksi diplomityön tavoitteena oli visuaalisin keinoin helpottaa virtauksen havaitsemisessa ja johtamisessa. Päätavoitteena oli luoda layout ja visuaalinen järjestelmä joka tukee uuden linjan 360 minuutin tahtiaikaa.

Työn tutkimuskysymykset oli *kuinka visuaalisuus tukee prosessin virtausta ja johtamista*, *kuinka visuaalisuudella voi kehittää kokonaisvaltaista hyvinvointia työpaikalla* ja *kuinka visuaalisuudella voi kehittää jatkuvaa parantamista.* Työ vastaa näihin kysymyksiin.

Tuotannon layoutin, prosessien ja toimintamallien nykytila on esitelty ja niiden pohjalta havaittu kehityskohteita prosessin virtaukseen, visuaalisuuteen ja toimintamalleihin liittyen.

Lopputuloksena tuotantoon luotiin uusi tuotantoalue, jonka suunnitteluun ja rakentamiseen osallistui useat tuotannon työntekijät ja toimihenkilöt. Uuden tuotantoalueen materiaalin ja prosessin virtausta tukemaan kehitettiin Leanin työkaluja hyödyntämällä visuaalisia apuvälineitä tukemaan tahtiajan saavuttamista ja tuotannon epänormaalien olosuhteiden havaitsemista. Näillä toimenpiteillä pyrittiin myös tukemaan prosessin johtamista. Kehitetyt toimintatavat ja työkalut tarvitsevat tarkastavan kehityskierroksen, jolloin varmistetaan niiden toimivuus ja kehitetään ne edelleen paremmiksi tukemaan erilaisia toimintoja.

ABSTRACT

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This thesis is written for the Metso Minerals factory's development project of creating new production line and more precisely of production layout planning and operation visualization. Visual flow in production and operations is the goal for many companies in manufacturing industry. Flowing process will improve the efficiency and manageability of operations. Planning an optimal layout and internalizing lean thinking are essential parts in creating flow.

The goal of this thesis is to create a new production layout that supports process flow and enables certain operations to reach defined takt time. In addition, the goal is to improve visualization to ease flow observation and process management. The main goal was to create a layout and visual system that supports the new 360 minutes takt time.

The research questions were *how visualization supports management and process flow, how visualization can improve overall ergonomics in the workplace* and *how visualization can support continuous improvement.* These questions are answered in this thesis.

The present state of layout, production processes and operation models are presented. Based on that information new development targets in process flow, visualization and operation model are observed.

Finally, the new production area was created and most production and office workers participated in this change. A visual management system was created by using Lean tools to improve material and process flow. Visualization supports takt time management and perception of abnormalities in production. All developed operating models and tools require a check round to ensure that they work as intended and to improve them to be even more supportive of different operations.

PREFACE

Studying at Tampere University of Technology has been an unforgettable journey. The past six years have included many challenges, instructive courses, priceless moments and feelings of success. TUT has given me great memories and lifelong friendships but now it is time to turn next chapter and go towards new challenges.

I want to thank Metso for giving me an opportunity to participate in an extremely interesting development project. It was challenging and interesting to write thesis from creating new production area and operation models. I want to thank all the employees in Metso for sharing their knowledge of the processes and participating in my thesis research. Especially I want to thank my thesis advisors Project Manager Juha Erkkilä and Development Manager Sampo Myllymäki for answering all my questions, giving helpful advice and supporting me through this project. I also want to thank examiner Professor Minna Lanz from Tampere University of Technology for valuable feedback and advice.

Finally, I want to thank my parents, my sister and my brother for supporting me during my studies, cheering me towards my goals and encouraging me in every field of life. I also want thank Niko who has been invaluable support for me every day and encourages me to reach my dreams.

Tampere, 28.2.2018

Anna-Leena Lehtonen

SISÄLLYSLUETTELO

LIST OF FIGURES AND TABLES

LIST OF DEFINITIONS AND ABBREVIATIONS

MES	Manufacturing Execution System
SLP	Systematic Layout Planning
TPS	Toyota production system
JIT	Just in time
VSM	Value stream mapping
NVA	Non value-adding activity
VA	value-adding activity
WIP	Work in process
P	Product
Q	Quantity
Speedline	Final assembly line
LT	Lokotrack machine
ERP	Enterprise resource planning
DPD	Delayed product differentiation

1. INTRODUCTION

Metso Minerals Tampere factory's line assembly department is assembling mobile crushing equipment in line production. It has implemented Lean to the factory activities and ways of working. Lean in the production area has brought some positive results already and the goal was to implement more Lean practices to new production area to enable the visual process flow and improve manageability.

This thesis was written for Speedline 2 -project the goal of which was to increase the production capacity for larger models and fasten the lead time. In the project the final assembly line, Speedline, was moved to the largest production hall and all smaller subassemblies were moved closer to it under the same roof. At the same time, the amount of stations was increased from 4 to 6 and takt time was changed from previous 8 hours to 360 minutes to enable even the most difficult models to go through the line on time. This thesis creates a new layout to the production area and improves production flow and management processes with implementing visualization to different operations in the new layout.

The layout planning process was full of difficult compromises where all spaces had specific requirements. Decision making was restricted by the physical requirements of each station and their influence in material and process flow. Making a change in production layout provided an opportunity to have an even larger change in common practices and culture. The Production process and operating model was considered again and improved to respond better to its current and future requirements.

This thesis was done to improve the process flow and management of the new line by visualization. Research methods are used to analyze the models that could be suitable for the transformation. That way the best models can arguably be chosen and implemented in the production line transformation project. A new visual management system was created to support the 360 minutes takt time and management.

This chapter introduces the thesis goals and research questions followed by used research methods and thesis structure.

1.1 Goals and research questions

The goal of the thesis was to create new production line and visual management system to support it to achieve the 360 minutes takt time. The system goal was to support the process flow and management. Smaller goals to support this goal were to minimize created waste, create pull system, create system to takt time management and to make employees multi-skilled. The main goal and smaller sub-goals are presented in figure 1.

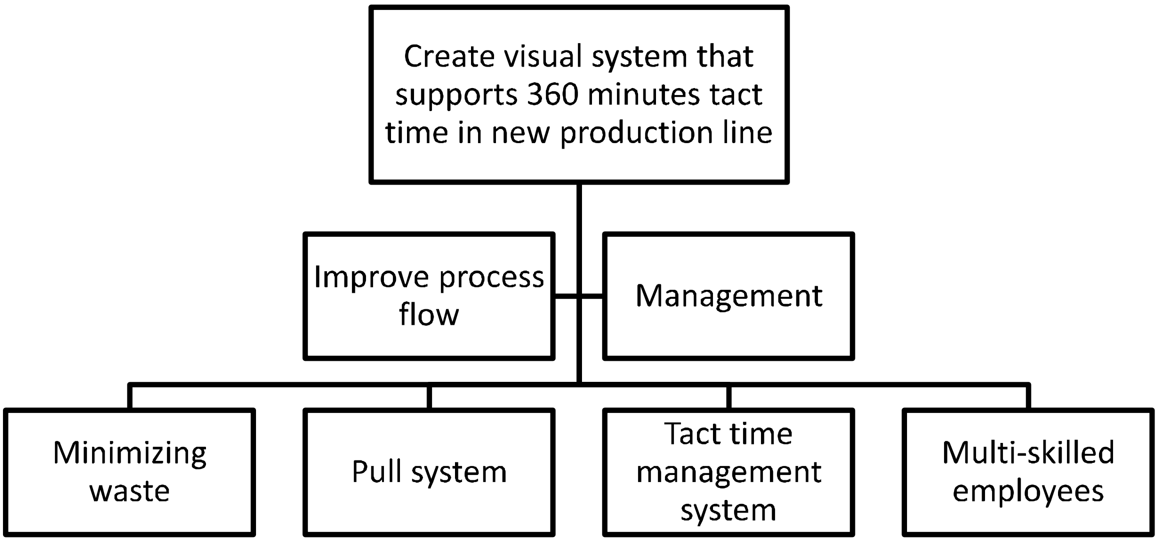


Figure 1. *Main goals and sub-goals of this thesis*

The first sub-goal was to detect waste in the old production and surrounding processes and to ensure that same waste is not present in the new production area. That way the waste in the new production area can be minimized. The second sub-goal was to create an operating model for a successful execution of pull system that would improve material stream and create as waste free material flow as possible. The third sub-goal in the thesis was to create a system that helps the takt time management and ensures the conditions of successful takt execution. The fourth sub-goal was to create a learning model to improve learning processes and increase skill levels.

By setting these goals three thesis research questions could be defined:

1. How does visualization support management and process flow?
2. How can visualization improve overall ergonomics in the workplace?
3. How can visualization support continuous improvement?

1.2 Research methods

This thesis is an action study of creating new production layout and visual system to help process flow and management. This project was chosen for the action research since it is a common goal in the industry to create more visualized production to support the process flow and management. These types of large projects are not common in the company so it gave good opportunity to enhance visualization at the same time when also other major changes were happening. In addition, the timing was suitable for project execution and this thesis research. The research methods used and the objectives why they were chosen to this action research are presented in figure 2.

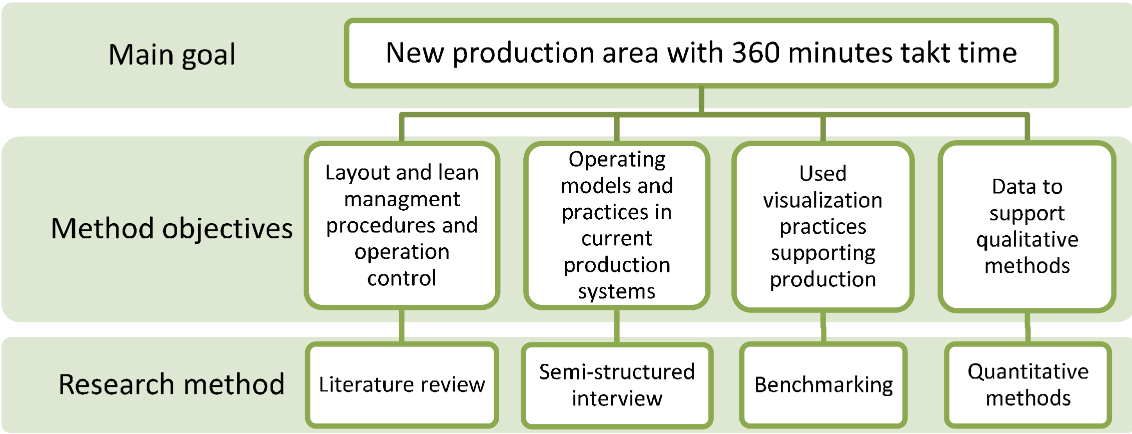


Figure 2. *Research methods used in this thesis*

Literature review was used to get to know procedures that would be useful in creating new layout and learning of different lean management practices that could be used to visualize the production. Literature review was also used to get familiar with manufacturing control and other visual management systems as well as change management.

Semi-structured interviews with many employees with different backgrounds were used to find out the current manufacturing processes and operation models. The method was also used to find out commonly used practices in production management as well as already known problems that could be fixed in the new line.

Benchmarking was used to find out how other companies in the industry implement daily management practices and visual management system. The goal was to become familiar with their observations of different procedures and learn from used practices.

In addition, a few quantitative research methods were used to get data that supports results from qualitative research methods.

1.3 Thesis' structure

This thesis is divided to eight chapters. It starts with the theoretical background of the production development procedures. Chapter two introduces guidelines for decision making in layout planning and the structure of layout planning process. It will explain the development of lean management system and fundamental features of lean. It will also go through manufacturing control and visual management systems considering lean management.

The third chapter introduces basic principles of research methods that are used in this thesis. It will present the theory of semi-structured interview and how the interview events were carried out. In addition, it presents a theory of benchmarking and how the research method was used in this thesis. Lastly it presents a few quantitative methods that were used to get supportive data.

Chapter four explains the current state that will be changed during the project. It starts with a short company introduction and continues with introducing the current operation models and production control procedures. It will also present the current layout and introduce all assembly areas in production. Finally, it will introduce all challenges and problems that the current layout and working methods have.

Chapter five presents the planning process of the layout with its targets, restrictions and methods. It will also introduce the visual management system planning process. Lastly it introduces the main decisions that were made concerning the operating model, physical layout ergo location of each assembly area and added visual elements. It will also introduce the new layout with its capacity and safety considerations as well as the transition process from the old layout to the new layout.

Chapter six introduces the changes that were performed in production. First it will introduce the new layout and take a closer look at safety and capacity improvements. It will also explain the transition process from the old layout to the new layout. Then it will explain how the visual management elements were implemented to the operations to improve the process flow and management. The chapter also presents the analysis and results of each used element.

Chapter seven discusses the achieved results and presents further development topics that came up as the project proceeded. It will set the basis for the next step in action research.

Chapter eight generates a summary of the thesis. It presents how the set goals were achieved and evaluates the success of the thesis.

2. THEORETICAL BACKGROUND FOR LAYOUT AND OPERATIONAL DEVELOPMENT

Development processes are essential for the company to maintain its competitiveness and improve its market status. Sometimes large and radical development processes are required to ensure long term competitiveness and capacity to meet future market requirements.

This chapter presents and examines the theoretical background of layout planning, lean, production controlling and visualization. First it concentrates on layout planning and its development process. Then it explains the principles and techniques of lean followed by a section of lean management and manufacturing control. Then it introduces some ways of visual management and how it can be a helpful tool in production. Finally, this chapter focuses on lean leadership and how to face change resistance.

2.1 Layout Planning

The need for layout changes is driven by several factors. Factors such as product changes or design updates, changes in markets, an attempt to reduce costs and the well-being of employees are a few of many common reasons for companies to change their layout. The layout is a critical factor for the process and material flow and since an efficient material flow through manufacturing process can create competitive advantages for the company, layout planning needs to be done carefully. (Munroe, 2009; Green et al. 2010)

Muther (1955) mentions eight factors that are influencing layout and they all should be considered when creating a new layout. When considering the factors, the emphasis of each factor can be decided. These eights factors are materials, machinery, man, movement, waiting, service, building and change. Under each factor there are several features that need to be examined. All the features are not important in each layout, but by going through the list of features one can ensure that all important factors have been taken into account and the research has been complete. Later when the layout plan has been done the list can be used as a check list. (Muther, 1955; Naqvi et al 2016)

A few fundamentals provide the guidelines for the planning process. The planning process should always start from planning the general layout and then planning the details. The planning process should also always plan an ideal layout and then form and modify it to be practical. The ideal layout plan rarely comes true due to practical limitations but by modification it is possible to get as ideal a layout as the conditions allow. These two fundamentals can be fulfilled if the planning phases overlap during the planning process.

Some information from a previous phase might be essential to decision making and therefore the previous phase should not be decided before checking the following phase. (Muther, 1955)

Before the layout planning process can start it needs to be confirmed that the part is designed to be successfully manufactured. The production processes and needed machinery are then planned around the required materials. After that the layout planning will start by planning the layout around the just defined processes and machinery and then the building will be planned around the layout. (Muther, 1955)

The layout planning process should be clearly visualized. Drawings, models and other visual aid will help to eliminate potential mistakes before installation and they are a great help when explaining the plan to others. Planning should always be performed with the help of experts in the field. Decisions are usually compromises but when everyone gets to share their opinions and suggestions the best result can be achieved. It is easier to a plan layout with multiple groups if the visualization is well organized. (Muther, 1955)

2.1.1 Layout types

Moore (1968) has classified layout change types to four categories in which we are only focused on relocating into existing facilities. In this thesis, the facility of the building already exists. Relocating into existing facilities gives an opportunity to fix and update outdated production methods and develop processes with lower cost than normal since the layout change involves major changes anyway. (Moore, 1968)

There are three classical types of layouts: Product layout, process layout and fixed position layout. Product layout is commonly known as an assembly line where the production is divided in stations and each station has specified tasks to complete until the product moves to next one. The product needs to be well standardized so that certain activities can be done in the same stations of the line. In process layout, all similar value adding activities are done in the same departments. In fixed-position layout the product does not move but the workers and material move. It is rare to use only one of these layouts and most practical and used layouts are built as a combination. These types are integrated together to gain advantage from each type (Muther, 1955; Moore, 1968)

Multiple objectives can be achieved with a new layout and since the layout affects many people it needs to be considered with all parties. In an optimal layout the process has been simplified, the unnecessary equipment has been removed and material movement and work-in-process has been minimized. A good layout also considers workers’ safety, well-being and utilization. (Muther, 1955; Moore, 1968)

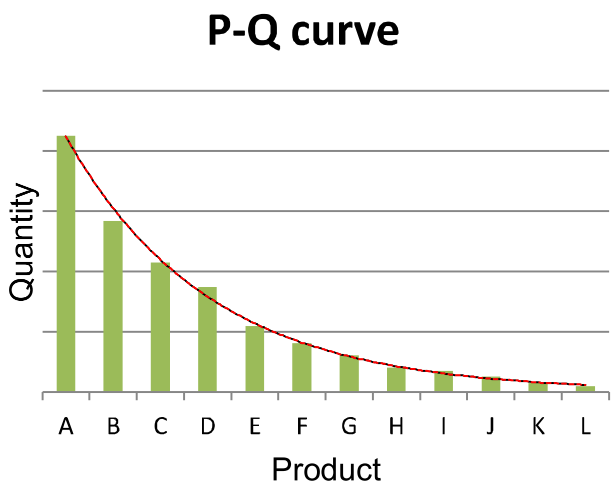


Figure 3*. Product-Quantity chart (Muther, 1973)*

Product and Quantity are the key elements in every layout problem and therefore they have a big impact in choosing the best layout type. Volume-variety analysis, also known as product-quantity (P-Q) chart that is presented above in figure 3 reveals which layout type would be suitable for each product. The “fast-mover” end (products from A to D) on the left has few product variations with high production volumes and therefore those products favor mass production methods. The “slow-mover” end (from H to L) on the right where the production volume is small and variation is high, favors individual production methods. The most efficient results can be obtained if the products are divided and produced in separate layouts when neither end needs to compromise. Products between these two extremities (from E to H) would be efficient to produce in a combination layout. The product-quantity chart does not consider delayed product differentiation (DPD) analysis where the product bases are similar but their differentiation is done at the last stages of production. The goal in DPD is to keep common product configurations and assembly line and processes as long as possible. (Muther, 1973; AlGeddawy et al. 2009)

2.1.2 Layout planning process

Muther (1984) divides layout planning to four phases which are following

1. Location
2. General overall layout
3. Detailed layout plans
4. Installation.

The first phase focuses on determining the area where the new layout will take place. It usually means determining if the planned layout will stay in the same place or if it is moved to another potential place. (Muther, 1973) In this thesis the place for the new layout has been assigned beforehand so we will not further look at this phase.

The second phase result a rough layout in which the relationships, sizes and configurations of all involving parts of the layout have been considered. The third part goes into layout details and it locates all machinery and equipment that the production needs. The following table 1 presents six steps of phase two and phase three. Both phases go through same steps but with different intensity and points of view. (Muther, 1973)

Table 1. *Tasks in layout planning process phases two and three (Muther, 1955)*

	Phase 2 **General over-all layout**	Phase 3 **Detailed layout plan**
Step 1 State the problem	Get clear picture; ensure the assignment and the scope. Schedule the project.	Get a clear picture of the assignment e.g. what are assigned areas and how detailed layout is wanted.
Step 2 Get the facts	Get data from present and future plans, production requirements and affecting factors.	Re-examine data to ensure that all needed facts have been collected and gather additional production data such as volume, time and cost
Step 3 Restate the problem	Review the problem and facts together to clarify the problem.	Review the assignment considering data; ensure that there is enough data and it is broad enough. Define critical factors in each area.
Step 4 Analyze and decide	Evaluate and organize the facts to set up relationships. Finish analysis with decision general over-all layout.	Determine the flow of material, men and tools. Evaluate the facts from every aspect and take into consideration adjoining areas to create detailed layout to each area.
Step 5 Take Action	Make the layout and check it with project question. Review with people in charge and submit.	Clarify the plan, check the layout, go the plan over with operating people and if no suggestions come up finalize it and present for approval.
Step 6 Follow up	After deciding the over-all layout move to phase 3 and focus detail planning on each work area.	Prepare detailed drawings for installation and schedule the process. Check the layout after installation if needs for layout changes emerge.

The last phase is the installing phase where decided moves are carried out and the layout plan is fulfilled. In general, there is going to be more and more detailed information as process proceeds. (Muther, 1973)

Muther (1973) introduces the Systematic Layout Planning (SLP) pattern to give an organized way to layout planning. Relationships, space and adjustment are always in the key role when planning a layout and therefore the SLP pattern is based on these three fundamentals. The SLP pattern of procedures is presented in figure 4. Muther (1973)

Product and quantity, the basic elements in every layout, were introduced before. But layout planning process includes other important elements as well. When the product and quantity tell what and how many products are made it is as important to know how it is made, when and what supporting services are needed to make it. Therefore, other important input data is process routing and equipment, supporting services and timing. (Muther, 1973)

The first box of the procedure is analyzing material flow. Flow is an important factor in every layout but it needs to be integrated together with supporting activities to create basis for the layout. After the information of the order of activities and important relationship requirements of activities has been gathered it is possible to form a relationship diagram which is a very simplified layout. The next step is to analyze the required and available space which will assign a location for each work unit. The results from a space analysis will form space relationship diagram which is a very simplified layout. Then the diagram is modified and adjusted with multiple modification considerations that affect production, such as handling methods and utilities, and practical limitations like existing facilities, contracts or regulations. The modification process will create a few alternative layout plans that will be evaluated by various methods and the final layout proposal is decided. If the decision needs to be approved by someone else, it is sent for approval. If not, the process will continue with detailed layout planning. (Muther, 1973)

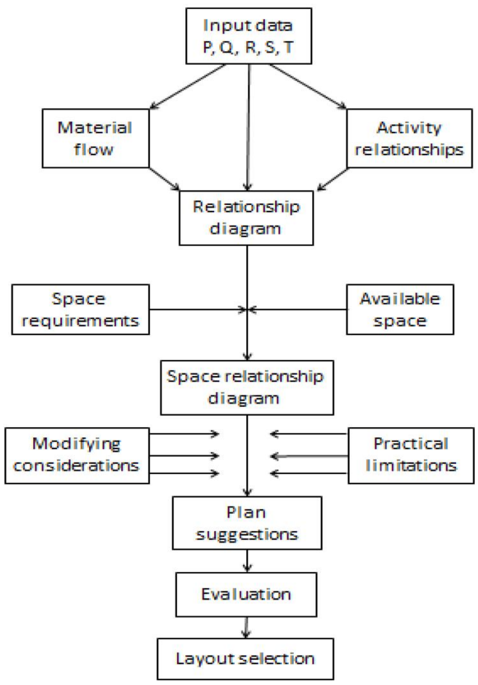


Figure 4. *Systematic layout planning process tree (Muther, 1973)*

Detailed layout planning requires more specific data and dimensions to do analysis but the pattern of procedures is the same as in overall layout planning. One major difference between detailed and overall layout planning is the people involved. In overall layout the planning process should involve managers whereas in detailed planning the process should include people that are directly responsible for or involved in the work at that area. Those people can be foremen, supervisors and workers. (Muther, 1973)

2.2 Lean

Lean philosophy is developed from Toyota's production system. Lean manufacturing is a demand driven production system that was developed to compete with traditional mass production. Lean's main idea drives from customer need: the focus is on waste elimination and creating perfect value for the customer. The system aims to a balanced system that is flexible, smooth and waste free. Lean implementation requires time, resources and systematic work. Starting lean journey is rather easy but sustaining is the challenging part and will require patience and commitment. (Beecroft, 2003; Liker 2004)

2.2.1 Toyota Production System (TPS)

Lean is developed based on Toyota Production System. Toyota developed TPS after the second World War to respond to the needs of post war Japanese car market. The conditions were much different from the US competitors and therefore they needed a different approach to improve their processes. American car brands had more resources and they assembled high quantities of one model in mass production lines when Toyota struggled financially and needed to use the same assembly line for multiple models and be productive. Mass production advantage of continuous material flow needed to be achieved without storage and creating waste since they lacked the space and resources. (Liker, 2004; Ward, 2009)

These conditions helped Toyota to discover that flexible production and short lead time resulted in higher productivity and quality as well as higher utilization of space and equipment. Therefore, Toyota focused on eliminating all non-value adding activities along their value chain. Toyota researched and implemented different techniques, such as basic supermarket filling process, to create a "pull system" and one-piece material flow which led later to the creation of Toyota Production System. Toyota started to spread TPS philosophy to their suppliers and the one lean manufacturing plant grew to be a lean enterprise. In 1960s TPS was rather unknown outside of Toyota and its suppliers, but after the oil crisis 1973 the fast recovery of Toyota draw others attention. (Liker, 2004)

Companies are using various tools and methods to be Lean but they miss the most important thing in it, the one that can't be seen. If a company wants to be a lean enterprise it needs to follow the five-step process of identifying customer value, defining the value stream, creating flow, creating “pull system” and creating a culture of continuous improvement. (Womack, 2004; Liker, 2004)

Toyota has worked together with many companies and universities and shared the tools they use to improve production but even using all the lean tools does not make the company lean. The secret of success is not the tools but their business philosophy that has grown together with Toyota and still develops continuously. Figure 5 presents the Toyota’s principles which are divided to four P’s: Problem solving, People and partners, Process and Philosophy. (Liker, 2004; Modig et al. 2012; Womack, 2004)

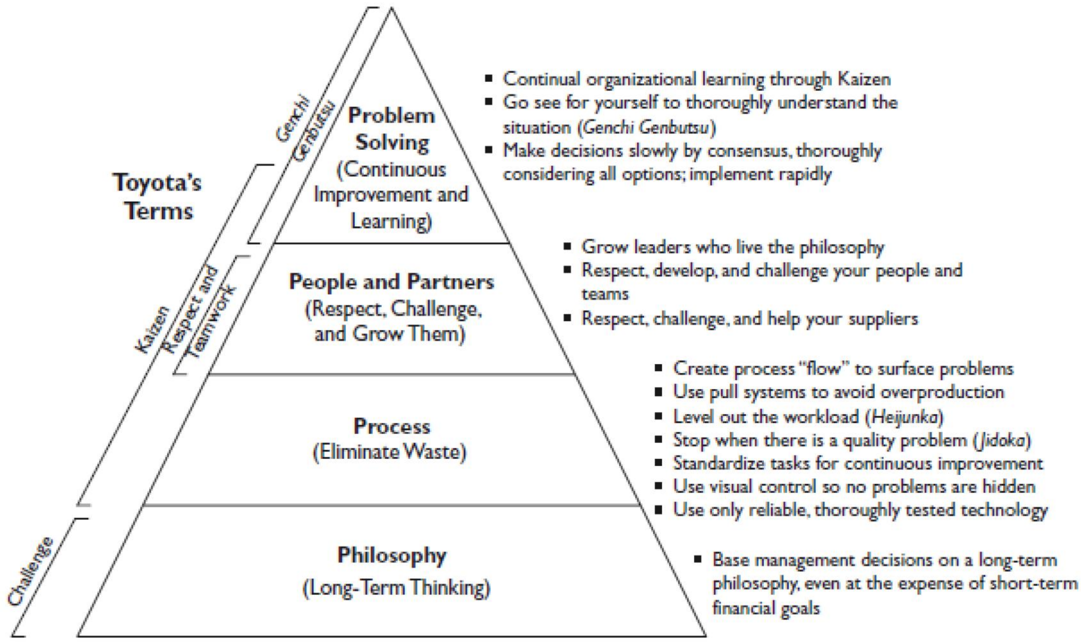


Figure 5. *Toyota's principles (4 P's) in iceberg model (Liker, 2004)*

The iceberg model presents that the tools on the top are just a small part of lean and the base is a challenge of the long-term thinking and commitment. Many companies only focus on “process” level and forget the other levels, which keeps them from reaching the culture of sustainable continuous improvement. (Liker, 2004; Womack, 2004)

TPS House seen in figure 6 is commonly known diagram in manufacturing. It presents how TPS is one tough structure which is created from strong parts that support each other. Many companies have created similar houses to present their principles, but the basic idea of each house is similar. (Liker, 2004)

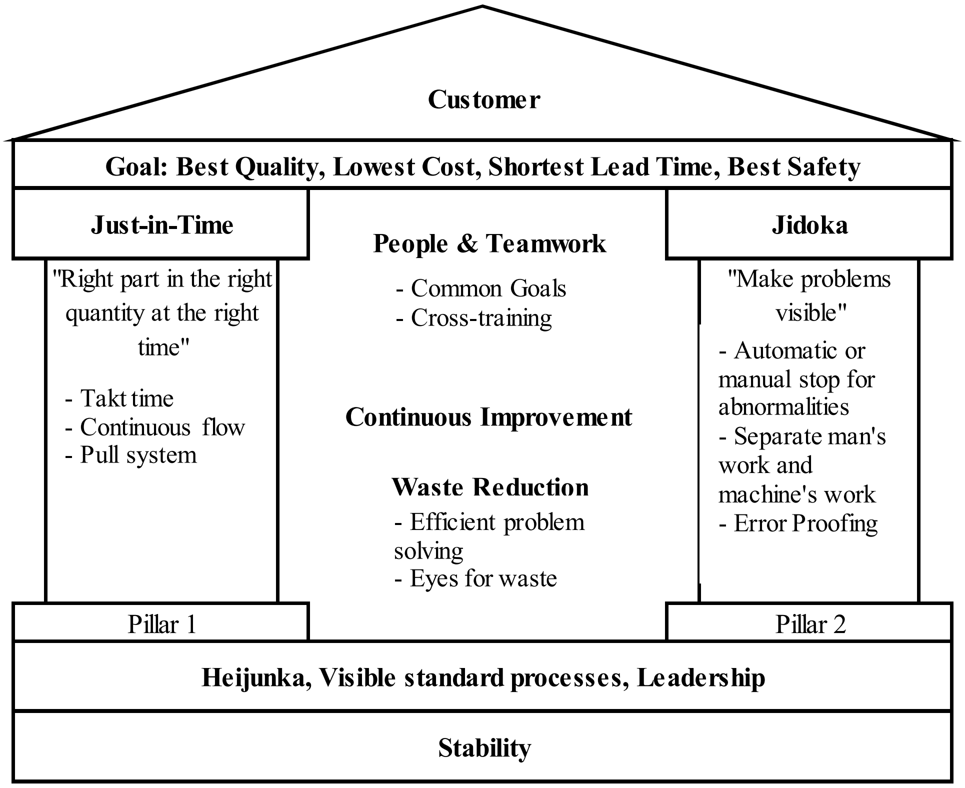


Figure 6. *TPS house presents principles and goals as a strong structure where all parts support each other, modified from (Liker, 2004)*

The top of the house is the roof which presents goals. The roof could not stay up without its two pillars: *Just-in-time* and *jidoka*. Just-in-time (JIT) is a strategy that allows company to deliver the right amount of the right product at the right time and that way to eliminate waste. In the "pull system", the material flow is seen as one-flow in the whole production process and it ensures that the work station gets the needed parts just when they need them without unnecessary storage or waiting time. The material is delivered based on demand. That saves space and allows being flexible on customer demand. Jidoka means built-in quality. When a quality problem emerges, the production is stopped immediately by the worker and the problem is fixed. It prevents faulty products from proceeding in the production. Every worker is responsible for stopping faulty products immediately. The solid foundation of the house consists of elements such as leveling production and stable and standardized processes that enable efficient activities. In the center of the house are people and the various operations that create a base for continuous improvement culture. (Liker, 2004; Stevenson, 2014; Modig et al. 2013; Tuominen, 2010)

2.2.2 One-piece Flow

Mass production and lean have different approaches to manufacturing. Mass production's focus is to benefit from the economies of scale and high utilization of people and machines, which can lead to long lead times and to the creation of different types of waste.

Lean production focuses on delivering the product only for customer demand and to deliver the need as quickly as possible. In one-piece flow the batch size is lowered to one and there is always one product completed for each started product. (Liker, 2004; Beecroft, 2009; Rother, 2010)

Material handling can cost production over half of the manufacturing cost by requiring employees and equipment to move and store parts. The goal in lean manufacturing is to create one-piece flow that optimizes the production so the flow of material allows the part to flow through production quickly. One-piece material flow and shorter lead time will drive to the use of other lean tools. Flow reveals problems and gives an extra boost to solve them and practice continuous improvement since some problems can stop the whole production line. Creating flow can be difficult since the comfortable inventory is removed and the hidden problems are brought to surface. One mistake with implementation is to give up when problems occur, because the problems are still present but hiding behind inefficient process. (Liker, 2004; Green, 2010;)

One-piece flow creates benefits in reduced work-in-process, WIP, and free floor space which have a straight correlation to manufacturing costs. Those two also improve safety since there is no inventory on the floor and small batch sizes are easier to move. Short lead times give more flexibility, and productivity is increased when utilized resources produce only needed parts that the customer wants. (Liker, 2004; Womack, 2004)

2.2.3 Types of Waste

Lean is all about eliminating waste. The types of waste can be divided in three categories of *Mura, Muda* and *Muri*. Muri means overburdening people or processes which will result in safety and quality errors as well as unexpected breaking of machines and other failures. Mura means unevenness in production and it is caused by uneven production schedules or customer demands. Uneven production results in overuse of resources or sometimes lack of work. Muda is the most known waste type and means all activities that do not add value to the product. Liker (2004) wrote that the start of each process should start with the question *"what does the customer want from this process",* then start to minimize non-value adding activities. Multiple sources have identified eight types of waste and they are listed below. (Liker, 2004. Modig et al. 2012; Tuominen, 2010; Beecroft, 2003)

1. **Overproduction**. Production without orders generates storage and other costs. Production should always be based on actual customer need.

2. **Waiting.** The time when a worker or machine is waiting for work, material, tools or having no work is wasted time. The production needs to be planned to avoid unnecessary waiting time.

3. Transportation. Moving work-in-process or material long distances or back and forth. Transportation distances should be minimized by changing the layout.

4. Processing. There should be no over processing of products if the customer does not require it.

5. Inventory. Avoid having excess raw material or ready products to minimize tied capital and to avoid problems that inventory hides.

6. Movement. Any unnecessary motion such as walking or searching for tools or parts should be eliminated by better organization of the work place.

7. Defects. Production of faulty products creates unnecessary work. Therefore everyone along the production line is responsible for the production of a quality product.

8. Unutilized creativity. Utilize people's skills, knowledge or experiences e.g. to get new ideas, improve operations and save time.

The worst of the different kind of waste, is overproduction since it usually generates other kinds of waste. It leads to inventory of parts and waiting, which leads to the reducing of motivation for continuous improvement. Overproduction also creates the need to move a part to the storage and the reprocessing of parts that have been in storage long enough. (Liker, 2004)

Mura, Muda and Muri are not separate kinds of waste but rather influencing each other a lot. They all are causes and results of each other. Eliminating Muda is the most common focus in implementing lean thinking and in many cases Mura and Muri are left out, which will later result in more Muda. It is a never-ending treadmill if the eliminating concentrates only on one of three M's. (Liker, 2004)

2.2.4 Lean tools

Value stream mapping (VSM) is a visual tool to identify value adding (VA), non-value adding activities (NVA) and activities that are necessary but do not add value. VSM should always be the first thing to do when approaching the process. The process can be visualized to be a map that shows for example distances and times of the material flow and workers as well as information flow in the process. VSM is a quick tool to help reduce the total lead time closer to the actual value adding time. It provides information about activities in the process such as actual work, mistakes, waiting and used working methods. Based on the VSM the bottlenecks and waste creating activities can be identified but it does not eliminate waste so it needs to be performed together with other tools to achieve improvement. (Liker, 2004 p. 29; Beecroft, 2003, p. 136; Stevenson, 2014. p. 635; Green, 2010)

The goal in VSM is to describe all performed steps that form the current state of the process. Specific questions of its VA activities, capabilities, availability and capacity are asked in each step to find out which steps do not add value to the customer and which steps require improvement. In addition to the steps the VSM includes analysis on how these steps are connected to each other. The current state map reveals the current performance level and the information is summarized in a box score. The current state map and box score give information on the parts that need to be improved for a future state map. To achieve the future state there is a need to perform a series of development projects, kaizens. (Womack, 2004; Stevenson, 2004)

The VSM process can be seen as a continuous wheel in which at some point the future state becomes the current state and the cycle begins again. VSM process reveals the improvement in the process performance level that can be achieved by small flow and process improvement projects and sustaining them. Some problems can occur in achieving the future state if there is not any implementation plan to follow. The plan can be presented for example with Gantt – chart and it should have clear list of all objectives, a monthly or weekly schedule for their implementation and the person in charge of each implementation process. (Womack, 2004; Beecroft, 2009)

Kanban is a visual signal that is used to manage the flow of materials in JIT production system where small inventory is needed. Kanban makes the "pull system" possible when it gives a signal to previous operators to deliver the right parts, at the right time to the right place. In large factories, the parts can be scattered around the plant and a signal of the need is necessary. Kanban can be an empty bin which signals to fill specific amount of parts or it can be a card that provides all required information of the needed part. Kanban can be compared to the refueling of a car, which is not done every Monday but every time the light signals that more fuel is needed. Kanban can also signal that the part is ready to be delivered to the next station (Stevenson, 2014; Liker, 2004; Tuominen et al. 2009; Burton et al. 2003)

The two-bin system is a commonly used Kanban system. It is a simple system suitable for small and rather cheap parts that have high consumption. At the beginning, both bins are full. Workers only use the front bin until the bin is empty and it will give a signal such as turning the box upside down. The person responsible for filling the bin will then get a signal to fill or order more parts to the empty bin. The bin needs to be filled before the other box is empty, but filling it before the other box is empty will create storage. In a perfect state filling is done exactly the same time the last part is used from the other bin. It is possible to outsource the filling to the supplier so that they are responsible for the part management. Kanban is an important lean tool, even though in some cases it means creating buffer storages. The long-term goal and a challenge for lean is to reduce the number of Kanban systems and finally eliminate them to create a continuous one-piece pull system without any storages. Kanban system requires discipline to follow set rules or it can fail. (Tuominen et al. 2009; Munroe, 2009; Corke, 1969; Beecroft, 2009; Eilon, 1969 p.450-451).

One of the most known and used lean tool is *5S* which uses visualization to keep the work place in order. It is commonly used in various fields from manufacturing to health care. 5S reduces problems in workflow and the training time for new workers since all needed equipment and parts will always be in the same place. Other improvements are for example safety that will be improved by eliminating safety hazards and communication between people by visual presentation. Among all these improvements together they also improve productivity of the place. (Modig et al. 2012; Burton et al. 2003. p.113; Gapp et al. 2008)

The five S's consists of five steps: *sort, straighten, shine, standardize and sustain*. They form a circle that is presented in figure 7. First the items are sorted into necessary items and rarely or never used items (sort). Then unnecessary items are disposed of and needed items are set in order (straighten). Every needed tool should be appointed a specific place that is the most suitable for it. Most commonly used tools and items should be within easy reach. The next step is cleaning and inspection process (shine) followed by creation of standardized systems and training the workers to maintain and monitor the previous steps. The last and the most difficult step is to sustain the reached state by continuously developing it. Sustaining the 5S state it needs to be audited regularly by the manager or the workers themselves. Sometimes sixth S, safety, is included to reduce safety hazards. (Gapp et al., 2008, Beecroft, 2009; Tuominen et al. 2009; Liker, 2009)

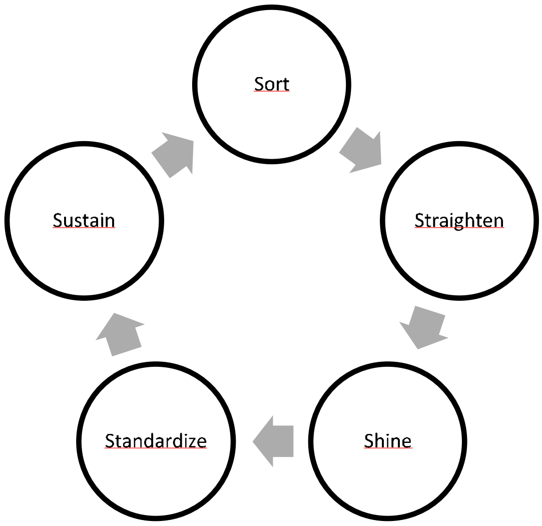


Figure 7. *5S is a never ending circle of continuous improvement.*

Over time mass production will gather all kind of waste without implementing 5S. Waste covers the real problems and creates more unnecessary work. 5S is a tool to make problems visible and it can work together with other tools to improve activities. (Liker, 2004)

Andon is a visual tool that indicates if something is different from standards. It can be a flag, light or noise that can be created at the working area when the problem has been observed. Every station has designated standard work that is the best way to perform tasks and create flow in the stations. Deviation from standard indicates problems and then Andon signal is given. Some companies use “traffic lights” Andon that works similarly to the real traffic lights. Green is go (no problems), yellow means a little trouble that will have minor affect to the lead time and red serious problems. The purpose of Andon is to increase the transparency of the system and inform others how work is proceeding. (Tuominen et al. 2009; Liker, 2004; Stevenson, 2014)

2.2.5 Continuous improvement

In lean organization, everyone must engage in continuous improvement, kaizen. Continuous improvement requires management commitment as well as good training for workers. It aims to develop a learning organization and activate everyone in the organization to participate in the improvement of each area from process development to develop themselves as workers and people. Continuous improvement includes everything from equipment and products to methods and people. Stevenson (2014) describes the philosophy to be transition from “It it ain’t broke, don’t fix it” to “Just because it isn’t broke does not mean it can’t be improved”. (Tuominen et al. 2009; Haverila et al. 2005; Stevenson, 2014)

Continuous improvement is the base for the success of lean and a rather cheap, quick and low-risk approach to improving the process and getting rid of waste. Kaizen is a small improvement process that is well planned and executed in fast pace but many kaizens can create big overall results. Kaizen requires high focus level in every step on its way from planning to implementation and it should not be disturbed with other tasks. Large radical changes are not part of continuous improvement and they are called Kaikaiku or breakthrough kaizen. (Haverila et al., 2005; Burton et al. 2003; Rother, 2010)

Kaizens can be divided to a few different types of events. Kaizen blitz is an event that takes three to five days to execute after workshop planning process. Kaizen super blitz is a quick event the duration of which is measured in hours and it is the result of fast reaction to defects. (Burton et al. 2003, Liker 2004)

Applying continuous improvement to existing company requires effort and participation from many people with various backgrounds. Same workers with same mindset and process will most likely mean same results and failure of kaizens. (Burton et al. 2003)

A key factor to kaizen is the use the right tool for the right cause. The problem does not go away if the fixing procedure is not aimed at the root cause but at its spill over. The root cause can be found out by doing simple “five times why” analysis or A3 report. In the "five times why" analysis why is asked five times from the answer resulted by previous why. It will take back to the event chain and at last reveal the root cause of the problem. A3 report is a large paper that is filled by facts that help state problems. By fixing the root cause, also spill over problems are fixed. A3 can include other tools such as fishbone diagram or five times why. Other good tools to discover root causes for successful kaizen are previously mentioned 5S and VSM or pareto analysis that reveals the most common and important problems that need to be prioritized over other tasks. Going to the source, Genchi Genbutsu, is an important part when making decisions and developing operations. That requires the upper management to go and see how everything is proceeding on the floor. (Rother, 2010; Modig et al. 2012; Liker, 2004)

Kaizen workshop is a three-phase process of first planning and preparation of the workshop, then the actual workshop and lastly the reviewing of the results and sustaining the created state. The structure of Kaizen is presented in figure 8. Preparing the workshop is essential for process flow and it ensures that participant's time is used efficiently during the actual workshop period. The actual workshop includes a lot of planning before actual implementation. There are tasks that can't be finished during the short period of workshop so those tasks are added to the next project plan. To reach the future state, tasks are finished by an assigned person. After the actual workshop the assigned sustaining team will ensure the development is done to sustain the created state. (Liker, 2009)

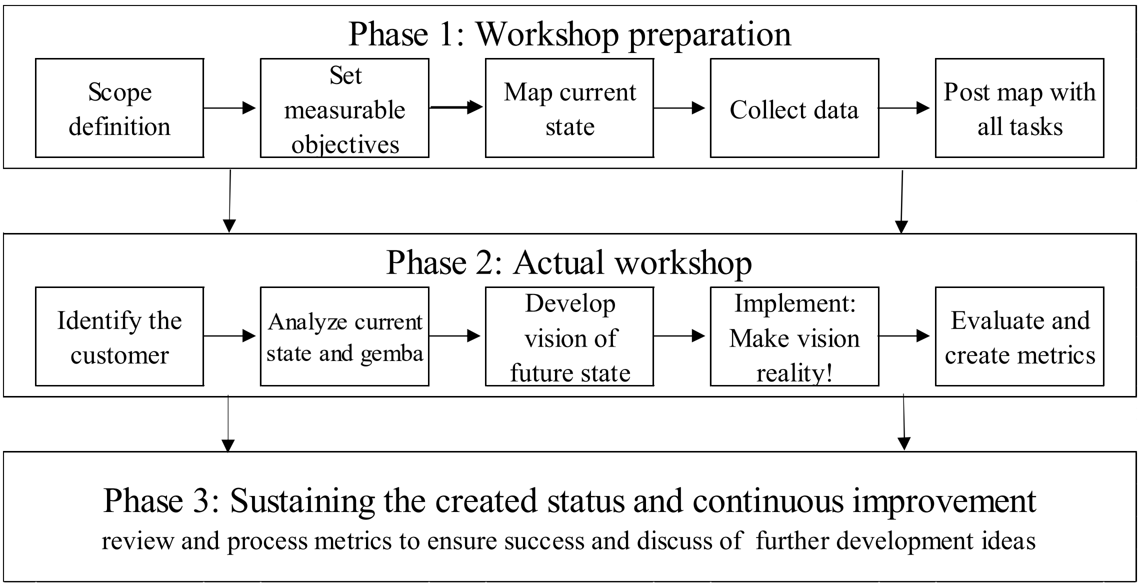


Figure 8. *Kaizen consists of three phases that has multiple steps to ensure successful kaizen workshop, modified from (Liker, 2009)*

Kaizen is done with a group of experts from different fields. The group is formed based on the improvement target and they are educated to perform the task. Kaizen projects should be followed with worksheets on a visual presentation board that will inform as well as motivate other workers. (Tuominen et al. 2009; Rother, 2010; Burton et al. 2003)

Hoshin Kanri, also known as target management, is a multi-step process which is used to cascade the company targets from executives and managers to the shop floor level. These set targets are a part of long-term goals so the time to execute them is counted by years. A set goal needs to be specific, measurable and challenging to create motivation. It can be approached like it is a game or sport. The primary goal is set at the executive level and then it cascades down to each level which develops supportive goals in their areas to reach common goals. PDCA-cycle (Plan-Do-Check-Act) is a commonly used visualization tool to support and coordinate the process. It gives a systematic approach to development work and reminds of the critical parts of check and act in the process. The part “Act” starts the PDCA-cycle again until the hoped result is achieved. Later “go and see” -phase was added in the middle of the cycle to remind the importance of seeing real process during each step and not only in the beginning. (Liker, 2004; Stevenson, 2014; Rother, 2010)

When talking about continuous improvement many references compare it to fishing. In this context the fish is a problem. There is a difference between catching a fish or learning to fish. Problems can always be solved, but learning to be a self-problem-solving organization is a challenge and it takes years to develop. (Modig et al. 2012, Liker, 2004; Burton et al, 2003)

Life-long learning, continuous self-improvement, is an important feature in continuous improvement. Developing employee competence will improve the performance by growing experience and skills and it allows a quick reaction to technology developments. It might be difficult for an employee to decide or know what types of courses or trainings they should get and what knowledge to acquire. It requires personalized training concepts and long term plans that will be based on the demand of that skill. (Werner et al. 2012; Liker, 2004)

2.3 Manufacturing control

Manufacturing control is based on the general goals of production which include minimizing WIP and inventory, high productivity of capacity, short lead times and reliability of delivery. Manufacturing control aims to reach these goals with systematic control and organization of resources. Variation in products and processes creates challenges for manufacturing control. Flowing production is easiest to control since it happens constantly and that is why it is easy to forecast and plan. Job-shop production requires more control since it happens rarely which creates uncertainty of methods and future load among other things. (Corke, 1969; Haverila et al. 2005)

Standardization is one of the key factors in lean. It is effecting in many topics such as production flow, quality and process development. The standardization of processes includes the process description and methods that should all be repeatable and predictable. Most efficient and safe working methods are standardized by a group of people with different backgrounds, not only engineers or workers. Standard work instructions can be visualized in a chart that specifies all tasks in right sequences also containing possible quality errors. It needs to be visualized in a visible place in a work station as well as in a notebook with a more detailed description. Methods need to be specified in instructions and they should be simple enough for everyone to follow. Standardized working methods improve the learning process and the control of the process status. Standard work is also a useful tool for leaders and office workers. Cancelled work always take time to get back on full speed, so it helps to focus on specific tasks and to avoid unnecessary stops which create waste. (Torkkola, 2015; Liker, 2004; Tuominen et al. 2009; Tezel et al. 2016)

Standardization is also the base of development and innovations. Changing work is difficult to improve since the improvement will probably be seen as another variation. Standards need to be improved by the people who are doing the work and are most imposed with the work routine. Production quality errors are easier to avoid with good and updated standard methods. (Liker, 2004; Tuominen, 2010)

2.3.1 Pull system

There are two types of inventory control systems: "push" and "pull". Push system obeys a previously formed production plan accordingly and pushes material and batches through production. It can be difficult to handle since plans do not always correspond with reality and the production might not always be able to perform operations as planned. This leads to the creation of inventory which complicates planning and control. In a lean organization, the production is managed by previously mentioned "pull system" that pulls the production by responding directly to the needs of customers. When the need to each part emerges, it creates a signal that the next one must be ordered or delivered to fill the need. It makes just-in-time production possible. (Haverila et al. 2005; Ward, 2009; Lapinleimu, 2000; Tuominen, 2009)

To support the "pull", Toyota divided their production process into steps where each step had an internal supplier and an internal customer. Each step needs to be finished as if the next step was a customer: the right product to the right place in the right quality and quantity. The pull system requires stability from production which means that the schedule needs to be frozen early enough that the upstream work centers have enough time to react. Another requirement before the pull system can be established is determining the size of containers and amount of parts in them. The pull system requires discipline and persistent work to make it work. But it pays off in the production lot size reduction, reduced WIP, faster lead times and quality improvements. (Stevenson, 2014; Modig et al. 2012, Jacobs et al, 2011)

The signal in the pull system can be created in various ways such as different Kanban cards and 5S visualization. A common pull signal is a painted place on the floor that is allocated to specific part or parts. The empty spot gives a signal to produce or deliver more parts. This needs clear specification of the space. All production activities are done only when they get a signal of need from downstream work centers. There is no need to produce more parts and increase work-in-process just to keep equipment or workers busy. The pull system does not have a buffer storage, and therefore transformation from push to pull system should be applied in stages. (Liker, 2004; Jacobs et al. 2011; Stevenson, 2014)

The pull system is suitable for material that has steady consumption when the scheduled system might be a better option for special or single-used items. Pull system requires top quality since even small problems in any station will quickly cause the line to stop. (Haverila et al. 2005; Stevenson, 2014)

2.3.2 Balancing the production

Balancing the production is crucial to the smooth work flow. Capacity planning plays a critical role in balancing since it must ensure the availability of needed resources at each stage of production. Balancing can be done by timing the production to match takt time and by leveling. (Eilon, 1969; Liker 2004)

The goal in timing the production is to divide the work evenly to each work station that the utilization of the resources is optimized. The work needs to be divided so that the workers can perform all assigned activities in the previously defined takt time. In lean production, the takt time is carefully calculated and it is the base of the production schedule. It is difficult to form task bundles with the same duration since some tasks can't be combined in the same bundle because they might require specific resources or some other task is required to be performed before the next task (Stevenson, 2014. p. 252; Tuominen, 2010)

Leveling the production, *heijunka*, balances production by eliminating the unevenness, *Mura*. Like mentioned before in chapter 2.2.3, waste reduction should focus in all three M's. Achieving *heijunka* eliminates unevenness which is the basis of eliminating also other wastes *Muda* and *Muri*. Some products might be ready more quickly than others which creates waiting time on line. On the other hand, some products take longer which forms a queue and waiting in the next and previous stations. Sequencing the production by volume and product mix is recommended to avoid those situations of over- and underutilization of resources. Even production schedule is the baseline to creating standardized work and establishing flow through systems. (Eilon, 1969; Liker, 2004; Stevenson, 2014, Rother, 2010)

In a leveled production line, the products are not produced in the same order that they are ordered by the customer but the orders from some period have been put in a new order by a before defined product mix that ensures that there are enough resources for each stage of production. The tool change times between products and how many resources each product requires must be considered when optimizing the product mix. (Liker, 2004; Eilon, 1969; Rother, 2010)

2.4 Visual Management

Good visual management systems are compared to traffic lights since they are easily understandable from anywhere at any speed. Various simple visual ways are used to help the communication between everyone in the company and spread useful information. Visual management (VM) system helps everyone notice at a glance how everything should work and if there is a problem and standard work can't be done. Variations from standards are made recognizable with visualization and that way the waste targets are easier to spot and eliminate. (Kapanowski, 2016; Tuominen et al. 2009; Burton et al. 2003)

VM can be divided into two different categories: it can either be an informative tool that spreads information among employees or it can display requirements or guidelines. Informative tools are tools like VSM and manufacturing cell layout, and requirement displaying tools can be for example Andon, standard work instructions and Kanban. Although the methods vary from status indicators to 5S and from KPIs to standard work charts, everyone must be able to see and understand the aspects of the operation and status. (Womack, 2004 Eaidgah et al, 2017)

Charts, post-its and white boards are sometimes considered old fashioned or a childish way to control working but they are working perfectly if a person can get the information easily and clearly. Visualization with technology, such as screens and other digital equipment, is also a good method if it is easy to control, it can react easily to changes and provides the same information that the manual board. In many companies, the managers can get all important information from one glance of a board. Visual boards that include various charts and graphs assist in decision making and problem-solving processes that improve the flow of products and information. (Torkkola, 2015; Liker, 2004; Kapanowski, 2016; Tezel et al. 2016)

Obeya is Japanese and it means "big room". It is a common lean tool that is used by management. Obeya room or war room is inspired by war where, generals are standing in one big room planning for the next move. Many companies are creating obeya rooms not to plan activities but to improve collaboration and create better facilities for problem solving. Key in the concept is to use visual management to get the big picture of activities. Many types of information are gathered and analyzed as a whole, and then decisions of actions are decided. An obeya room is covered with various charts, graphs, magnets, white boards and other data that will make the problem-solving process quicker and more efficient. (Austin, 2017; Jusko, 2016; Ward, 2009)

Obeya room is not just any large room with a bunch of engineers in front of white boards and a large screen, it is a process with a purpose. A defined process makes information visible and collaborate, since just having a lot of information on the wall does not add value if the information doesn't have any connection. There should be only one copy of each piece of information to prevent confusion. When walking to the area it should be easy to notice what the situation and current problems are. The purpose is to get everyone out of their offices a few times a day to collaborate and converse about key information and that way speed the problem solving. (Austin, 2017; Jusko, 2016; Ward, 2009)

Internet and technology have made data collection easier which means that there are a lot of data and information available. It needs to be considered carefully what kind of information is dealt with with different people in different meetings. Information overload happens in situations where there is too much information the person should be able to deal with. It can cause stress, misunderstandings and worrying that can expose to poor performance and lead to a situation where some information might be forgotten. Overload happens when some people value some information more which creates a lot of important information that needs to be shared. Therefore, shared information needs to be considered carefully. (Edmunds et al, 2000; Tokola et al. 2016; Tezel et al. 2016)

At first the visualization of one's own work might be considered as increased control or supervision but it is later found to be a great way to grow openness and communality. However, it increases communality when problems are solved together and it eases independent decision making when the whole picture of goals and activities is available. (Torkkola, 2015; Tezel et al. 2016)

2.4.1 Improving process flow

In an ideal state, there is no variation but in reality variation is present in all environments. In lean some level of variation is accepted and the challenges set by it are resolved with developing the adapting abilities such as visualization. The variation in process flow can be visualized to improve the efficiency as well as increase transparency between everyone in the company. The workers can see their own station process flow and how it is connected to the whole process and the managers can easily see the complete process flow. The process management gets easier when the work and assigned employees are clearly visualized. It reveals the barriers that can cause problems in process flow, such as lack of capacity. The workpiece can either flow or not – there is nothing between. Therefore, the visual status indicator should also be binary and physical. (Tuominen et al. 2009; Womack, 2004; Torkkola, 2015)

Many tools of lean tools that aim to improve process flow are based on visualization. Tools are combined to create visual control systems that improve process flow. For example, Kanban and 5S can together create a pull system and eventually Kanban is not needed anymore when 5S is creating the signal. (Liker, 2004)

A good visual control system will reduce the lead time since the amount of WIP, variation, mistakes and resource utilization rate causes higher lead times. The company can decrease the amount of WIP by the previously mentioned Kanban pull system and one-piece flow. Visualization of any type of variation, employee knowledge based variation or work-related variation, help everyone to be prepared and act at the right time. The visual management system aims at mistake-proofing. A mistake can multiply the working time and therefore it is important to get it right at the first time. It will also increase the resource utilization rate since the work needs to be done again. Common reasons for mistakes are insufficient or incorrect instructions and not obeyed or non-existent work orders. Visualization can increase the discipline and ease job facilitation so the process will flow correctly. The number of mistakes should be visualized using pareto-diagram or other tools, so that everyone can see the performance, and the root reasons of frequent mistakes can be fixed. (Torkkola, 2015; Tezel et al, 2016)

Dashboards are common in manufacturing industry and they are used to show different kinds of information, it is up to the company to choose. They are not just screens with a lot of graphics but a carefully planned business information system. It needs to be designed differently for different people since different people need different information. A survey made by Tokola et al (2016) states that three different dashboards need to be created to meet everyone's needs: operational for workers, tactical for managers and strategical for executives. The research reveals that even when different dashboards are created, some information is important to everyone: the most important and wanted KPIs in every dashboard is reliability and punctuality of delivery (Tokola, 2016; Eckerson, 2010).

Going through visual boards is essential to the upcoming work day. Regular and systematic meetings with employees provide updated information how the work is proceeding in each station and what the goals are today. It is also a channel to express the need of help and other information. After the board meeting, everyone knows what they and others should do that day. Having the visual board makes the meetings flow faster and eases the understanding of process. (Torkkola, 2015)

2.4.2 Visualization in continuous improvement

Continuous improvement culture is challenging to create but visual management can support in the development process. Good visualization can be a base to continuous improvement and by providing necessary data it can help in identifying and prioritizing of kaizen projects and that way drive continuous improvement process. Visual aids help identify variations from standards and point continuous improvement tasks to right direction. VM brings the information close to employees and allows everyone to participate to continuous improvement of process and people (Eaidgah et al. 2016; Tezel et al, 2016)

Pareto diagram is a powerful tool to identify trends and changes in process. It reveals the biggest contributor to a problem and leads the way to the problem-solving process. Pareto diagram can be used to identify major problems but also to follow the development of smaller problems. When the problem has been found, it needs to be solved. The problem-solving process needs to be systematic and ensure that the focus of the process is the root cause and not spillover. The root cause can be identified by using problem-solving tools like "five times why" and A3 from the problem. The projects should be approached with standardized and structured ways such as PDCA-cycle, and the activities should be clearly presented on a visual board that everyone can see at any time how the project is going. (Kapanowski, 2016; Eaidgah et al. 2016; Tezel et al. 2016)

The VM system for Kaizen projects is important to the execution process. The project procurement status (PPS) shows what projects are on and the state of each project. It reveals if some projects are stuck in one state and requires more resources and how many projects are on. Kaizen board limits the projects that are on by following a pull system: when one project is done, another can start. That minimizes the work-in-process and encourages to finish before started projects. (Eaidgah et al. 2016)

Continuous improvement is not only for processes but also for employees. Cross-training of people should be the priority of the company to ensure committed work force and the growing amount of knowledge. It creates an asset for both, company and employee. Implementing cross-training culture can start by creating skills training matrix that has a list of employees in y-axis and the operations as x-axis. The matrix can be filled by numbers, figures or colors that indicate the skills in that operation. The filling is done together by the manager and an employee. Table 2 presents skills training matrix filled by numbers from zero to four. Four is the most skilled level and the person in this level can teach others to perform the job. One means no skills, but would like to learn. Zero means no skills and does not want to learn. Two and three are training statuses. Skill training matrix below indicates that the most critical skill that needs more training is operation 2. Cells with line means that the person has some restriction to do this operation. (Feld, 2001; Jääskeläinen, 2013)

Table 2. *Skills training matrix (Feld, 2001; Jääskeläinen, 2013)*

	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5
Employee 1	4	1	4	3	4
Employee 2	4	3		4	1
Employee 3	2	4	4	3	4
Employee 4	1		1	2	3
Employee 5	3	1	3	1	1

An example of variation is filling the matrix with colors where green corresponds four, yellow correspond one and red correspond zero. The list should also indicate if someone has restrictions to do or train specific operations. (Jääskeläinen, 2013)

The skill training matrix is a useful visual tool for both managers and employees: employees can see all personal development areas and managers can see the most critical areas for training. The goal is that eventually everyone has excellent skills in all areas. It is also a useful tool to new or seasonal workers to see easily who is an expert in what areas and who can provide the needed information or skills when it is needed. (Feld, 2001)

All continuous improvement board meetings need to be frequent and they require managerial attendance. It is important to have someone higher in the hierarchy attend the meetings to show managerial support to the continuous improvement and also provide the opportunity to discuss things that employees can't control and need managerial actions. (Eaidgah et al. 2017)

2.5 Change Management

The cause for many programs to fail is that the changes face such hard resistance. Changes are important for companies to keep up with the increasing competition and innovative atmosphere. Projects can meet skeptical thoughts that mirror these changes to previous improvement projects. Only tools can't result any remarkable or sustainable changes but they require changes in leadership and mindset to result major changes. The same people with the same thinking and the same ways of doing will most likely result in the same results than before. (Burton et al. 2003; Beecroft, 2003)

The attitude towards change can vary among the employees and it probably will meet resistance on different levels. Resistance is faced because change means changing from a previously known state to an unknown state. Therefore, it is important to involve everyone to a change project and to communicate with people who the changes are effecting. Even those provisions do not guarantee that there will not be any resistance but they can increase acceptance. (Canning et al, 2015; Bhasin, 2012)

Bhasin (2012) suggests that most of the problems causing the change resistance are related in people factors, such as bad communication. All companies face different types of reactions towards change so it would not be wise to replicate processes from other organizations. Change resistance towards lean production can emerge anywhere regardless of plant size, age or unionization. (Shah et al, 2000; Bhasin, 2012)

Lean is a lot more than just technical tools and methods – it is a culture. Lean management consists of waste elimination and not so well-known Respect for people. Respect for people is equally important to eliminate waste but it's not so clearly known or understood through management and therefore it is hard to implement. Changing a non-lean company to lean is not just applying tools and waiting them to work. It is a change in culture that needs to be changed simultaneously. To make lean tools to work they require a company culture where everyone works on reducing waste and helping others. (Syed, 2013; Modig et al, 2012)

Respect for people or humanity emphasizes the basic values of human relations to create a comfortable workplace where everyone is challenged to improve themselves and their surroundings. According to Womack (2008) the respect for people is not just treating everyone fairly and trusting them but challenging them and having mutual respect for each other. Managers should lead the way of root-problem-solving process by challenging employees with a set of questions and not by trying to solve the problem themselves. Managers must understand and show that they do not have enough facts to solve the problem and by challenging employee they respect the employee's knowledge. Managers needs to question the cases that a worker might have difficulties to question because he or she is working too close to it. (Cardon et al. 2015; Womack, 2008; Ward, 2014)

Respect for people highlights the importance of enhancing worker capabilities and improvement by trust. It emphasizes the understanding, that people are valuable assets – it is men or women who operate the conveyor and not the other way around. Chapter 2.2.3 mentioned the eighth waste of wasted abilities of the workers, which walks hand in hand with respecting people. The most efficient utilization of people does not only come from the actual value adding work but also developing and thinking ways that the work can be done better. In a work place people work in teams and succeed as a company. However, everyone must be considered and appreciated as an individual. A work place should not be only a work place but a place where everyone can grow as individuals and develop their skills and abilities. People's competence must be respected by providing challenging tasks that give them possibility to keep constantly learning and growing. Toyota gives everyone an experienced worker as a mentor to provide a suitable platform for the development process. Educating people is the key for growing a company. (Cardon et al. 2015; Liker, 2004; Rother, 2010)

Mutual trust is an important factor in respecting each other. Mutual trust comes from the belief that everyone in the company, worker and manager, will work to make the company a success. Mutual trust is not something that can be given but it needs to be earned through various and continuous activities. (Cardon et al. 2015; Rother, 2010)

2.5.1 Lean leadership

In lean thinking the value-adding activities that a customer has defined are generally seen as correct shop floor operations. Leadership itself is not a value adding activity but it can set up a framework for the value creation by driving system development and sharing knowledge. It is a link between continuous improvement and lean tools. Communication and co-operation between employees and leaders are a priority in the mutual striving for perfection. (Dombrowski et al, 2013, Rother, 2010)

Lean leadership plays a critical role in the creating of improvement culture that is striving to perfect state. Improvement culture is a long-term goal and needs the leader's commitment. In improvement culture failures are seen as possibilities to improve and learning happens through trying. (Dombrowski et al, 2014)

Being a role model is an important lean leadership principle. Leaders need to constantly develop their leadership skills and learn new ones. For leaders only developing themselves is not enough but they need to drive everyone to self-develop themselves. Long term development will ensure the competence of employees so they can engage in continuous improvement. Continuously developing people will make continuous improvement process possible. (Dombrowski et al, 2013; Rother, 2010; Ward, 2014)

Genchi Gembutsu, commonly known as Gemba, is one core lean leadership method. It means going to the shop floor where everything happens to see the actual situation and understand it. Decision making and identifying root causes of failures becomes easier when the information is based on actual firsthand knowledge. Gemba can be done by observing the process for failures and seeking improvement possibilities or it can mean getting hands dirty in process improvement. President and executives have less time to go *gemba* so they need to trust people around them and get secondhand information from them. The method is called *hourensou.* (Liker, 2004 Dombrowski et al, 2013)

Previously mentioned Hoshin Kanri is an important lean leadership tool that focuses on continuous improvement processes and ensures that all improvements done in each area support the long-term goals. Everyone should know their own targets related to the big-picture and work decisively towards them. (Dombrowski et al, 2013; Liker, 2004)

3. RESEARCH METHODS

This chapter presents the research methods used and the theory of action research. This action research is characterized as qualitative research which means that the data is mainly based on interviews and observations. However, there are also some quantitative characters since small part of the data is from MES, Step calculator or Happy or Not -devices that deliver numerical answers.

Manufacturing execution system, MES, is an online integrated computerized system that is the accumulation of the methods and tools used to perform production. It will collect and present online data of the complete production process that is used to enhance processes to optimum level. MES will work as guiding and reporting tool as well as provide a platform for the decision-making and problem-solving processes. (McClellan, 1997; Zhou, 2005)

In this study, the research methods used were literary review, semi-structured interviews benchmarking and collecting empirical data. The theory of these research methods as well as their implementation in this study is explained in this chapter.

3.1 Action Research

Action research is a method where the current practices are investigated and improved. Research is trying to find solutions to existing problems in the researched environment and bring new approaches to current practices. The method combines the scientific and practical approaches and includes the activation of people around the research target. It is important to engage people around the topic in the research and improvement processes to avoid change resistance and increase efficiency. (Kuula, 2006)

Action research is a continuous process and it can be described as a spiral that never ends. The first step is planning the action. Then executing the plans followed by monitoring and evaluation. After the process returns to the plan and the action steps to improve the already changed practices. The reason for the circle is that the situation can be best understood by changing something and testing if it works. The key goal in action research is to create change. (Kuula, 2006)

Typical approaches for action research are that it has a practical approach and it is centered around problems that needs to be fixed. The researcher and the research target are both active during the change and they engage in very close collaboration through research. (Kuula, 2006)

3.2 Literature review

Literature review is a research method and technique in which the researcher gathers results from previous researches that will be a base for another research. In a way, it is a research of research and reveals what is already known of the area. Literature review will also reveal other research topics in the area and it will help recognize the most important thoughts and theories and their relationships. In this thesis, the theoretical background of lean management, layout planning and manufacturing control are researched with literature review. (Salminen, 2011; TUT library, 2018)

In this thesis, the literature review is done by using material from books, scientific research journals and internet. The material is searched by using Tampere University of Technology library and its database, database in Google Scholar, the internet and recommendations by people working in this field.

3.3 Semi-structured theme interview

Semi-structured interview is a research method in which the data is collected by asking an interviewee open-ended questions. It will help the researcher to manage the interview better than in an unstructured interview and it gives more freedom and flexibility with answers and that way brings up deeper information than in a structured interview. It will also give freedom for interaction between the researcher and interviewer. Semi-structured interviews are suitable in situations where the topic is known and deeper information is required. (Ayres, 2012)

The material for the interview needs to be prepared carefully beforehand. Some researchers prefer to create quite specific questions when others make a list with discussion themes. Question types also vary: some of them ask for very concrete information when others require a more narrative reply. The interview is not restricted in specific questions and active researchers might present follow up questions to gather more information from the research area. In all cases the questions are based on the research question. (Ayres, 2012)

In theme interview the researcher is required to have familiarized oneself with the topic and the knowledge of the situation to be able to focus on specific themes. Questions and topics need to be considered carefully as well as interviewed people. People having the most knowledge and being most informative should be chosen for the interview (Saaranen-Kauppinen et al. 2006)

3.3.1 Interview event

This action research is focusing on creating the new production line area and improving the visualization to improve process flow and management. The interviews aimed to gather information from personnel working in production or close to it. The interviewed people were selected from the organization to map the complete process from production planning process to daily production management and find out other used management processes and practices. The interviewed people were production workers, supervisors and production controllers. It was important to have people with different experience and points of view. The interviewed people were selected because of their experience and knowledge of the process as well as current problems.

The semi-structured interviews were held at two different events. One of them was targeted to supervisors and production controllers and the other to production workers. The selected theme for supervisors and production controllers was the present production planning and management practices and current problems. This theme was chosen to find out current processes in takt time management and common practices or caps in processes. The other theme set for production workers was the process flow and production methods. It was chosen to find out how the production workers see the production process and to find out the critical production processes to improve the layout. The production layout was made together with experienced assemblers who knew what additional tools every station or assembly area require and what types of tasks each station includes. In the first interview, the questions were semi-structured to gather basic information of all production requirements, but later in planning process the planning meetings were made in unstructured discussion meetings where the goal was to create suitable layout based on the information that was covered in the first interview.

The interview events started with explaining the topic of the thesis and the reasons for the interview. The interviews were more discussion type events than questionnaires and the topics created good conversation. Every topic created multiple follow up questions, which increased the amount of shared information. Everyone works in close collaboration with each other, which created different points of view. The interviews provided comprehensive information of the process of production planning and common practices of management as well as process flow. In addition multiple discussion events were held along the planning process to get all necessary information.

3.3.2 Material and objectives

Appendix A and B describe the interview structures. Every participant had specific questions to get more and deeper information of their professional topic.

Appendix A is a structure for the interview held for supervisors and production controllers. The goal for this interview was to get information on the production planning processes and tools used, management practices and daily routines, as well as how responsibilities are shared in production management. Some of these facts were known beforehand but discussion of these topics was necessary to gain deeper information.

The first question was *"How are the estimated finishing times set and how is the fine scheduling done?"*. It was meant to find out where the production process starts and how the deadlines in production are set. It creates the base for production scheduling and the later process management.

The second question was *"How are the stations balanced and tasks allocated between stations?"*. It was asked to find out how balancing in the production line is done and how it has reacted in production changes. Since there are constantly product updates and corrections in products, it is important to know the current practices of how those changes are noticed and how these changes affect the working pace in the stations.

The third question "*How is the material stream in production controlled and supervised?"* was meant to figure out what kind of practices are created to ensure efficient material stream and how the process is supervised. There are multiple different models of products produced in the same line and every model has its own different parts so it was important to get information of how the material stream is now managed. Efficient material stream and processes have been one of the most talked topic so it naturally created good conversation on current problems and development ideas.

The fourth question was *"How is the capacity of workers and other resources planned to meet production needs?"*. It was to find out how the capacity and resources ensured to complete the production needs and used operation models that are used prior to the production of Lokotracks to ensure the efficient flow. Control and capacity in production is important to the whole operation so it was critical to get clear information on the used processes and tools.

The fifth question *"How is the production process managed?"* was meant to get idea of management processes when the Lokotracks are in production line. It was asked to find out the common processes and practices in following the daily outcome and to ensuring the success in every takt. This question was essential since it had straight correlation to the research question of how visualization can improve the manageability of the process.

The sixth question was *"What type of daily routines does the production have?"*. It was asked to discuss the present routines in production and process management. To create efficient and useful management processes and visualization it is necessary to know the current use of information and all routines.

The seventh question *"What are the most common problems in production and how would you improve production?"* was meant to find out if there is any topical related problems or improvement ideas for the future production line or processes. The eighth question gave the interviewee a chance to share any other relevant things they would like to add to help research if all necessary topics were not covered in the prepared questions.

Appendix B includes the base for the interview for production workers. The goal was to get information of the production workers point of view and production processes. It was not only to get information for the creation of new efficient layout with tools, equipment and required space but also to get information on management processes and cases that cause problems in production flow.

The first question was *"How do you become aware of complete production process? What type of information would you like to get more?"*. It was asked to find out how the guidance and control of the process is affecting the process flow. To improve the transparency between stations and the information flow through the production process require more knowledge of the present state. That is strongly related to project goals to create more transparent flow and better work place.

The following questions *"What type of material is needed in the area where you work, what resources do you need in each station and how much space or height do you require to perform at each station?"* were aimed to figure out the layout requirements for each station. Assembling complete mass customized products requires special tools and devices and all of them require space or other considerations. We returned to these questions multiple times during the layout planning process and these were under a lot of discussion.

The fifth question *"What are the most common problems in production and how would you improve production?"* was the same that was asked in interview A. It was asked to get the assembler's point of view of present problems and their development areas related to work stations or case research questions. The sixth question gave production workers an opportunity to add other things that should be considered in the research.

3.4 Benchmarking

This thesis included two benchmarking events in two different companies that have done collaboration together and the employees visit each other regularly. One company visit was done simultaneously with a lean coordinator-course and the topic of visit focused mainly on lean practices. These companies were chosen because they are familiar with using various visual aids to improve process flow and production management. The companies visited were both producing large industrial equipment so they were suitable benchmarking targets.

Benchmarking is a popular improvement tool because it is a good way to prevent "inventing the wheel again" and to find out the best processes and practices by comparing with other organizations that usually are leading with the improved topic. The company can adapt some generally approved practices straight to their operations but usually all implemented parts need some development to be better for the company needs. The point of benchmarking is to find out suitable development targets and find out potential targets for creative breakthrough. (Bhutta et al, 1999)

Benchmarking is a continuous process and it follows the previously mentioned PDCA cycle. Benchmarking in this thesis is done by using five benchmarking steps that Bhutta et al (1999) have determined. The first step is planning the study which means deciding what the benchmark goals are. In this case the goals were to investigate the visual aids that were used to help production and process management. The second step is form the benchmarking team. The team needs to have proper training of the topic and determined responsibilities before the visit. The third step is to identify benchmark companies that are top in the researched area. Usually these companies are not competitors but they can still be working in same industry. The fourth step is to collect information and analyze it. The fifth step is to adapt and implement these practices. These implementations are part of this thesis. (Bhutta et al. 1999)

The first benchmark focused on management control visualization and work planning methods. The participants were the manufacturing manager, the production manager and supervisor and the thesis worker, who formed the leadership and management workshop group in the project. The benchmark company was known to use different types of visualization to improve the efficiency and manageability. The benchmark research topic was agreed with the benchmark company representative prior to the visit and they organized the presentation and visit to relevant places to introduce their approach to the topics. All of the topics in appendix C were included in the presentation.

The second benchmark visit focused in 5S and other lean tools and it was organized to be part of a lean coordinator course. The participants took part in this course and this was the final task of the course. Due to many visitors and the course focus being on lean tools, there was not a chance to previously present the topics in appendix C but they were covered in an interview with a company representative.

The benchmark method turned out to be a very efficient and eye-opening research method that provided a lot of different angles and approaches in the area of study. The benchmark researches were both very important part of the study.

3.5 Quantitative methods

This thesis research used some quantitative methods where data was collected with different types of devices. Quantitative research aims to collect data to understand the current state. These methods were chosen to support the observations that are made with qualitative research. The data that was used in this thesis was collected by step calculator, Happy or Not device and MES.

Steps that production workers made were measured with Garmin step calculator. There were nine different test persons that carried the calculator for a shift at a time. Every person had the calculator for three days so the data was gathered from 27 shifts. The meaning for the data gathering was to find out how much the production line workers needed to walk during the day to search parts around the production facilities.

Happy or Not -device is a data collection device that has four different stages you can answer from bright green to dark red. The colors define the scale of satisfaction by the person regarding the question area. The question in the survey was if the assembler needed to search or seek parts from unusual places that day. If they had everything that day they pressed bright green and if everything was somehow lost they pressed dark red. The colors in between were to answer if they still had a day in between these two situations. (Happy or not, 2018)

Daily MES data was used to evaluate the different situations and how the process could be improved to maintain the set takt time. The data used helped find out the repetitive problem areas and it provided information for takt time management.

4. PRESENT STATE

Metso is a world leading industrial company serving in the mining, aggregates, recycling, oil, gas, pulp, paper and process industries with its 2,6 billion € net sales in 2016. Metso is listed on the Nasdaq Helsinki in Finland. This thesis is written for the Metso's Aggregates Equipment business area that produces crushing and screening equipment to its customers worldwide. It focuses on Metso's Tampere factory and line assembly department.

The line assembly department produces mass customized mobile crushing plants, Lokotracks. The line assembly produces nine different models of Lokotracks, and in the future the number of models will be increased to 12. The line department employs over 100 employees in various tasks of assembly and office work.

Metso has been on Lean journey from 2014 and it has successfully implemented a few Lean principle routines. The operational house of Metso has similar features than TPS house basing its activities on common values and operating models with its pillars being JIT and one-time quality and roof being customer success. In the center of everything is co-operation and development. One of Metso Tampere factory's target for 2018 is to create visual flow which is the subject matter of this thesis. Other targets are to reduce variation by 50%, increase efficiency and involve everyone in continuous improvement. These targets go hand-in-hand, and by improving one you improve all of them.

To find out about the processes and practices behind production control and management and production methods, the personnel was interviewed with topics presented in appendix A and B. The result of that interview is described next. First the production control and operating models are explained followed by an introduction of the production processes. Then current layout is presented. Lastly challenges in current layout and operating models are introduced.

4.1 Production control and operating model

The products in line are made by assembly to order (ATO) production strategy. Most parts are ordered according to demand forecast but the assembly is done based on customer order. If a customer would like to add some options in the product after the order it can usually be done if the production process has not started, but if the production is already on, the option will be assembled later.

The timing of the production is done by prioritizing target times and according to demand management. The demand management has estimated the production volume of each product roughly a year ahead to get the estimated amount of long delivery time parts to production in time. It has data and experience of customer behavior and trends that helps them to estimate amounts for example different conveyors that need to be ordered before. Demand management sets estimated target times for each different product type in line and for example some products might have availability much further than others due to estimation of the parts.

Production controllers will schedule the production. The order office takes orders in and a production order comes to Enterprise resource planning, ERP, system. ERP is commonly used a computer software in manufacturing industry to integrate all key factors in the factory and ensure continuous communication. (Law, 2016; Bhumgara et al. 2017) The customer or sales dealer can configure its own product when making an order by using available variation combinations or the order office can create the order themselves. An email from order office gives production planner a signal that new products need to be scheduled in the production plan. There are no specific rules to production planning but experience has taught that when possible two products with longest production time are not in a row but there are some easier products in between them to ease the load.

Plans are not made by working capacity but open work centers. There is no data or precise information on the duration of some tasks so exact assembly times are hard to determine. That way production planners put work load to the work centers that are assumed to be having full capacity and ability to meet an eight-hour takt time. It is easier to add extra workers to meet the capacity requirements that some products require than open and close the stations every now and then when some non-value adding activity such as morning meetings and afternoon catch up meetings happen. It requires more attention from management but it makes production flexible and easier to adjust in surprising situations.

The production planner schedules the line from three stations – engine module assembly line station 5, Speedline stations 1 and 4. Everything else is set in the master routing of products in ERP and it will schedule the rest of the production automatically. Product routings are similar to each other and it saves a lot of time when the routing itself will schedule the production but it requires that master routing be constantly up to date. If the production schedule is updated when the production has already started the scheduling requires more work since the master routing can’t perform scheduling anymore and it needs to be done manually to all assemblies.

Each station has a computer that has MES so the assembler can check the done activities off and report any errors. MES communicates with ERP schedule and set upcoming activities in line with the planned schedule. That way the assembler knows what products they should assemble next. MES is also a supervising tool for supervisors. It shows who is doing assembly in each station and presents the status of the product with colors.

MES is an important tool for process management and it helps with process flow. To visualize the process flow MES has all standardized tasks in each station, it collects data from error reports and takt times and works as a process guide for assemblers. MES also provides data from quality problems, missing parts, repairing duration and many more. That data is useful for finding problems in process and developing activities. For management use it provides data of overall production state. All products on time are presented with green background and if they are late it turns red and number appears to tell how many days it is late. MES visualization is used to provide information of the finished tasks and if some of the tasks cannot be continued.

MES collects approximately 1000 reports monthly concerning various topics. These topics are visualized in MESfeed which is an excel file that gathers data form MES and presents it in a more visual way. It provides useful information on most challenging stations, products or materials. It will also present data of the most common error causes and how long it takes to react to error reports. MES is now used in all areas but it still needs to be reminded that everything must be written in MES for documentation and development projects.

Production capacity planning for each station is done daily by the supervisor. The white board next to the office has areas for each station and everyone has a magnet to show which station they should work at that day. Figure 9 shows the white board where the upper line is morning shift and the lower line is evening shift. All yellow magnets refer to new employees, blue colors to electric assemblers and black to mechanical assemblers. Some of the workers are more self-imposed to find more work if they finish their tasks in their station but others need guidance. The supervisor is responsible for planning the capacity to meet the requirements of the line and enable the line to proceed in planned schedule.

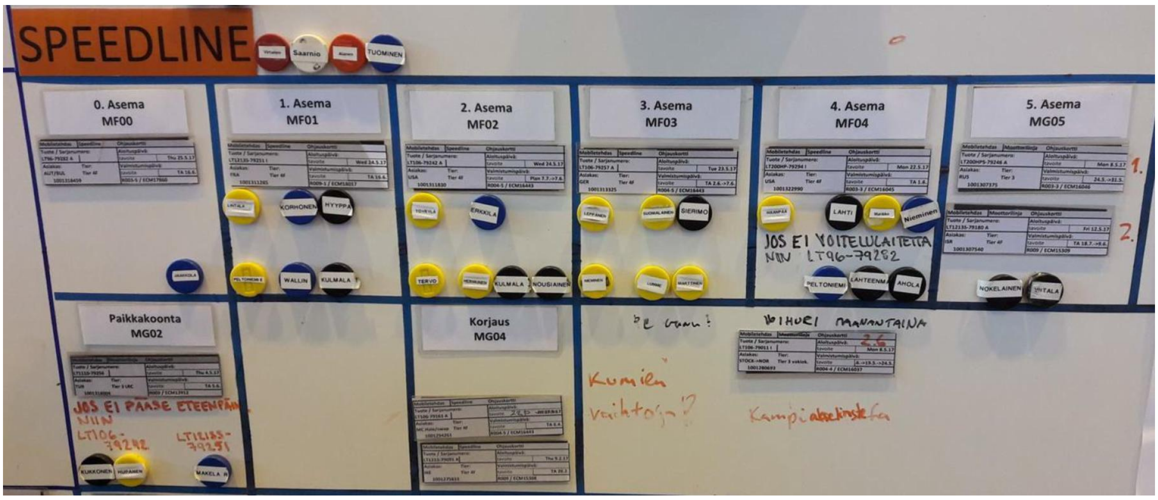


__Figure 9.__ White board indicates everyone's allocated work place

Daily meetings are held in front of the white boards. The engine module assembly and Speedline have their own 15-minute morning meetings held by supervisor. After that the supervisors are gathered together with the manufacturing manager and share their area information with everyone. Other meetings that are held are regulatory safety meetings and continuous improvement meetings.

In Speedline, the workers are either specialists in electrical or mechanical assembly. In a full production load each station requires at least three assemblers in which at least one of them is an electrical assembler and one a mechanical assembler. The number of workers and their type depends on the product since some of the products have more electrical assembly work than others and some products have more mechanical work. That requires attention from management and they need to plan production groups to each station to meet the needs of the upcoming product. Workers proceed in line with the product from the first station until it is ready. It is up to the worker to change work stations with the product since it creates a positive self-made feeling. Continuously changing work stations supports work rotation but can create a longer learning process for a new employee who has too much information to absorb in a short period of time.

In engine module assembly, electrical and mechanical assemblers are not differentiated and everyone can do most of the work. There are some exceptions such as add in options or difficult and not common products. Each engine module requires two workers to reach current takt time and some products allow three people without them being in each other's way. The engine module line also produces engine modules to stationary assembly which requires more planning from supervisor.

Workers in other subassemblies are working in specific sub assembly spots and focused only on that. Each sub assembly has various parts to assemble so the work is changing, but they are not changing the sub assembly spots. That way they are taking care of their success in that specific spot, but it creates challenges if one spot requires help.

When working in one shift it is also easy to continue working from the same situation where it was left in. Work in two shifts brings its own problems since the next shift can not continue where the job was left by them the day before and the information transfer from evening shift to morning shift can be difficult even though there is MES. MES provides assembly pictures and standardized tasks that are set in order but everyone works the way they have got used to doing. That brings challenges to daily management and to learning processes.

The workers' knowledge is based only on the supervisors' knowledge. There is excel that presents the skills of workers' factory accuracy, but not in task accuracy. It is difficult for new people or trainees to know who is capable of performing specific operations.

4.2 Production process

Production is done mainly as line assembly and these lines are supported by subassemblies. The process consists of Speedline, engine module assembly line and five supportive subassemblies. The average lead time for the products varies between 29,5 to 40 days. Variable production process of different products and customization create some challenges in production management.

The production process is scheduled in ERP and the process starts to follow the schedule when the supervisor releases the order. From that moment, the production process follows the set schedule, and parts in the warehouse are picked and sent to the factory. The complete releasing process is described in a swimlane process diagram in appendix G. To assemble an engine module the order needs to be released but releasing sets the whole releasing process in motion from engine module assembly to final assembly and packing. That creates challenges if the process is for some reason late, the program will keep pushing parts from the warehouse to the factory and it can't get stopped without sending an email to the warehouse. It means extra work for the material handler to search parts, and parts can get lost easier with greater amount of parts.

The assembling process varies between different products and options but the general idea stays the same. Variations are caused for example because the same parts are assembled in different stations for different products, some assembled parts are only needed in some specific products, the work load is different between products, and add-in options that the customer can choose will take longer to assemble. The general assembly process chart is presented in appendix D. Takt time in each station in both assembly lines is 8 hours which equals one shift.

Subassemblies assemble parts that are more convenient to assemble in production cells rather than in line. These types of products are for example light masts, distribution gear boxes, feeder units and hydraulic boxes. Assembling times vary depending on the sub assembled part from one hour to one and a half days. When many subassemblies can be assembled at the same time, it has the mass production benefits of faster assembly time. There are smaller valve sub-assemblies used in most of the stations among the production stream but they are not shown in the appendix D.

The assembling process usually starts with engine module assembly. A distribution gear box and an air filter are sub assembled and delivered to the engine module assembly station 3 by a specifically designed cart or pallet jack. Sub assembly starts usually the same time as engine module station 1 starts, to meet the need of those parts. Some products require buildup station before they can start on line. Otherwise they wouldn't be able to meet the set takt time. When the engine module is ready it is tested in testing hall and then it is delivered to the Speedline station 2.

The final assembly process starts usually with hydraulic module sub-assembly and conveyor sub-assembly. A hydraulic module is most commonly needed in Speedline station 1 but in a one product model it is already assembled in engine module assembly station 1 and for that model hydraulic assembly needs to be started before engine module assembly.

Most commonly the hydraulic module, conveyor and magnet are assembled in the first station. In some products the magnet is added in later stations. In the second station, the engine module and crusher are assembled following by third station where feeder assembly or lift conveyor and lubrication device are installed. The lift conveyor and lubrication device are required only in one product model. The last station is for final part assembling, oil filling and for functional testing before it is driven to the testing. The testing usually takes from one day to three days. If the tests reveal defects that need repair the Lokotrack is driven to the repair spot. If no defects are found, it goes straight to painting and then packing.

Supplier quality control is mainly done by people assembling the product but sometimes a quality team performs pre-production quality checks from parts that frequently have quality errors. Assemblers are responsible for the quality of their own assembly work and the work quality errors can be noticed in tests when the machine does not work as it is supposed to work. If a quality error in performed work is detected, the assemblers who were working on the product can be easily identified by MES and they are guided to perform the work correctly. Random quality checks for final products are done before they are sent to the customer.

4.3 Layout

Producing Lokotracks the way previous chapter 4.2 explained is not a small process and it requires the main assembly line as well as many different sub-assemblies. Lokotracks are large products and require a lot of space. Space is required for work and for tools that ensure safe and ergonomic working environment. In the current layout, the production is done in large (10 000 m^2) and old industrial building that is divided into smaller hall areas by pillars. In figure 10 the current factory layout is presented with color coded assembly areas. In the figure hall areas are divided by darker grey.

The layout figure is a general rough draft from actual production. Each station includes multiple specially designed tools that are required to assemble or platforms that are designed to ease the current activities or making them safe. Production requires also various lifting tools to perform safe lifting of parts.

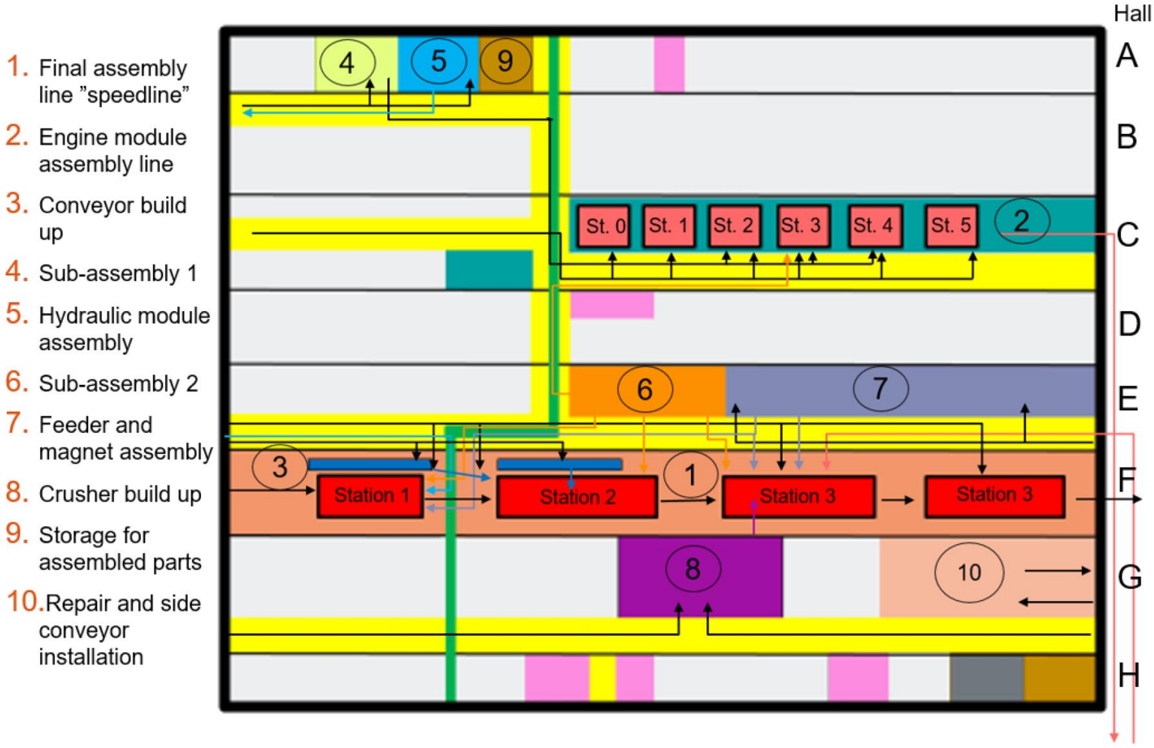


Figure 10. *Production layout with numbered areas in mobiles factory. Material stream and production areas are color-coded.*

The present production line requires several support functions to work. Sub-assemblies are divided into seven different work areas that support Speedline. Sub-assembly 1 (4) supports engine module line in distribution gear box, air filter and valve assembly. Parts are rather heavy and that's why the lifting of parts is done with a small crane. Sub-assembly 2 (6) supports mainly Speedline. In producing smaller parts such as water pumps, light masts and control boxes. Sub-assemblies are all their own work stations and work rotation between the areas is small.

The hydraulic assembly (5) produces hydraulic boxes and assemblies to Speedline. It requires special equipment that is customized for these boxes. That is why it also produces parts for the stationary assembly department. Following two different production schedules is challenging for the management. The scheduling of the station is done through the master routing and that is why it can have huge variation in workloads.

The conveyor build up (3) prepares the conveyor to its assembly. Build up is done in a specifically designed assembly rack and the process takes approximately six to eight hours depending on the product. The build up next to the assembly line is tight but it is convenient to do it next to the station where it can be lifted on the track by a crane. The conveyor is a very long part and it is transferred with a cassette. Cassettes can't be transferred by a normal forklift but requires translifters. Doing the build up somewhere else would require two extra lifts and one extra delivery compared to doing it next to the need.

The crusher build up (8) prepares the crusher to be ready to be installed on Lokotrack. Crushers are also transferred with translifters so moving them around is not efficient. Crusher activities are not under the same department and they are not controlled by the same management. That creates its own challenges for line management and requires communication.

Production building is not only used for line production, but in between the cells and lines there are other production operations (light grey area) such as the crusher assembly and painting. These areas are not under same the supervisor so they are controlled by others than engine module assembly supervisor and Speedline supervisor. The painting area divides the area with walls and it separates the assembly areas from each other giving the impression that they are not working for the same production goal.

Figure 9 shows also color-coded material stream from each production cell to another or to production. The material is brought to the area from a warehouse in Messukylä, Tampere or straight from the supplier. The material is delivered outside the building where a material handler will deliver it to the station. Controlling and developing the material stream is difficult without any larger operational change. Previously determined schedule and lack of communication between warehouse and production will push the material around the plant. There is not any specific place where material is delivered, only door number which will indicate which door is closest to the area where the part is going. In the worst case, parts might be waiting outside for days and it becomes difficult to control when the amount of parts increases. It will increase the work that the material handler needs to do when some specific part is needed, since if it has been delivered many days ago it can be lost in the yard.

Inexpensive bulk material is in storages next to the production line. The engine module assembly has Kanban system where two boxes are in a row on a shelf and when the first box is empty it is turned around to another side of the shelf and a full box of material is pulled to the front. All engine module stations have their own shelf of bulk material and they are planned so that the assembler doesn't need to leave the station to get parts. In Speedline the bulk material shelves are centralized next to station three. That means long walking distances for assemblers when they are working elsewhere. There is only one box of each bulk material and therefore boxes are often empty. Step calculator calculated that average steps taken by assembler in one shift is 5866 steps largest being 7798 and smallest 2614. The day that the smallest amount was measured was a day that the product had all equipment available all the time. The other days small bulk material needed to be searched for from other halls.

In Speedline the track is first lifted on air floats which will help the product to change stations. That requires air pressure spots in every station nearby the floats. Smaller floats are also used when crushers, feeders and engine modules are transferred from one hall to another. That transfer is not possible with cranes since those can only cover one hall space. Heavy parts are first lifted to the air float and then it is moved a few meters to the other side of the pillar line and lifted on track. Engine modules have wheels under them during their assembly so they are moved with man power. Assemblies from sub-assembly areas require special devices or a forklift to transfer the part.

4.4 Challenges

Current overall layout brings its own challenges to production. Different resources being scattered around the large space creates challenges to process management and the process flow. Assembly lines and subassemblies located far away from each other means that moving the part from a subassembly to the line most commonly happens with a forklift or a pallet jack. Long transportation distances and waiting times outside is a challenge for material handling since in many cases transportation requires additional resources such as forklifts. Every time an engine module is ready from line it needs to be moved to the test area by a forklift and the tested engine module needs to wait outside if the final assembly line is not on schedule and the previous engine module is still in the air float. Another example is when the hydraulic boxes that are made in area 5 are needed in Speedline's first station and they are moved closer by forklifts. Long transportation time is non-value adding activity and should be eliminated.

The transparency of different functions is a challenge since the areas have difficulties in knowing what the next sub-assembly they should do to support the Speedline is. The proceeding of one's own work and the production line can be seen easily in MES but the transparency of the complete value-adding process is a challenge. For example, workers in hydraulic sub assembly area rarely know what is going on in Speedline which is its internal customer. It makes sure that it keeps up with its own schedule which creates buffer storage near hydraulic assembly cell if Speedline is off schedule. Supportive sub-assemblies need to go and ask someone if they want to know how they are doing compared to main assembly.

Transparency with the engine module assembly and crusher assembly is mainly based to supervisor communication. There have been many cases where Lokotrack has been started in Speedline and it has waited for an engine or crusher. Critical material needs are not systematically checked and that can cause interruption in production.

Sub-assembly assembles either straight to final product order or to order that is made for specific amount of assemblies. Smaller assemblies are made when the order of some specific amount is scheduled. Some sub-assemblies follow MES schedule but others do not have MES in active use and they require paper orders to perform the assembly. The problem emerges when the schedule follows the main routing and the sub-assembly's schedule is not updated when lines are updated which means that if Speedline is late the sub assembly will keep assembling parts. That creates buffer storages for assembled parts and those storages have a place in the ready part shelf but many times the shelf is already full when another load of assemblies is ready so it is placed on the floor. A different problem occurs when for some reason the order is not in MES or the paper order has not reached the sub-assembly so the line assembler needs to go ask where the needed assembly is. Another big problem is that there are some parts that have problems with availability, and them being tied in assemblies that are in storage is a waste of resources. For example, there are six different valve assemblies that require the same part. The alarm for each assembly is four pieces and that means that there are four of each assembly all the time in line and every assembly will hold resources.

Building restrictions is another challenge that has affected the production. Speedline is in a hall that is half a low-roof and half a high-roof hall. Some of the operations like crusher and engine module installations can't be done in the lower roof area. If there is a block in production line and the Lokotrack in station 1 would be ready for proceeding to do tasks in the following station it can't do it and the production stops.

The overall material stream needs focus and development in the future to minimize waiting and unnecessary movement. For two months, Happy or Not -device asked assemblers if they needed to wait, search or look for the parts today. "Mad face" was specified to a situation where they were required to wait or go ask for some part that they needed or if the bulk material box was empty in their station and they needed to go search the part from somewhere else. If everything was good that day they could press "happy face". During these two months 451 people were unhappy while 26 were happy. The survey was meant to give data of how an assembler sees his or her work conditions to perform assigned tasks and support data that comes from MES reports. MES had 906 missing part reports during that same time. All missing parts do not end up to error report since it is easier to pick it up from another station or go ask straight the material handler or supervisor to get the part.

The behavior of workers highly impacts to the cleanliness in the work place. In a large group of people cleanliness easily deteriorates because no-one is taking care of the working area. Production uses tool walls that are shared by everyone and personal tool boxes. Personal tool boxes show the difference of taking care of an organized work place. Some of the boxes are tidy and well organized when others are full of collected material and tools. Tool walls are slightly better organized, but maintaining is a challenge. New tools don't have standardized places and they are left in random boxes located at the tool wall. Unused parts that are collected to the order can be found from shelves or secret storage areas. Assemblies where there is only one shift working everything is often left spread around to wait for the next day.

Visualization has been applied with 5S, kanban boards and a few two bin bulk shelves. The 5S has been applied to the work stations before but they are not well maintained and it is not in 5S level anymore. The reason for not maintaining is for example that new people are not trained to 5S and lack of standard work of maintaining the cleanliness in work place. There has been standard work for cleaning a few years back, but it has slowly ended.

5. PLANNING PROCESSES IN PRACTICE AND MADE DECISIONS

The first part of this chapter goes through the layout planning process with its targets, restrictions and planning methods. Then it will introduce the creation process for visual management system. Lastly it explains the major decisions that were made considering layout area locations, operation models and visual elements.

5.1 Layout Planning Process

Layout changes create an opportunity to solve many problems that have come up but have previously been difficult to solve. Information on emerging improvement ideas is important but so is information on present problems. On the contrary, it is equally important to know good practices and methods since they could accidentally be removed without knowing of their existence. Therefore, the planning needs to done carefully.

Like the theory of layout planning stated, the planning process started with the gathering of all information of current processes and activities to avoid any unwanted surprises along the way. It's important to know the product specifications, production process, all possible variations in between different products and the equipment needed to perform the assembly so that the planned layout will support the process flow and enable future development. Work restrictions and special requirements in each work area needs to be brought up in the planning process. The value stream map was generated from the material stream around the process. Gathering information on the material stream inside and around the process is critical since it influences the overall process and it is an important factor in production flow.

All procedures were considered again and developed to be better and more functional to reach the final and optimal state of the layout. More functional procedures improve efficiency and flow which has a straight impact on efficiency. The layout affects the process efficiency and when following lean manufacturing principles, it should require minimum movement from employees which means less walking when searching parts, less parts lifted by hand or crane and less looking for help.

A key goal to layout changes is of course providing the company with those economic benefits that were the base for the investments but also creating more ergonomic, safer and better work place for everyone. The functional layout ensures a safe working environment for all employees and provides enough space for needed equipment. Lanes for material flow and people need to be considered carefully. All supporting operations such as maintenance need to be taken account. Maintenance is needed for the continuance of the process and it is necessary to make sure all maintenance operations are possible to perform.

The gathered information is the base for further investigation of how everything is linked together and how the procedures implemented will affect performance. Information of allocated work sequences will be the base for layout planning but will also help in health and safety or economical risk assessments.

The basis for all planning is to improve everything to a better version of its current state to enable better performance. Transferring all the same materials and the same working methods and routines will only change physical layout but not really improve activities since the old problems will follow to the new production line. Therefore, all activities and changes need to be challenged and questioned to ensure the improvement.

5.1.1 Targets

The reason for a new layout arises from growing market demand and a need to produce larger products in line assembly. It will shorten the present production time of larger products that are produced in stationary assembly. New larger products are added to the production line systematically as the project proceeds. As the layout changes are made there are also updates in the product structure and design to support the change from a stationary assembled product to a line assembled one and to make it suitable for line assembly.

Minimizing the lead time and increasing the efficiency in the line assembly is one of the major goals. Developing processes to minimize the unnecessary material flow and improving the transparency and visualization brings us closer to reaching these goals and they are one focus area in this project.

The present assembly line is moved to the other side of the pillar line to the higher hall in order to facilitate also larger products. The new production area is also wider which enables the Lokotracks overlap each other. That allows transforming the production line from 4 station lines to 6 station lines which means that more products will be produced simultaneously. It increases work-in-process but the products are finished more frequently.

Part of the transformation is to change the 8 hour takt time to 360 minutes takt time. Eight hour takt time is easy to perceive since it is duration of one shift but 360-minute takt time means that one shift can cover 1,33 takts. Going from hour to minute schedule requires major changes in the mindset of workers and management since every day has a different schedule. Changing to a minute schedule will set a basis for improvements. Now developing takt time from eight hours to seven is a huge leap but improving from 360 minutes to 350 minutes seems much easier. The layout needs to support shorter takt time with as little waste as possible.

The new production process is meant to increase well-being in work and safety. The well-being and ergonomics are concerned in every stations' layout and devices are used to make them better.

5.1.2 Layout Restrictions

Finding out what the restrictions of the layout were was one critical part of the planning process. Every layout planning process has its own restrictions and they create the framework for planning. In this project, every station had some specific requirements that restricted the layout planning and every place was divided to enable optimal performance. Table 3 presents basic requirements needed in each sub assembly area and material hallway.

Table 3. *Major restricting requirements of each subassembly area*

Area	Crane capacity	Major physical requirements
Material stream		4m wide hallway to deliver even the widest parts
Engine module	15 000kg	Long six station assembly line, close to final assembly station 3
Crusher preparation	50 000kg	Place for three assembly areas, close to final assembly station 3, two smaller cranes, space for large components close to assembly area
Subassembly 1	500kg	Additional space to assemble lubrication device when needed
Subassembly 2	500kg	Small crane and close to engine module
Hydraulic assembly	2000kg	Two large racks
7th station	15 000kg	Space to assembly sieve
Feeder and magnet ass.	10000kg	Space to melt frozen large parts, close or easy access to station 4

As mentioned before, this layout change was made in existing facilities, which creates many restrictions to the layout planning. The building is old and it has pillars every 5,5 meters dividing the area into four sections. The width of these sections varies and roofs are at different heights. The hall widths and heights are presented in figure 11. The grey area is the high hall area with cranes with higher capacity. The green area is a lower roof area and the red area is not in production use. The only thing defined before was that Speedline will be moved to the widest hall since Lokotracks need to overlap each other to fit in the hall. The height of the hall was a significant factor since some of the operations can't be performed in lower hall parts due to crane capacity. Crusher preparation needs to be done in the high hall since the required capacity to lift crushers with cranes is 50 000kg and those cranes are only in the high hall areas.

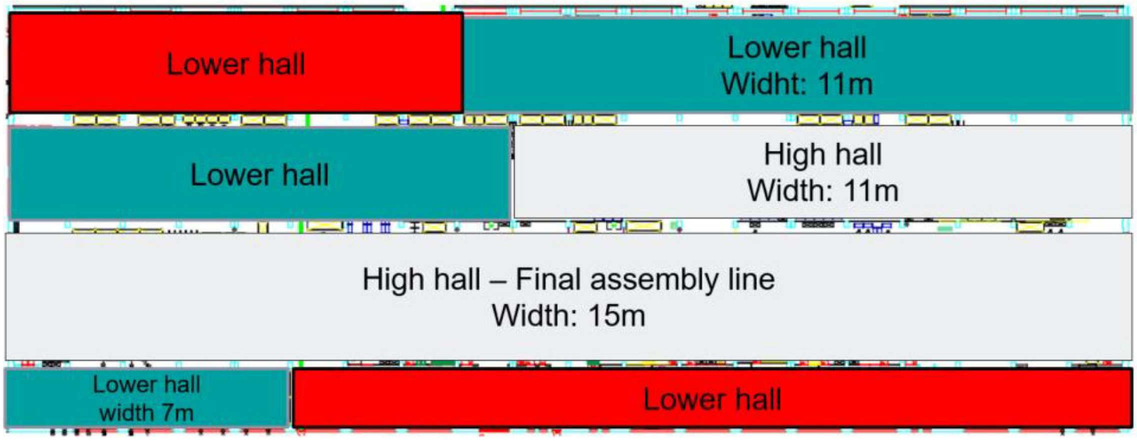


Figure 11: *Restrictions set by the building*

One of the big restrictions for the layout change is the budget of the project. This means that a lot of the old infrastructure needs to be used in its current places and there is limited ability to purchase extra equipment to places where it does not previously exist. Equipment such as cranes is expensive and therefore purchasing new is not first in the line, and mapping of other options is essential.

One goal for the project was to get all assembly lines and subassemblies "under the same roof". Changing all stations close to each other and on the same side of the painting hall will improve communication. There is a limited space to use and everyone wants to increase his or her working area. In this case it is especially important to question the need for extra space since if the feeling of a small working area comes from lack of order or too many unnecessary parts it will not be fixed with increasing the assembly area but creating order and maintaining it. New processes and practices that can improve performance needs to be implemented. Some assembly areas require multiple assembly racks and therefore require more space if all racks have storage next to the area.

5.1.3 Planning Methods

The planning process started with a discussion event with assemblers. Assemblers from each assembly area were interviewed with questions in appendix B to find out the critical requirements for each station. After starting the interviews there were multiple discussion events with various assemblers and everyone could attend the discussion if they wanted. Assemblers participated actively in the planning process and brought up important factors that needed to be discussed and decided. Conversation with production controllers and supervisors of the complete process was needed to find out how all areas are connected to each other.

When planning the rough layout, there were discussions with multiple assemblers from each production area to find out the physical requirements of each station. It was important to be familiar with previously collected data of all requirements so the space requirements could be challenged. After multiple discussion rounds, there was a clear picture of where all production areas would be in the layout and how much they would get space. More specific layouts of each area were made together with assemblers in that area to get the expert knowledge of the performed activities.

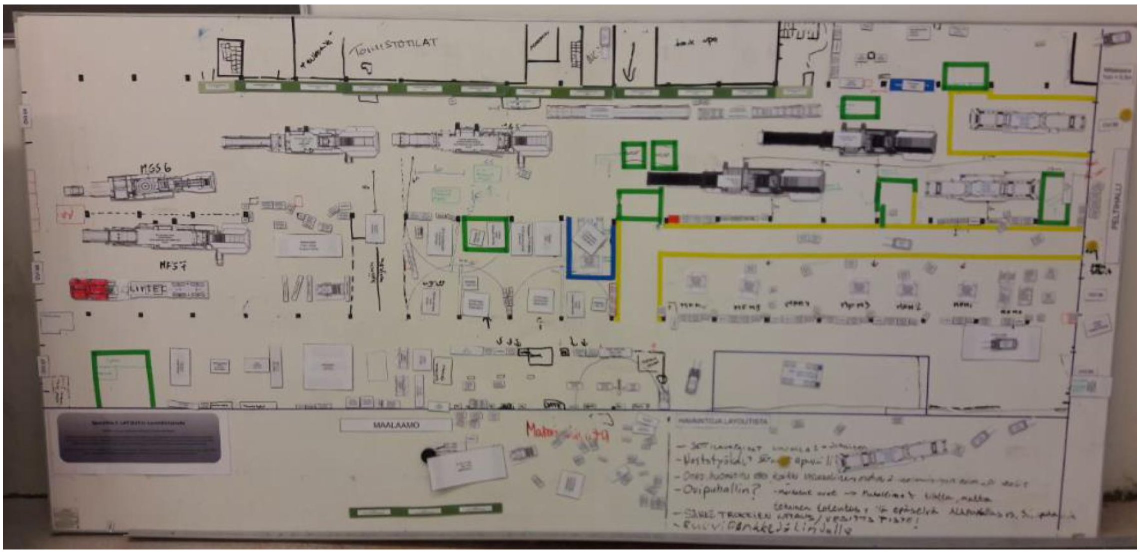


Figure 12. *Layout board that was built on scale. It changed frequently during the process and now it presents the final version of new layout*

An essential equipment during the planning process was the layout board (figure 12) that was built on scale. Manually working white board layout was practical when making different kind of drafts of possible layouts. Manual layout was chosen over digital layout draft since assembler would not have been able to try their own drafts with it. The layout on the board changed multiple times during the day and the documentation of the changes was done by capturing a picture with a camera.

5.2 Visual Managment System Planning

The planning process for visual management started with creating a list of problem areas that need to be improved and areas that need a brand new approach. The visual tools that were developed were based on lean management principles.

The goal of reaching 360 minutes takt time required a visual management system that provides a platform for takt management and success. The takt management boards were developed to fit together with daily management boards to be easy to follow. The planning was done together with a production supervisor and a production manager who both had their own opinions of what information the board should include and how it should work.

The material flow was seen as a problem by everyone. It needed to be developed to minimize waste time and activities in the whole material stream process and around it. One goal was to create a pull system for material stream to prevent material piling up in the area. It was developed together with logistic department workers, material handlers, development engineers and production planners to ensure that it will work from every angle of production and there will not be any problems for any process. It required a lot of knowledge on systems, material stream, processes, common procedures and principles. A few ideas were developed with brainstorming and a new releasing procedure was chosen over other ideas because it was the easiest to execute with the given resources, and other ideas required more standardized state from the production process.

One goal for the project was to get closer to one-piece-flow and remove all unnecessary buffer storages. One-piece flow is a big part in creating the pull system. It is a basic lean principle and applying that to the operating model was important to gain a more efficient and visible material flow. The production area size is rather small and the space is prioritized for production areas so there is no extra space for inventory. Visualization of one-piece-flow will reveal material problems in the process. A previously common procedure was to replace a missing part by “stealing” it from the next one. In one-piece flow there is no other orders the material could be stolen from so it needs to be ordered, which reveals whether the material is allocated right or whether the product structure requires some other part. One-piece flow for subassemblies was created together with production planners who know what requirement days need to be added for each subassembly. Subassembly structures needed to be integrated to ERP system so all assemblies would be ready on time.

A visual system needs frequent monitoring and that is why daily routines were changed. The changes considered mainly the supervisors’ daily routine but also the assemblers’ daily schedule was updated to be able to meet the new requirements.

5.3 Major Decisions

After multiple conversations and a planning process, creating a new layout and processes requires decisions that are based on gathered information. It is difficult to make good decisions considering the layout without knowing the assembly and management processes. Major decisions were made considering the production flow and requirements of each production area. Major decisions concerned assembly area locations and process management as well as the management of different processes and visualization features. Decisions were made based on problems and challenges mentioned in chapter 4. They are inspired by lean theory, benchmark visits and common industrial procedures.

5.3.1 Assembly area locations

Deciding locations was like doing a puzzle. Trying to fit all areas under the same roof and optimize their sizes was challenging and it required many compromises. In the end, the decisions were made and accepted. The only assembly area that had its location set by the project was Speedline, others needed to be decided. The previous area locations were a challenge for the transportation, management and process transparency. It was important to locate linked areas close each other to enable better communication between employees. Then the communication is not only done between supervisors and parts will not require special vehicles for transportation.

One of the first decisions was the location of the engine module assembly line. It required a large area because of the amount of assembly stations that needed to be increased from 5 to 6 to meet the 360 minutes takt time requirements. In addition, one build up station for engine and engine module platform was added to the beginning of the line so it makes a total of 7 stations. Every station requires almost one pillar cap but it does not require high roof capacity. Therefore, it was convenient to locate the engine module assembly line in the longest lower hall part. It was also important for the material stream to place the assembly line close to Speedline station 3 where the engine module is needed to minimize the transportation distance and the need for special transportation. The engine module is large and heavy so a forklift is needed for longer distance transportation. The final reason for placing lines close to each other was to increase the transparency and visualization that eases process manageability. Speedline workers can easily ensure the availability of the engine module when it is assembled next to the line so the closeness of these two lines will help the process management. In the flowing one-piece process, Speedline and engine module assembly are highly dependent of each other and every stop in either line will affect the other line. That is why it is important that error situations and their possible consequences can be understood easily for fast reaction. Producing next to each other it is easier to communicate and share information in specific situations.

Another major change that was decided for the engine module assembly line is that everyone needed to give away their own lockable tool boxes and start using tool walls. Figure 13 shows the difference between tool boxes and tool walls. Personal tool boxes go far in the company history so change wasn't easy to execute. Tool boxes take a huge space in production floor and because they are lockable no one else can use them. It is also rather expensive to buy new equipment for every employee when the tool could be on a wall in the station where it is needed. Tool walls have a straight impact on equipment utilization rate and it will encourage people to take better care of common equipment. It will also bring more space to the area.

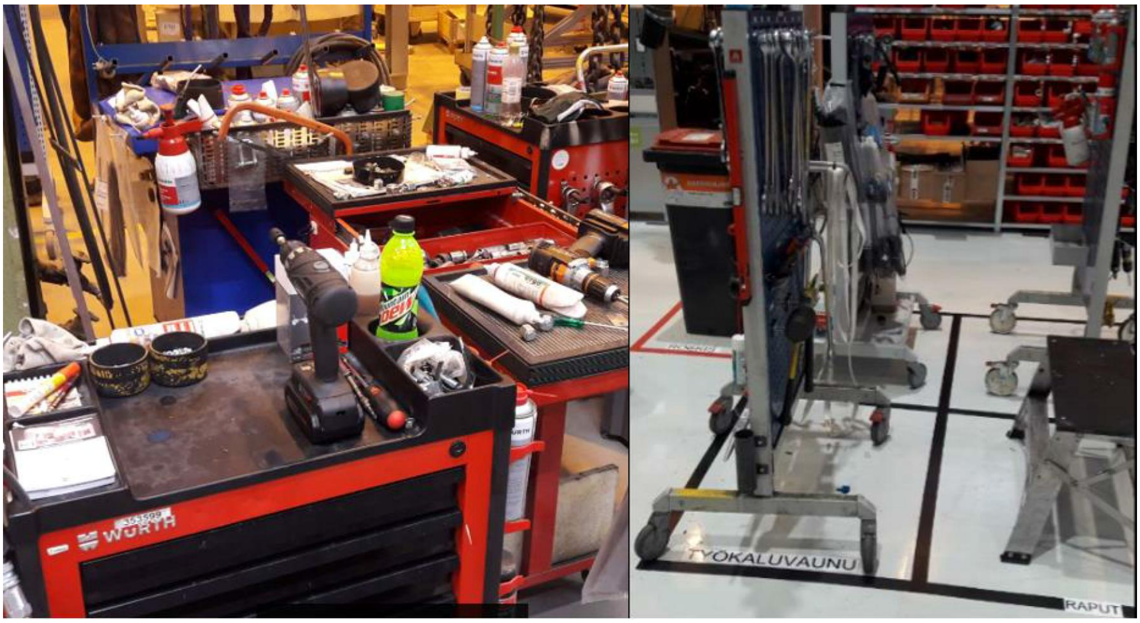


Figure 13. *Assemblers' own tool boxes in their storage area (left) and three tool walls in their assigned area (right).*

The place of crusher build up was a critical layout decision since the crusher is not easy to transfer when it has been prepared with certain add-ins. Crane capacity made the decision process easier since it determined that it must be placed in the high hall. The parts installed to the crusher in the buildup area are large but not heavy so those can be lifted and are easier to lift with two smaller cranes. But also crushers need to be lifted and that requires a high capacity crane. Since Speedline takes a large part of the high hall capacity there was only very limited half hall space where the buildup area could be located. It was decided to place it in the middle of the hall because of its current space requirements and material stream. At the start it requires the whole hall width of 11 meters and it would cut the material stream to the middle if it was located closer to the door.

In the new layout the crusher's build up requires three assembly spots from their assigned area. The buildup is done in stationary assembly since it takes only six hours to prepare it for Speedline. It means that there is one additional assembly area for stationary crushers. It was decided that the build up stayed in the present area until a better and more permanent area for it has been found since the area has all the needed material available and it is planned for the assembly process. Crushers going on Lokotrack and sold as stationary crushers use same racks and tools when they are assembled so it is convenient to produce them in same area until the new place is founded or demand outgrows the capacity.

The hallways for the material stream and the material areas were one of the most difficult decisions during this process. It is important that material flow works because without it there would not be any parts to assemble. Creating efficient one-piece flow is one of the key elements in lean manufacturing and the goal was to get as straightforward a hallway for materials as possible. Interviews revealed that all parts should be able to be transferred if the hallway is four meters wide and that was set as standard width for all material hallways in the area.

Safety and work space requirements were in high priority in deciding that a forklift will not operate in the Speedline hall. It will operate in the next hall by the engine module assembly line and feed the first four Speedline stations between the pillars. The engine module assembly line, crusher assembly and small subassemblies are also fed from the same material hallway. The engine assembly line is a straight production line and it requires less width than a complete track and therefore there is more space for a forklift to move. It is an identified risk that at the beginning there can be a lot of forklift traffic next to the engine module line, but the traffic will decrease when the material is organized in standardized pellets and the material stream has been improved to be more efficient.

The location of station 7 and the feeder assembly created a lot of discussion. Neither of them required a higher hall but both were important to place close to the Speedline's end because the feeder is assembled in the fourth station and the products coming to station 7 are coming from Speedline. The feeder assembly has been located next to Speedline before and it was easy to deliver the assembled feeder to the next hall. Moving Speedline one pillar cap away does not really change the situation since the feeder needs to be lifted to the air float anyway and transferring the float 5 or 12 meters does not make a big difference. The area in the higher hall is narrower than the area in lower hall, which had a lot of weight in the decision process. The feeder assembly requires more width so the area in high hall area would be too narrow for it. In addition, placing station 7 in the higher hall enables it to perform even larger fixing operations if necessary.

The location of other subassemblies was decided based on their internal customers' location. The hydraulic assembly was placed in the lower hall next to the Speedline's start because the parts assembled in the area are needed in the first two stations of Speedline. The hydraulic assembly also continues to make hydraulic boxes for stationary assembly department because all hydraulic boxes require the same assembly racks that are placed in the area and both assemblies require the same equipment. Subassembly 1 and 2 were placed right next to each other. Subassembly 1 produces small subassemblies for Speedline and therefore it was not critical to place at any specific area. Sub assembly 2 does subassemblies for engine module assembly so it was good to locate close to the engine module assembly.

5.3.2 Operating model

Changing the layout and physical location of equipment will not automatically improve the performance and efficiency. Like said before, the same people with the same thinking and the same ways of doing will most likely result in the same results as before. That is why it was decided to do some things differently and change a few operating models.

The material flow for assembled parts from sub assembly 1 was a problem for management, data management and material requirements, and that is why it needed to be improved. Assembling parts with separate orders and put on a shelf to wait for their need was not efficient and did not support the material flow. Their production control method was changed to making assemblies straight to order, making the material stream to work more like a one-piece flow. That also allows the use of MES which will allocate all error messages, needs of help and assembly times straight to order. Other subassembly areas already make all assemblies straight to specific orders and it has improved their manageability and material stream.

Material building up next to the line has been a problem for production flow so from the first weeks on it was decided that the material control will not be continued using similar practices. Metso has been on the lean journey for a while and now these changes created an opportunity for making large changes to the material stream. The goal was to build an efficient pull system where all parts would be delivered to the area just in time to fulfil the need. Basing the pull system on visualization would have been an excellent way if the material and the products were more standardized. When the line includes ten different models it requires as many different parts, so creating a visual pull system would be challenging and require more time and resources. That would be a suitable improvement project and needs more investigation and development resources in the future. It was decided to use the ERP releasing system to deliver the parts from warehouse to the production at right time. ERP system has list of all needed parts and their exact requirement date and time but when Speedline is late from schedule it pushes the material to the line.

It was decided that releasing the whole order is changed to releasing only those operations that can be started for sure. The releasing process by operation is described in swimlane process diagram in appendix H. Releasing the operations one by one means that the material stream from warehouse to the line can be stopped at any time if any problems that can stop the production occur. For example, if assembly for product 1 has started in the first station of Speedline and the supervisor finds out that there will be some error in the fourth station, the material stream can be stopped by not releasing the operation. That enables the supervisor to manage the material stream and make sure that any not needed material will not be delivered in line. It will also release the resources from logistics when only necessary parts will emerge to the picking lists.

The capacity shortage was decided to be fixed with a group of people, Quick Response (QR) team which can perform any task anywhere in the production. They can fill in when someone is absent or help in more challenging stations that require one extra person. The idea for QR team came from lean management and car manufacturers who ensure undistracted process flow by a small amount of extra capacity. Like the name indicates they are quick to fill in when production needs it. Due to their experience and knowledge of products and processes they can also have an advisory role and they can perform smaller development projects in production. QR team will also ease the process management when only few people are changing areas during the one week cycle.

Waste management was one environmentally and economically important development target. The decision of adding plastic collecting bins in the stations decreases the amount of energy waste. All stations have energy waste, carton recycling and plastic recycling bins within easy reach to help recycling. The purpose is to make the recycling guides visual by adding similar color bins and pictures to describe what is collected in each bin.

5.3.3 Visual elements

Instead of having one 15-minute morning meeting every morning, assemblers have one 5-minute meeting at the start of the shift and another 5-minute meeting at the end to improve the visual presentation of the performance for each takt and shift. It gives a chance to set a goal for each shift at the beginning and see if they were accomplished in the end. Station performance is monitored on the meeting board with red and green colors. It is meant to reveal if some product or station is always late from schedule and new allocations are required. The supervisor will have regular scheduled gemba to production area to make sure everything works as planned.

Process transparency was the major goal in the project and it is what Andon aims for. Like the theory explains it is a visual tool to indicate if something is different from standards and it was a problem that only a few people had information when help was needed in the process. It was decided that Andon will be applied to all production areas and there were many options to choose the most suitable and most effective way to implement it. The criteria were that an Andon signal must be easy to create by the assembler, it must enable quick reactions and anyone in the area must be able to get the signal so help will be always available. Andon was decided to be added by integrating it to MES and all visualization screens so that everyone in the factory can see if there are problems. Pressing the button gives immediate signal and the assembler does not need to leave the assembly area to get help. The feature was not only implemented to this production area but all over the factory since it is very transparent and even the factory president can see if something is wrong and how fast people in the area can respond to Andon signals.

Cleaning and keeping assembly areas organized was one of the challenges that were presented in chapter 4. It was obvious from the first meetings of the project that the production needs to be improved and get closer to 5S state. Almost all areas were moving to new facilities and routines which created a perfect opportunity to implement it. 5S is supporting takt management by demanding that tasks are done in their allocated areas. Lifting equipment, specific tool walls and other needed equipment have their own places in the area where they should be used. The engine module and crusher should always be assembled in station 3 so all needed equipment has its own places in station 3. That helps the supervisor to control the process and everyone can see the abnormal situations on the production floor. For keeping 5S in good condition supervisor has a 5S round before the shift ending meeting to ensure that each station is ready for the next shift.

The visualization of bulk material flow was decided to improve by increasing the amount of two bin and Kanban systems. The engine module assembly already had two bin systems for cheap bulk material and now that system was implemented in all shelves in the area. It is not obvious that two bin systems will work automatically and it requires good instructions and continuous process observation. When the two bin system works as planned it makes sure that there will always be needed bulk materials in bins.

MES, ERP and other systems gather a lot of data that is not visible anywhere close to operations and therefore there are not actions to make sure that the same errors are not happening in the future. One room was emptied during the project and it was decided that it will be Obeya room and collect data that would be helpful for production development.

Skills-matrix was decided to be built to share knowledge and avoid the previously mentioned problem when capability knowledge is based on someone's memory. When those people are away it is difficult for substitute workers to know who can help. It is also a tool to increase the skills-levels of employees and a change from one-skill environment to multi-skill environment. The skills-matrix was decided to be set in a visible place so that everyone can see their improvement areas and what the most critical and needed skills for production are. In addition, it was decided to change supervising areas so that hydraulic assembly and subassemblies 1 and 2 are under the same supervisor area so they can improve rotation frequency between the areas and training new skills.

One of the lean principles mentioned was standardizing everything that is repeatable and forecastable to ensure efficiency and safety. A standard work board was made to visualize the daily work schedule of all department officials. The building of standard work for officials was inspired by one of the benchmark companies where scheduled standard work board had achieved good results and it was understandable at one glance. A scheduled board was needed since some of the work has a specific and irregular time for their execution so only listing the tasks was not sharing enough information. It was set at a visible place so that it can remind everyone to do the tasks and help in noticing if some tasks are not done. It will ease the learning process for new employees and help create routines.

The creation of pull system requires specific accuracy to function so the visualization of releasing was decided to be integrated on the assemblers' daily meeting board to show the releasing status for everyone. There are 10-12 operations that a supervisor needs to release at once so there is a chance that they accidentally forget to release some operations. That's why visualizing the releasing process to everyone is good so even the assembler can notice if all needed areas are not released on time.

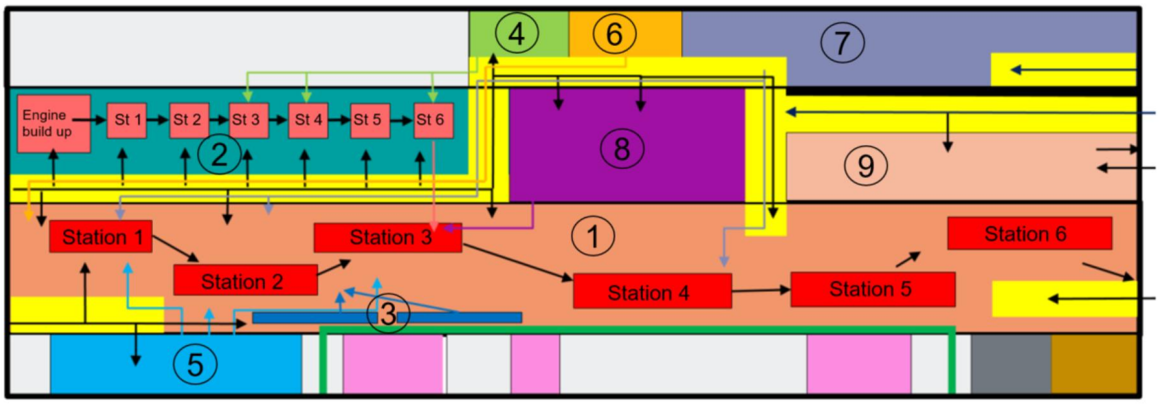
6. CHANGES IN OPERATIONS

As an action research, problems that were brought up in previous chapters are fixed by making the following changes to the production. These solutions are the latest versions of many that are done in close collaboration with department workers and managers. The new production process is presented in appendix E.

First this chapter introduces the new layout and its considerations for safety and capacity. It will also introduce the transition process from the old layout to the new layout. Then it will go through the visual features that were added to improve process flow and management.

6.1 New layout

The new layout was created based on the decisions presented in chapter 5.2. There were numerous different versions of the layout and all decisions made shaped it to be the most optimal solution. The area that changed most was the material hallway. In all different layout propositions the assembly areas have been placed in approximately the same places but their size has changed. There have been some minor changes along the way but the major places have stayed as planned.



1. Speedline 2. Engine module assembly line 3. Conveyor build up 4. Subassembly 1
5. Hydraulic module assemlby 6. Subassembly 2 7. Feeder and magnet assembly
8. Crusher build up 9. Side conveyor installation and repair

Figure 14. *New overall layout for Lokotrack production. All different assembly areas that are placed "under the same roof".*

Figure 14 presents the final draft of the new layout. Comparing the old and new layout figures, it can be noticed that the production area in the new layout is half of the previous situation. There are no walls between assembly areas which makes it one large area and the space around the final assembly line has been used effectively by supporting functions. The gray area in the left corner is the crusher assembly and that could not be moved. The other gray areas are offices or other facilities. The pink area is for coffee rooms or toilets.

The figure shows that placing the engine module assembly and crusher buildup in their areas is optimal for material flow. Both large components are assembled near their internal customer, and their transportation distances to station three is minimized. The crusher is transferred by an air float and the engine module with wheels. The engine module has also an air float that was used for the transportation between the pillars in the old line. The situation is different in the new line because the module is assembled near Speedline and it does not require forklift to move it. The module is moved through the line by wheels since it would be a waste of time to lift the module on an air float.

The close proximity of the engine module assembly and the crusher preparation will improve the visual information flow between the areas. It can be seen far if the engine module or crusher will not be ready at their needed time. It will help everyone and especially supervisors to perceive the whole production process as one and help gain fast information for quick reactions.

The objective of the new layout is that the assembler only needs to move from his or her assigned station when going to the toilets or a break. All needed equipment and bulk parts are placed next to the station to minimize the time of getting them from centralized bulk storages or other areas.

Excluding small changes, the created overall layout will probably stay as it was planned, but there are definitely going to be minor changes in fine layout when different products go through the line. All events can’t be forecast before and flexibility and fast reaction time to problem points is important.

6.1.1 Safety considerations

Safety matters are in high priority in all activities and changes. When the layout planning started, it was stated that the visitor policies in this production area needs to be changed for safety matters and to ensure that every place has enough space and work peace to perform needed activities. Groups of all sizes visits the production regularly and previously visitor groups and employees could walk through the line between stations one and two to get to the other production areas. Overlapping products and the lifting of heavy parts in all stations from two to five prevent creating clear visitor route through the production floor. Weaving one’s way through the line would be too dangerous for visitors and it would disrupt assembling work.

A walking bridge was built next to the office area to create the safest and most rewarding experience for the visitors. The bridge is at five meters' height and it is located next to the production line almost the total length of the hall. The bridge being that high allows visitors to see all production parts in the hall from a good distance and that way they do not bother the assemblers. In figure 13 the bridge is shown as a green line. The employees working at the other end of the building will not walk through the hall, instead they are advised to use the walking route outside.

Ergonomics was considered in the layout changes, and new adjustable tables were ordered for each subassembly that requires assembly tables. Those tables will make working more comfortable and unnecessary stretches can be avoided.

Risk analysis of each area was made before any of the new assembly areas started working. Analyze were made separately for each area to find out possible hazards that could happen in the area. The analyze were made with audit software that is used commonly in the company. They were made together with employees from each assembly area, the development engineer and the production planner. Each analysis meeting brought up prospective improvement targets that would enhance not only safety but also efficiency.

6.1.2 Capacity requirements

Capacity planning is an important part of production planning and it is done by a supervisor. Production controllers will plan orders for different days but it is the supervisor's responsibility to plan the capacity to assemble those products. Capacity planning is a critical activity that needs to be done weekly and it must enable fast reactions to unexpected changes.

It was decided that from the beginning of the new line all Speedline stations will have two mechanical and one electrical assembler. Those assemblers will stay at same station for a week and after that they will be assigned to another station. It will shorten the learning time when there are many repeats of the same task. That way new employees will learn to perform all tasks faster. All stations might not have enough tasks for all three workers because there is no data of the duration of specific tasks and the stations have new task allocations. If imbalance is observed as the line gets on full speed the allocations will be changed. It gives more information of true capacity requirements in each station when the production has been going on for a while

6.1.3 Transition to new layout

The transition process from old layout to new one was performed in a few different stages to keep everything under control. The process required a lot of resources since transition does not only mean physical changes but also changes in the system. Changing places of the material shelves required manual system change in material storage locations in the database, and the material supplier needed to be informed of changed storage locations. In addition, it was stated that unnecessary equipment or material would not move from the old line to the new one which meant that cleaning and sorting of necessary equipment was needed.

Table 4. *New layout transition process schedule.*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Feeder and lift conveyor														
Hydraulic assembly														
Speedline														
Crusher preparation														
Sub assembly 2														
Sub assembly 1														
Engine module assembly														

The transition process needed to be scheduled (Table 4) since the transition needed to be done without disturbing the production. Planning was done on a weekly basis and all assembly areas were updated even when there was not physical location change. As shown in table 4, a maximum of two areas was moved at the same time to avoid two simultaneous incomplete areas and disturbing process flow. The feeder and magnet assembly did not move but the area was improved by applying 5S. Every transition area had one or two weeks of preparation (yellow) before the move. The moving weeks (red) in the table does not mean that there was no production but it was the week that the moving process started. The moving did not disturb the production since the move was performed so that when the last product was finished in the old area the next assembly started in the new area. After short moving sprints, the production could start in each area (green).

The first assembly area that could start working was the hydraulic assembly. The area where it was placed used to be a buffer storage, so transition required storage move and some renovations. The crane and led lights were installed and other needed equipment was transferred to the area before production started.

Changing the Speedline and crusher build up to the other side of the pillar line was the most difficult transition and it was also taken into account in the amount of work by having a reduced work load. Moving needed to be done overnight since the crusher build up was moving to the area where the Speedline was and vice versa. There were two Lokotracks scheduled to be on line at the end of the last week of the old line and there were two different options how the change could be done. One option was to drive the last two Lokotracks to the end of the line as close to each other as possible so the crusher build up could be moved to the area where station two and three used to be. Products in the old line would be finished in the old line even though the new line started operating. Another option was to slide products between the pillars to the other side and finish them in the new line. It was decided to follow the first plan since all products in the new line were planned to follow 360 minutes takt time and products in old line were allocated to follow the old line's tasks and work centers. That could create misunderstandings and problems in the new line.

Subassembly 2 needed to be moved and improved before subassembly 1 could be moved next to it. Materials in both areas needed to be checked and unnecessary parts were removed. Some shelves could be removed as there was a lot of unnecessary material and some shelves could be combined since both assembly areas use the same materials.

The moving engine module assembly line was moved last since the place where it was moving had a storage area that needed to be dismantled and products in the new line required updates. The moving process needed to be planned carefully so that it would not affect the internal customer. The challenge with the move was that there was normal work load in the line since activities in Speedline had been normalized. In this case the move was rather simple since engines were already produced with 6 hour takt time and they could be easily moved from the old line to the new line with a forklift.

6.2 Visual aids to improve process flow

Like chapter 2 explains, visualization has a vital role in production efficiency and performance. Major changes in physical production gave a good opportunity to improve visual management. The goal for visual management systems is that the production process and its state will be easily identified at a glance. For many people, visual aids are quite new and they don't know how to make them work right. Clear instructions were created from all implemented visual applications to make sure that everyone knows how to use them and how to act in different situations.

The visualization of process flow was decided to be improved by adding Andon signals, creating pull system, increasing the number of Kanban systems, making 5S to the factory floor and by careful consideration of factory layout.

6.2.1 Andon

When the assembler notices problems that will put staying in takt time in danger and extra help is needed, he or she presses the Andon button in MES. It will send signal to all MES screens that are in production visualization mode. Normally visualization presents one production line and all subassembly areas that are associated with it. Visualization is divided to show either the whole engine module assembly process, Speedline process or testing and packing process. All stations and production areas have their own area that shows the state of the product, open tasks and who are working in that station. Colors in the visualization screen show if the product is on time or late.

Figure 15. *MES visualization screen that shows Andon signal in fifth station.*

Figure 15 presents MES visualization screen that shows Andon signal in the production line. When Andon signal is given, the product area is covered with a yellow octagon that indicates that help is needed. Inside the yellow sign time is running until someone has answered the signal. One purpose for Andon is to increase reactivity and fast actions to problems so the running time will measure and get data of how long it takes to get help. The signal can only be turned off from the computer where it was sent, so no one can not just check it off without seeing the situation. Every Andon signal will also require an error message to MES.

If a MES visualization screen is not open nearby, Andon signals can also be seen in each production area. All production areas have a large screen at approximately 3 meters' height so everyone can see it. The screens have a modified MES visualization screen and visualizes the work state in that area and who is working there. The Andon signal is shown as a large octagon on top of everything.

Everyone can answer Andon signals, but to avoid situations where no one is reacting, it requires a common procedure. It was decided that the foreman of the area is first in charge to answer to the signal during the first 5 minutes. If the foreman is unable to answer the call during the first five minutes, the supervisor needs to go see the problem. When the time in Andon crosses 10 minutes the production manager or other employees need to go solve the situation.

During the first three weeks of the new line it received 18 Andon signals. The average reaction time was 72 minutes (total 1299 minutes) and median 24 minutes. During the first week, there was two longer reacting times that grew the average and these times can be counted as feature launching errors since the feature was new and it needs time to get used to. Without these two amounts the average time was 25 minutes (total 441 minutes).

The goal is to get reaction times close to 0 which means that problems are solved as they emerge and the problem-solving processes are flowing.

So far Andon results have been positive. If the Andon signal is not noticed close to production, it is noticed by the manufacturing manager that will inform production supervisors. Problems are now more visible and that way people around the process can also see them and help solve them.

6.2.2 Pull system and standardized pallets

It was mentioned before that the pull system was decided to execute by doing systematic releasing of product operations instead of releasing the whole order. Releasing was set to perform three takts earlier at the beginning of the takt to get enough time for picking the parts from the warehouse and deliver them to the line. Picking the parts from the warehouse takes up to 6 hours and the delivering time can vary from 1 to 5 hours. Releasing the order three takts earlier means that if the line stops only parts for two takts can be picked and delivered.

Depending on the duration of delivery parts might need a small buffer storage before they are delivered to the line. There is a small area close to the production that has a space for storage. That area has been divided into sections in which all stations and assembly areas have their own storage areas. When a part arrives from Messukylä it is left to its allocated area and a material handler can pick up the part when it is needed in line. When all parts have assigned places and they are kept in order, it eliminates the waste of frustrating part searching around the site. The material storage area is large enough to store parts for two takts that can arrive even if the line has stopped. The material areas in production are only planned for one takts’ parts to make it easy for the assembler to choose the right parts and avoid confusion.

The difference between releasing the whole order at once or by operations was seen immediately. The storage area and yard that were previously full of parts have now only parts for the next takt. It is easier to keep the area in order when there are less parts and all parts have their assigned areas. The transformation to pull system has been successful and the change can be seen with bare eyes. The pull system supports one-piece process flow from warehouse to the buffer storage and finally to the line.

Creating standardized pallets for mass customized products is challenging but standardizing can be made partly. Hoses are divided to standardized sets and option add-in hoses. All different models have their own standardized sets which means a lot of different sets in the storage. All add-in option hoses that are not needed in standard products are placed next to the production area from where assembler can pick needed add-in hoses. For example, LT106 model has its own standardized set of 25 hoses that every LT106 needs. In addition, it has 22 optional add-in hoses that can be assembled if customers want. Standardized hose sets are coming straight from the supplier by using Kanban. Each model has a specific amount of spaces for standard sets and every time when there is empty space on a shelf the supplier will bring more sets.

The objective is to get all parts in standardized pallets which would make identifying missing parts easier and standardize the operations. It would be ideal if empty spaces in arriving parts areas could always be filled with another similar standardized set but in the case of mass customized products alternative options need to be developed.

Major decisions included a change in subassembly 1 operation model. Results can be seen in figure 16. The upper figure shows the typical situation in old operation model when parts were waiting for their need on the shelf or outside on the floor if they could not fit on the shelf. In the old figure, there are seven pieces of the same assembly waiting for their need. In the new operation model (below), all subassemblies for one product are placed in a pallet that is standardized. When all assemblies are done the ready pallet is placed at the outbound area where the material handler can pick it up and deliver to the right product. In the picture, there are subassemblies ready for four different products. All specific subassemblies for the product being in the same pallet enhances visualization of one-piece flow and it shows immediately if some parts are missing.

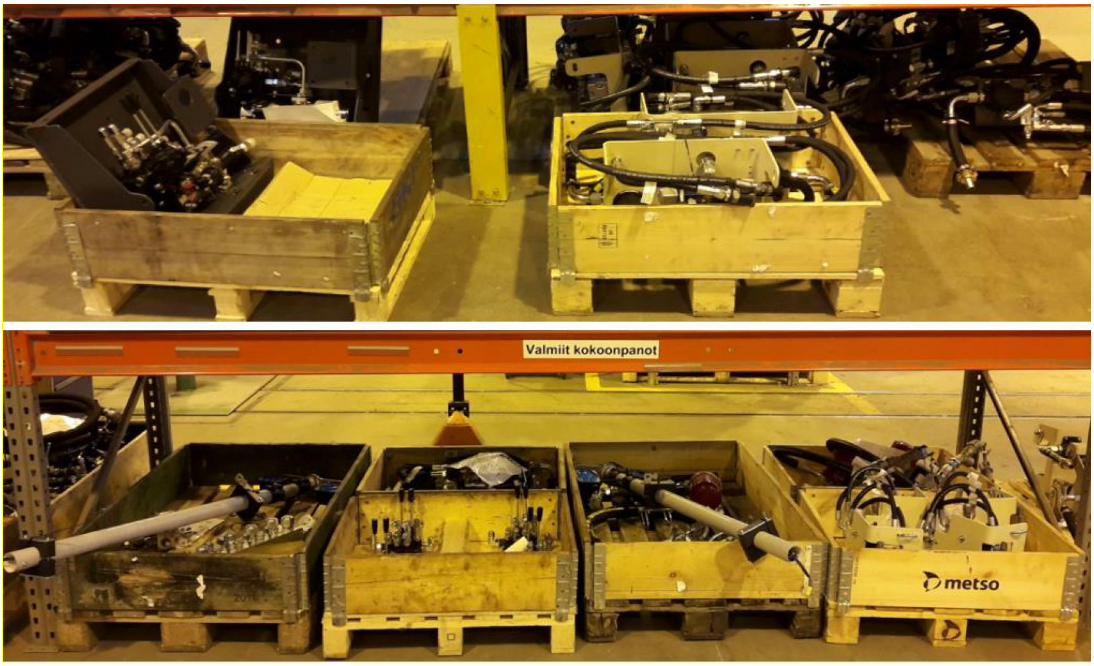


Figure 16. *Previous (up) and current (below) situation in Subassembly 1*

Every station has an assigned area for sub assembled parts and that area works as a pull area. It is obvious that doing assemblies separately takes more time and there are not mass production advantages but in one-piece flow there is no capital tied to in the waiting assemblies, time that was previously used for dissembling can now be used for value-adding work and it is a lot easier to manage when the area is in MES.

6.2.3 Kanban and two bin systems

There are two types of bulk material in two bin shelves: one type is that the supplier fills the bin automatically a few times a week and the other type requires order. The one that is automatically filled is in red boxes (Figure 17). When the front bin empties, assemblers remove the empty bin and pull a full bin behind it to the front. The empty bin needs to be facing backwards so the supplier will get a signal of empty bin. The supplier works behind the shelves and they see all empty bins facing out the back and the back of full bins. Components that need to be ordered are in a yellow box. When the front box empties the assembler removes the laminated order paper from the box and delivers it to the closest Kanban mailbox. The paper has the components' material code and shelf number so the order can be delivered to the right location. A logistic worker collects papers daily and orders more parts. All bulk material being in two bin and Kanban systems prevents missing any bulk parts. If any part in the two bin system is missing it requires a MES report and an investigation from the supplier and assemblers.

Figure 17. *Two bin system for bulk material. The system has clear instructions and uses parts as visual aid.*

All bins have one part attached to its front to show what the bin contains. People can easily see what the bin contains or should contain and there is no need to dig deep the bins or try to read the material code. It makes part recognizing much easier and faster which influences the assembly time and process flow.

The two bin system has worked well in engine module assembly but it requires communication with suppliers and good instructions for employees. Employees have been instructed how to act in empty bin situation but at first it requires more attention so everyone in the area learns how the system works.

6.2.4 5S

When starting to do 5S on an empty floor the first S is kind of skipped. Sorting of used and unused equipment and parts was made in the old production areas before moving to the new area. Used equipment was placed in appropriate areas and all unnecessary equipment was given to other departments or thrown away. Some of the largest equipment, which is needed occasionally but not on a daily basis, was stored nearby outside in a place where it can be easily found and delivered inside when needed. The old Speedline had multiple shelves that were not in official use but they were used as secret storages or trash areas where assemblers put parts they did not need. In the new production area, every shelf has some sort of function and there are no unused planes. That is done to prevent unused parts piling up next to the line and hiding parts without finding out their real use.

The systemizing of each station included deciding and taping good places for each equipment or needed tool in the area. All areas were color-coded with different color tapes: as lean says: blue is for outbound materials and green for inbound and so on. Each color has its own meaning. All areas were also named. Before applying systematic places to each function there was quite a mess. No one really knew where to keep tool walls or where the material should be delivered so everything was just left wherever. That created uncertainty and frustration among the assemblers, a messy environment that was difficult to manage, removed working space and created safety hazards. Every area has at least one area for arriving and one area for departing material and each area has their own areas for specific equipment. Organizing the area and taping assigned areas to all needed functions and keeping them there created a lot of space for production, and equipment is kept in the same places where everyone can find them. Tool walls were systemized before to some context, so the same system was applied to each station. It requires effort to create functioning tool walls since they need to be specified for the areas' needs but at the same time they should have a common logic that is easy to follow. All tools are not needed in each station which means that in some assembly areas there are extra tools just taking space from needed ones. Speedline station 4's 5S level is presented in figure 18. In the upper left corner, there is a green area for arriving materials. It is easy to see that the blue extra weight on the left side of the green area does not belong there so it should be removed. Other areas of empty pallets (up right), trash and computer area (below left) and tool area (below right) are easy to keep in good order when everything has its own place.

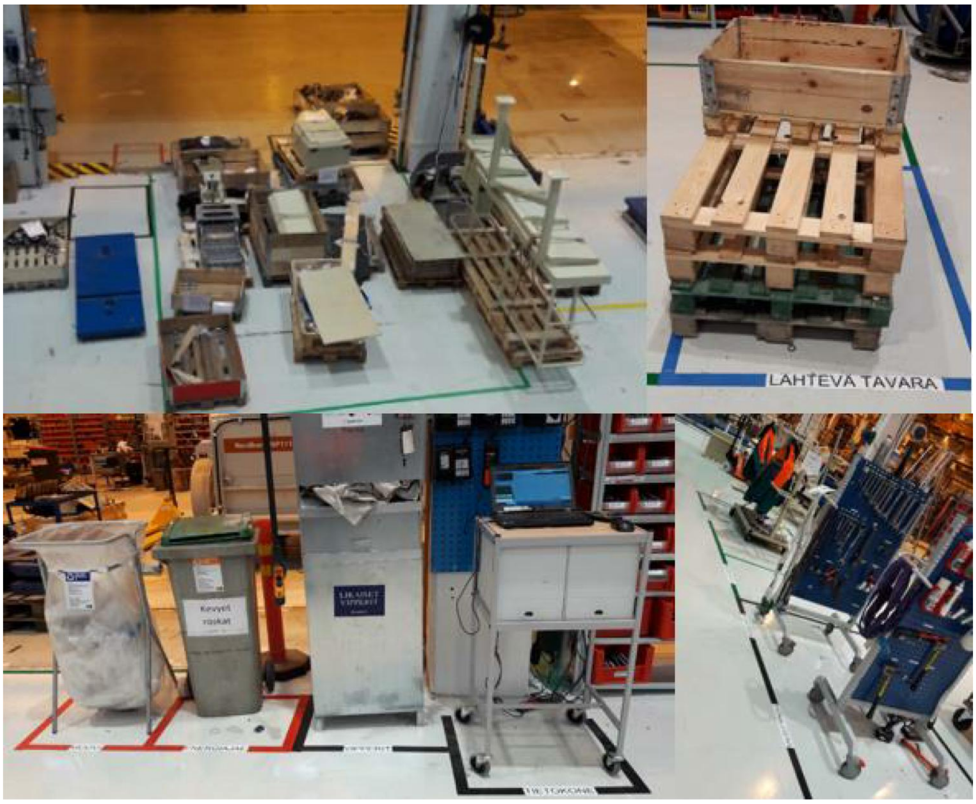


Figure 18. *5S areas for material in Speedline station 4 helps notice which parts belong to the station and which do not.*

To implement cleaning and 5S to everyday routines supervisors have a 5S tour 5 minutes before the shift end meeting where they encourage assemblers to clean their work place and remind them of cleaning and sorting targets. It is done to ensure that the area is left in the same condition that it was before the shift started and to guide people to sustain the achieved state. There is a five-step check-list that includes basic cleanliness criteria. Everything in the list needs to be done before ending the shift. The target is to create continuous cleaning routines so everything is automatically put in its right place and cleaned. Once a week, the supervisor does more intensive 6S checks in the area to find potential development targets.

Implementing 5S has been successful even though it is not in 5S state yet. Achieving the 5S state requires more time and guidance as there are people who do not know how to act in a 5S environment. Products, arriving and departing parts and equipment are in their places when they are not needed. All equipment does not have places yet since there are new parts coming to the area as different models go through the line. It can be seen clearly if some part should not be in the area and it usually creates a mess around the area.

Many employees have questioned the need of 5S but many also sees the positive side of it. It was noticed that by updating the order in the areas frequently will ease following the set instructions since when new equipment is added to production without a place it will automatically create mess. In the beginning the supervision is extremely important so everyone will see the benefits. Marking areas on the floor with tape does not automatically mean that the area will stay in good order.

Everyone needs to understand that 5S is not done because someone just decided so and because theory says so but to create a clear and understandable production area for everyone and make production flow and problems visible. Even at the beginning of the new production line it was easier to notice the problem areas and intervene when it was seen that production did not flow.

6.2.5 Factory layout

The factory layout was planned to improve the flow of production and help its management to see the production process as one. Being close to each other increased the transparency, and common protocols between operational areas could be developed to increase the flow. Future problems can be detected earlier which gives more time to find solutions and prevent them from happening.

The material flow was made straightforward from north to south. Only Speedline station 6 and large components for the crusher and feeder are delivered from south since they require more space for their delivery. Other parts are delivered from warehouse or small buffer storage, they go through the process and then the finished product will be driven out through south doors.

Building the visitor walking bridge next to the offices improved safety but also the visual presentation of process flow. Everyone can walk up whenever they want and see the process. From the bridge one can see the whole production process and it is easy to connect activities together. Spending a few minutes up on the bridge can help identify the process as well as problems that it is facing.

6.3 Visualization supporting management

The old production area had already some features, such as MES, that help management to control operations. Visualization to support process management was improved by creating the Obeya room that enhances the process and operation improvement projects, forming a QR team and its visual task board, implementing pull system by visualizing the releasing process and creating a standard work board and skills matrix.

6.3.1 Obeya room and daily meetings

The Obeya room was created next to the production line to where it is within easy reach for everyone who participate in daily morning meetings. Figure 19 shows the current state of Obeya room. Now the area has only a morning meeting board to describe the situation of the whole production process. The MES screens above the board support process management. The board includes the same safety, quality and current state observation parts as the previous board had but takt management and result parts are new. The morning meeting starts with safety and quality issues from the previous day. Then yesterday's results are listed in a weekly monitoring column followed by the current situation in each area and what the goals are for that day. The board will also have a small takt management area that will be updated after every takt. Each production area has its own column that will be filled with those product models that were not finished in time. It forms a pareto diagram and shows what areas and product models are the biggest problems that need fast reaction. The goal is that in the future MES screens will be used to show the current situation and the morning meeting board will focus more on improvement tasks and takt management, but the idea and MES requires some development.

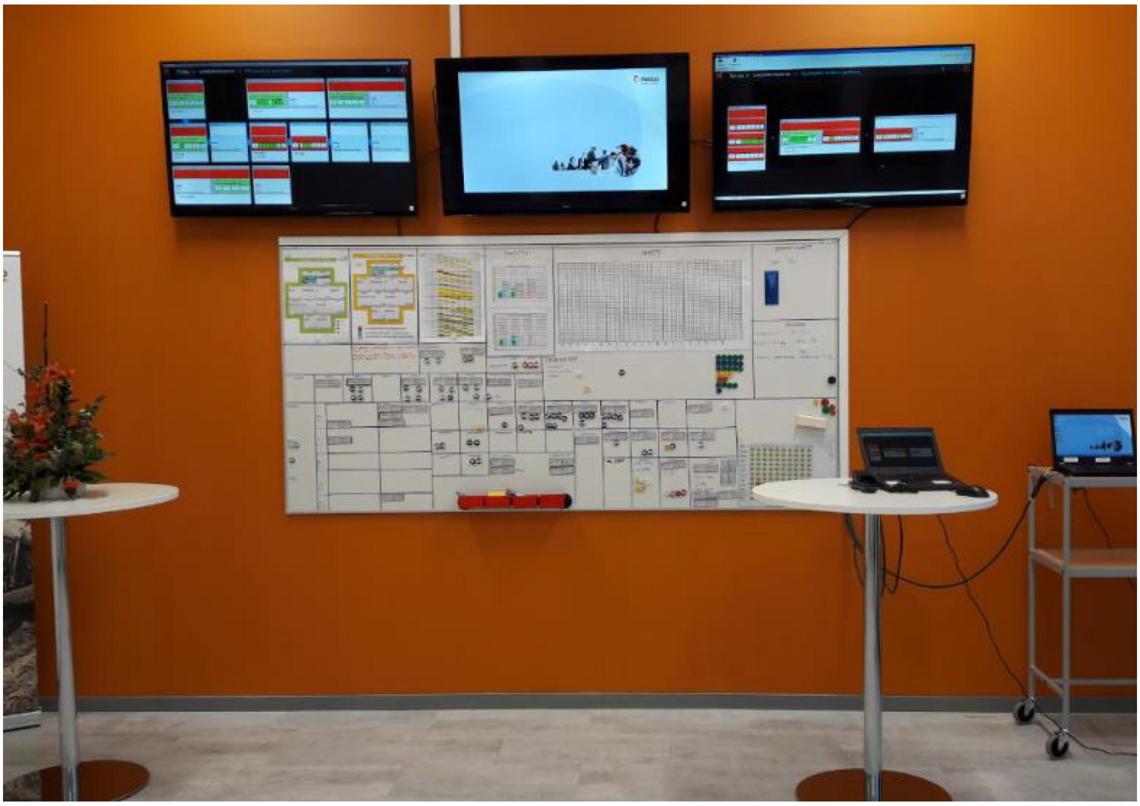


Figure 19. *Morning meeting board in Obeya room. Screens above the board show the situation in the production line.*

Data boards and other visual aids for the Obeya room will be developed during the spring. They will include visual presentation of important KPIs, development targets as well as a takt management board. This information will be synchronized together to show the big picture of the process flow and its biggest problems.

The Obeya room is used every morning but it still requires more of analyzed data to provide more efficient information and basis for development. The morning meeting is following all old board features and results part but takt management is not used. Without any takt management or without following what takts have been finished on time it is very difficult to find the most critical problems and then eliminate them. The concept of a problem-solving room still requires more development and guidance as well as management systems to provide analyzed information of the biggest problems and a clear presentation of planned versus actual state.

6.3.2 Visualization of the QR team

It was mentioned before that unexpected capacity problems are fixed with a group of self-imposed assemblers, QR team. The team gets their tasks signal either straight from the stations that lack assemblers or from a supervisor that has planned them to work for some products that require extra capacity or specific skills. It will help the management when there are a few extra workers that can be placed anywhere to fill in need and that way shortage situations are fixed.

When there is not assembly tasks the QR team does development tasks from their Kanban task board. The task board has small development tasks that need to be done. Tasks are added and prioritized by the supervisor but updating the task status is done by the team member executing the task. The whole team can be working on only three tasks at the same time to make sure that tasks are finished.

The concept of a QR team has been developed to a point where it needs to be tested. Procedures for the group have been determined but even with a good group of workers it requires mentoring to start working properly. The QR team can ensure that there will be enough people in all stations and knowledge to advice the work. It is easier to manage when there are only a few people moving between stations and it will improve process flow when there are no error situations due to station capacity.

6.3.3 Pull system and releasing the operation for management view

The monitoring board was created to remind to release the right operations of each product. There are 10-12 operations that the supervisor needs to release at once so there is a chance for human error and the supervisor to accidentally forget to release some operations. That is why visualizing the releasing process to everyone is good so even the assembler can notice if all needed areas are not released on time.

The releasing situation is visualized in the Speedline shift starting board with control cards that are presented in figure 20. Each product has one card and they are moved on the board as the product moves on line. Cards are placed on the specific area that tells what assembly operation is going on at that moment and what operations should be released at that point.

When the releasing has been done it will be checked off the card. The same time releasing is done also the material for that operation is ensured. Crusher availability needs to be ensured separately and checked to the C area. When releasing operation 1 in Speedline, the crusher needs to be in painting. If the crusher is not in painting the first operation is not released since the crusher will not make it to the line on time. If the crusher is in painting the first station can be released and material will arrive on time to station 1.

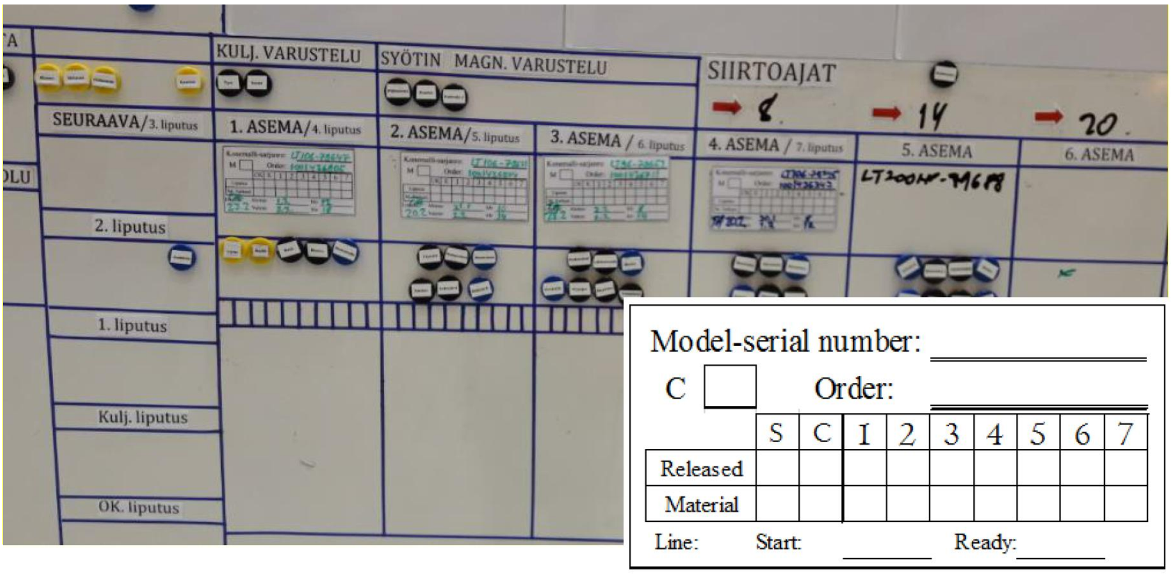


Figure 20. *Shift control board visualizes the releases has been done with a control card (front).*

This procedure requires that the supervisor needs to look two days ahead and be on track of what is going on with each product. Filling the cards might not feel necessary but it is important to make sure that material is available when it is needed. If the releasing schedule was not visualized it would be based on one person's memory which would increase the chances of error. Releasing operations takes a lot of time from the supervisor and that is why it needs to be improved or automatized. It has achieved its goal of making the material stream manageable, improved and visualized the flow and created a pull system but it would be even better if it did not take that many resources.

Shift starting meeting board also includes information on who is working and where. It also presents the next three times when takt is going to change and how the takt time was met in the shift. The success of takt time is colored with green or red in the small areas below each station. If the shift was not able to meet takt time it requires investigation of material flow and other related areas as well as analyzing MES reports.

6.3.4 Standard work board

Standard work board is a one-week calendar of five working days where each day is divided in to 30 minute slots. The manufacturing manager, supervisors, production planners and the development engineer list all their standard tasks on the board. The standard work board is placed in a visual place in the office where everyone can have access to it. The standard work board is presented in figure 21.

***Figure 21**. Standard work board on office wall*

The marking of tasks is done with color-coded markers to visualize what type of activities everyone's day include. The green marker means that this current activity is done on the production floor. These types of activities can be for example gemba and 5S rounds. The red marker indicates that these activities can't be disturbed and those activities are typically done in other rooms. Examples of red tasks are job interviews and meetings. The blue marker activities are done in their own place. Blue activities are that type of activities that could easily be done any time, like hour approvals, printing statistics and updating the morning meeting board. They are put to the schedule to create a routine for work, to remind people to do all those tasks and to get an efficient task flow. Black activities are other tasks that do not fit these descriptions.

When activities are done they are checked off with a green marker. At the end of the day everyone can see what tasks haven't been completed during the day. The following week's schedule is updated always at the end of the week.

Standard work makes it easier for new employees to understand what kind of tasks their job description includes. For older employees listed standard work shows what types of activities their work week includes and how much they have time to perform other activities. It also reminds them of releasing the operations since it happens at a different time every day. The board can have some starting resistance due to making everything transparent. Some people might not want to show everyone what they do and especially what time.

The board has not been in regular use yet since it was only just put on the wall and real results are difficult to estimate. The goal is that regular use of the board makes office work flow and it allows focus on scheduled work which improves efficiency. Starting to use it requires board updates in daily routines and keeping up with schedule and doing tasks in allocated time. Some office work, like hour approvals, could be at any time but doing it at the same time every day will make it routine which makes it more efficient.

6.3.5 Skills matrix

Skills matrix was needed to create a multi skilled environment and get rid of the division of an electrical and a mechanical assembler or the engine module and Speedline assembler. All assembly skills through the production process and supportive skills such as development work and welding are listed in the matrix.

SKILL	NAME	Assembler 1	Assembler 2	Assembler 3	Assembler 4	Assembler 5
Station 1	E					
	M					
Station 5	E					
	M					
Station 6	E					
	M					
Station 7						
Engine buildup						
Engine station 1						
Engine station 5						
Engine station 6						
Sub assembly 1						
Sub assembly 1						
Feeder ass.						
Conveyor ass.						
Material handling						
Fixing/welding						
5S						
Hose/pipe making						
LT7150						

Figure 22. *Skills matrix shows everyone's skills and reveals critical skills*

The matrix has all tasks listed in the first column and names of all department assemblers in the top row. Figure 22 shows the basic idea of the created skills matrix. Appendix F presents the whole matrix with all skills and also with a few scenarios. The green color indicates that the person can perform all tasks in that area, yellow means learning phase and red or empty means no skills. Assembler 4 can do all tasks from station 1 and 5 and learning to do tasks in station 6. Below the matrix there are some of the most difficult and uncommon product models listed as skills. These products go through the line a few times a year so they require special skills and that is why they are separated from normal station knowledge skills.

The skill topics of the matrix support the decision that people do not continue to the next station with the product but stay in their station for a week and then change to another station. The old thought of learning all mechanical tasks from all product models and stations will be transformed to learning all tasks, mechanical and electrical, in station 1 followed by learning all tasks in station 2. Current matrix still has separated rows for mechanical and electrical assemblers to ease management. During the transition time, it is easier to divide these skills to see who has expertise in these areas. In the future E and M rows can be merged as one skill. The skills matrix has all the stations separated and it will show when there are not enough skills for each area.

The skills matrix is printed on a magnet white board and filled with green, yellow and red magnets. It is visual to everyone in the area and assemblers can go see it whenever they want. Mainly it is a tool for management to see what skills are most critical to learn what would be the next development step for each individual assembler. New supervisors can also use it in problem cases if some specific knowledge is needed. The matrix can be copied to an excel file but then it would only be accessible for a few people.

A visible skill matrix provides a platform for life-long learning and self-development. The assembler can see a list of all possible tasks they can still learn and suggest possible learning targets to the supervisor. The supervisor and assembler need to have regular discussions of learning objectives to keep the continuous improvement cycle rolling. Knowledge is one of the most valuable assets a company can have.

The board is not in use yet and therefore actual benefits are difficult to estimate. It will bring up some discussion for sure, but trying new things is important. There are some benefits for assemblers who are multi-skilled and willing to train themselves so the matrix will work as a useful tool encouraging people to improvement.

7. RESULTS AND FURTHER DEVELOPMENT

The new production area started working in its scheduled time and without any serious complications. It was due to the persistent work of staying in schedule. Project management was in key role in confirming that there was not drifting in schedule. Deciding that the moving will be done at the time allowed project workers to plan everything to as far as it was reasonable and then move and try everything in practice. Many things changed afterwards so further planning would have been useless.

Unfortunately, this thesis did not have the time to follow the development and have long term results from the new production area. Visualization levels were increased in every area during the project and it has already shown some positive results. It takes time for everyone to adjust to the changes and start seeing the benefit in them and it is up to the management how many benefits each visual element provides to the production. It was mentioned in the lean theory that you can add many tools but it still doesn't change anything if it's not made to work and it was proved in this thesis.

The importance of the management's commitment to development projects was noticed as a critical factor in feature implementation. Visual elements were created to ease the work of everyone, but they take time and persistence to get everyone to use them before the benefits can be gained. It was said in chapter 2.5 that the management needs to be the role model and challenge people. It will also apply to implementing new tools. They need to show how they are used and challenge everyone to use and develop them.

There were many changes in the production area. In this thesis frame, there were ten development elements that were added to various parts of the production process. Table 5 presents observed results and next development steps of added elements. Further investigation of added elements and performing next step development tasks are critical for the new production area and for creating the atmosphere of continuous improvement.

Table 5. *Observed results and next steps for added elements*

Element	Result	Next step
Andon	▪ Line stoppers are visible to everyone ▪ Problem solving processes are systematic, fast and efficient.	▪ Develop system to decrease response times close to 0 minutes.
Pull system	▪ Material stream is easier to manage. ▪ Parts are systematically in order and easily found. ▪ Warehouse does only necessary work.	▪ Create material pull system from small buffer storage to the line. ▪ Development of automatic releasing system
Operating model in subassembly	▪ Assemblies for specific product are clearly seen and assemblies are made for need. ▪ Assembly area and production flow is easy to manage.	▪ Create visual instructions for each assembly by product model.
Kanban two bin system	▪ Clear process for bulk material flow. ▪ Both bins have sometimes been empty because new consumption estimations are not done.	▪ Consumption and patch sizes estimation.
Factory lay-out	▪ The whole process is transparent for everyone. ▪ Near locations allow convenient and efficient transportation.	▪ Fine layout changes are needed to create more ergonomic work space and efficient production flow.
5S	▪ Area is in order, clean and safe. ▪ Needed equipment is easily found. ▪ Reveals problems and abnormal situations.	▪ Continuous improvement process need to be developed for new tool addition.
Standard work	▪ Not yet in full use. ▪ Estimated to make daily tasks more efficient and create routines.	▪ Implementation phase. ▪ Develop systematic review routine.
Skills matrix	▪ Not yet tested. ▪ Estimated to improve process management and fasten learning process. ▪ Creates base for stationary assembly routine where assemblers are allocated to work in work centers, not products.	▪ Implementation phase. ▪ Create weekly planning routine for capacity planning ▪ Create systematic process for current state analysis and training processes.
Obeya room & daily meetings	▪ Not yet in full use. ▪ Estimated to help noticing most critical problems and improve problem-solving processes.	▪ Create systematic system to follow KPIs, problems and development goals. Make information flow logically.
Quick Response "QR" team	▪ Not yet in use. ▪ Can be estimated to ease capacity management in production.	▪ Implementation in phase.

Good results have already been noticed in most of the applied features. Andon has been in active use and it's efficiently followed by many officials in and near production. Reaction time needs to be improved but most likely it will be better as soon as large screens are installed in the supervisor area. Pull system cleared the material stream and it is easier for the material handler and supervisor to control it. It also balances the work load for the warehouse since now all picked material is for real need. The material situation can be seen at a glance and exceptions can be noticed early. The next step is to create a pull system from buffer storage to the production line to minimize the incoming material space next to line. In addition, the changing of operating model in subassembly has had positive results in its manageability and visual material flow. Instructions and assembly picture files could now be made separately for each product model to ease instructing processes. The new layout made the process transparent for everyone but fine layout changes and development tasks are needed to create more efficient production.

Positive results in 5S were based on experience when it was not applied to the area. Standardized places for everything improved the order of the area, created an efficient and safe work environment and together with those also improved visualization of process flow and management. Even though good results can be noticed in the beginning, 5S requires continuous development to sustain achieved state. Before production processes are stabilized 5S require additional attention so every added tool or device will have a specified place. Some problems have emerged with kanban two bin processes due to increasing amount of bin places on the line. Consumption estimations and pack sizes have not been determined for each place yet and it creates uncertainty with the supplier. The supplier has consumption data from the previous situation where there was only one bin location, but now the amount of bin locations can be increased to six and the consumption between bins varies. The two bin system requires more communication with the supplier so that they know how many parts are needed in each station.

Standard work, skills matrix, Obeya room and QR team have not been able to get to work at full or there has not been time for implementation yet and therefore their success can not be seen and results can only be estimated. The success of features is up to the attitudes towards their benefit. If they are followed regularly and systematically they can either create positive results that can improve the efficiency or turn out to have less benefits and require more development. But before getting to those results they need to be tested. Systematic review routines need to be developed by using personnel. The skills matrix shows a worker's capabilities by stations and drives the change from machine assemblers to station assemblers with a one-week rotation which eases capacity planning. The Obeya room is still under development but so far the space with a few boards has had a good reception. It needs to be developed to gather all information to one plot that will tell the essential information on current and target states. There have not been enough workers to establish a QR team, but when it is established it will ease the management work load in capacity management. To reach positive results it needs skilled and self-imposed workers.

Some of the developed features did not have enough time to be executed yet due to challenges in their software execution. Future MES updates will create a feature, that will show a green countdown clock from 360 minutes and if the time is over takt time it starts counting up from zero with red numbers. It will help takt management and it will easily tell how many minutes the production has delayed. MES shows how many days the production is late but it is important to shift the mindset into a minute schedule to support takt management and development. It might also be encouraging to see how many minutes the production has taken and it can challenge to improve and do better next time. In addition, in cases where production is late it is much easier to catch up minutes than days.

Further development proposals are derived from done activities and observed development topics. Figure 23 presents proposed development areas based on two criteria: impact and effort. The impact on operations is roughly defined by how large benefit the completed task will provide to process efficiency and flow. The required effort is defined by the estimated time and resources that is needed to fulfill the task. Any quantitative estimations of needed effort are not presented in this context.

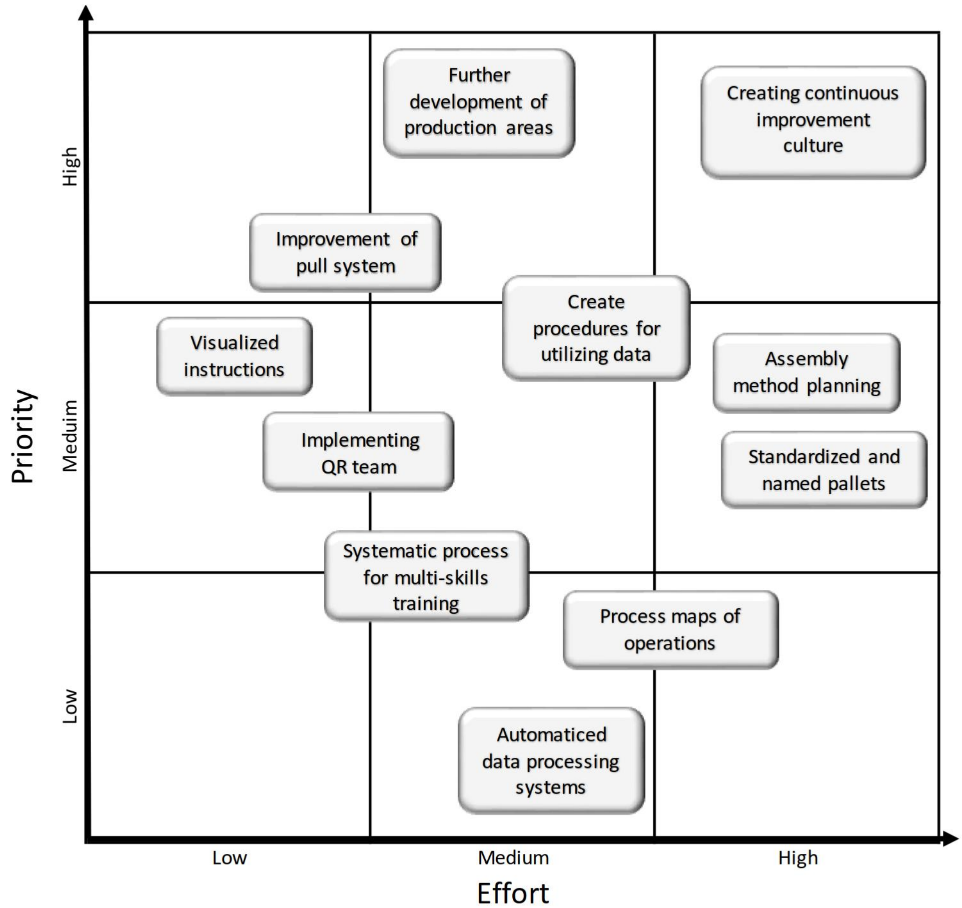


Figure 23. *Impact-effort action map for further development proposals*

The overall layout of production will probably stay as it is but each area requires development to improve the efficiency of operations and the material stream. All areas were planned carefully and everything was taken under consideration but in real life some areas might not work as they were planned and need improvement to reach their full capacity. It should be the next focus area to perform fine layout changes and create clear instructions of operations to ensure efficient process flow and an ergonomic working environment. A material requirements inventory should be made to find out if all parts have the right operation model. Also, the work procedures should be improved and standardized to be more efficient and logical and that way minimize created waste. For example, procedure planning and assembly method pictures or instructions for each station would improve quality and help in the assembly processes.

An other development area that needs to be considered in the near future is the pull system and operation releasing so that the best processes are found. It might require some operational changes either in the factory or warehouse or both to be able to find the best practices. The idea of the process is good and it prevents pushing the material to the production but it needs to be developed so that it is bullet proof and it will not require that much time from the supervisor. It should not be automatized yet since it has not been in use for long and some surprising cases might come up. Releasing operating areas in different sequences should be tried to minimize supervisor's work in the releasing process. The final assembly line could be divided to three sequences and each sequence would have specific requirements when they can be released.

Standardized or semi-standardized pallets require development to become more efficient and clear for everyone and to support the pull system and material flow. Developing semi-standardized sets has difficulties because of all add-in modifications. But it should still be considered and researched if a system that could support both, standardized and modified, could be developed. For example, if all standard parts to one station could fit in three pallets it would be possible to name all pallets with numbers or letters, A B and C, and when all of them have arrived it means that all standard parts are available for production.

Continuous improvement culture would have created a more suitable basis for this type of radical change. Implementing different ideas and lean principles in an area where the culture is open to new ideas and is prepared to develop existing or new ideas would have created more possibilities and ideas. A systematic roadmap to reach continuous improvement culture is important for future improvement projects. It is a long journey and requires high effort but it can be estimated to be an invaluable asset and create huge benefits for the company.

There are many systems that collect data from every point of the production process. Data is gathered and it provides information but it misses the logical process that connects the analyzing and operation points together. The Obeya room is a step forward in utilizing data and it requires to be developed to a systematic entirety that enables data to provide easier information and larger benefits.

Many changes have been made in operating models but many improvements are still required to create more efficient, flowing and functioning operations. Creating new routines and consideration of all activities that are done are essential for change. Everything in routines and common practices needs to be questioned and developed to be more efficient and useful for current needs. Different results can't be expected if the ways of working remain the same. It was noticed that guiding and informing is extremely essential for all performed activities and creating process maps that will explain how everyone is expected to act in each situation. Instructions for two bin systems are a good example of working instructions. Process maps and visual guides of activities are needed to share responsibilities and to achieve better performance. For example, a process map of Andon and material flow in the factory area as well as a visual guide that tells whom to contact in different situations would help everyone to fill their responsibilities.

8. SUMMARY

The goal of this thesis was to improve production flow and management practices by creating a new production area layout and use visualization to support management and flow. Many production and office employees were interviewed in the creating process of a practical and efficient layout. All areas had some critical requirements that needed to be considered when planning. Fine planning for each area was done together with area employees which provided them with an opportunity to take part in development activities.

Major decisions were made concerning the location of each assembly area, operating model and visualization. The basis for the decision-making process was lean principles, area restrictions and operational possibilities. Assembly area locations were determined by their needed lifting capacity, the location of the internal customer and the size of the area and product. The engine module assembly and crusher build up were placed next to the Speedline since they are heavy parts and their requirements were only met in those places. Smaller sub-assemblies were placed to be at an optimum distance from their internal customer.

Layout changes gave a good opportunity to change operation models. Making subassemblies straight to order and a pull system that prevents material piling up in storage minimize the waste of tied capital since material does not need to wait. Both processes ease management work since only needed parts are assembled or delivered to the plant. Changing the model required informing everyone of the new process models and creating instructions of the releasing process to the supervisors. Both changes have worked well and they have had positive results that were expected. However, both still require more development to minimize the required effort.

Visualization was a large improvement to the new line as visual elements were added to support the flow and management. Many elements were implemented for the very first time and a few were added since they were already proven as good practices. However, visualization can only reveal problems and provide an easier platform for work. To make elements work and execute development projects it needs management, persistent work and discipline to follow the common rules.

The goal of the thesis was to create a *visual management system that supports process flow and management to its objective to achieve 360 minutes takt time*. When the line has been working for five weeks takt time has been achieved in some stations but some stations are still struggling with it. Changes have revealed problems that have been hiding behind all waste, such as wrong material allocation and lack of communication between parties. Problems have forced everyone to do things differently. It takes time to change old habits and management needs to force them to change so the development in the area can continue.

One research question was *how visualization can support management and process flow.* There is no numerical data of how visualization has affected achieving the takt time, but material flow can now be seen clearly in the factory layout and it supports the visualization of process flow and its management. Visualization cannot do miracles so it is up to management how these visual elements are exploited and used to reach the goals.

The second research question was to see impacts of *visualization of overall ergonomics in the workplace*. Making clear instructions of how things should be done in specific procedures will give peace of mind to people and prevent feeling angry when parts are missing because of wrong procedures. It was found out that visualization cannot have a large impact alone but visualization with good communication and instructions together can make a difference. Just by adding 5S to the factory floor doesn't make a change in the area; it requires instruction on how to use it. A blue area is just a blue area to the assembler if it is not instructed how the outbound area process works. Uninformed people can have unsure feelings, which does not improve well-being at work.

The third research question was *how visualization supports continuous improvement.* Continuous improvement culture needs still to be created by making everyone participate in post-transition development processes. Self-development for each employee is considered in the skills-matrix and it gives an opportunity to change the culture from a person being an expert in one area to being an expert of the whole process. Visualization reveals many development targets but their execution requires many assemblers to take part in them. It is up to the production schedule and capacity planning how everyone is able to participate in development processes.

The thesis achieved its goals in creating a new production area that uses visualization to support process flow and management. All assembly areas in the new production area started operating at their scheduled time. All products have not reached the 360 minutes takt time but it is possible to reach it with a few improvements in processes and common practices. Minimizing waste in the material stream and creating a pull system will enable faster reaction to error situations and will help find all hidden problems in the system. Takt time management system was created but it needs more development to provide more benefit for its user.

Making these large changes hopefully change the culture but it will require time for everyone to see the benefits and reasons for the actions. Time will hopefully wash away the prejudice for this project and everyone will start to see it as a great opportunity to improve their own work area or practices. It has been said that there is nothing permanent except change. That will also describe this project. As it is typical for action research, done activities changed and improved the area and its surroundings and now it is tested if it works.

All improved features and operating models need to be checked again in a few months to evaluate their performance and if they have been as good as assumed.

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APPENDIX A: INTERVIEW STRUCTURE A

Interview with production controllers and supervisors: Current practices in production planning and process management

1. How are the estimated finishing times set and fine scheduling done? Describe the process and the people responsible.
2. How are the stations balanced and tasks allocated between stations?
3. How is the material stream in production controlled and supervised? Describe the process, tools and the people responsible.
4. How is the capacity of workers and other resources planned to meet production needs? Describe methods, plans, material requirements, working conditions and other resources.
5. How is the production process managed? Describe process, tools and people responsible.
6. What type of daily routines does the production have?
7. What are the most common problems in production and how would you improve production?
8. Is there anything you would like to add?

APPENDIX B: INTERVIEW STRUCTURE B

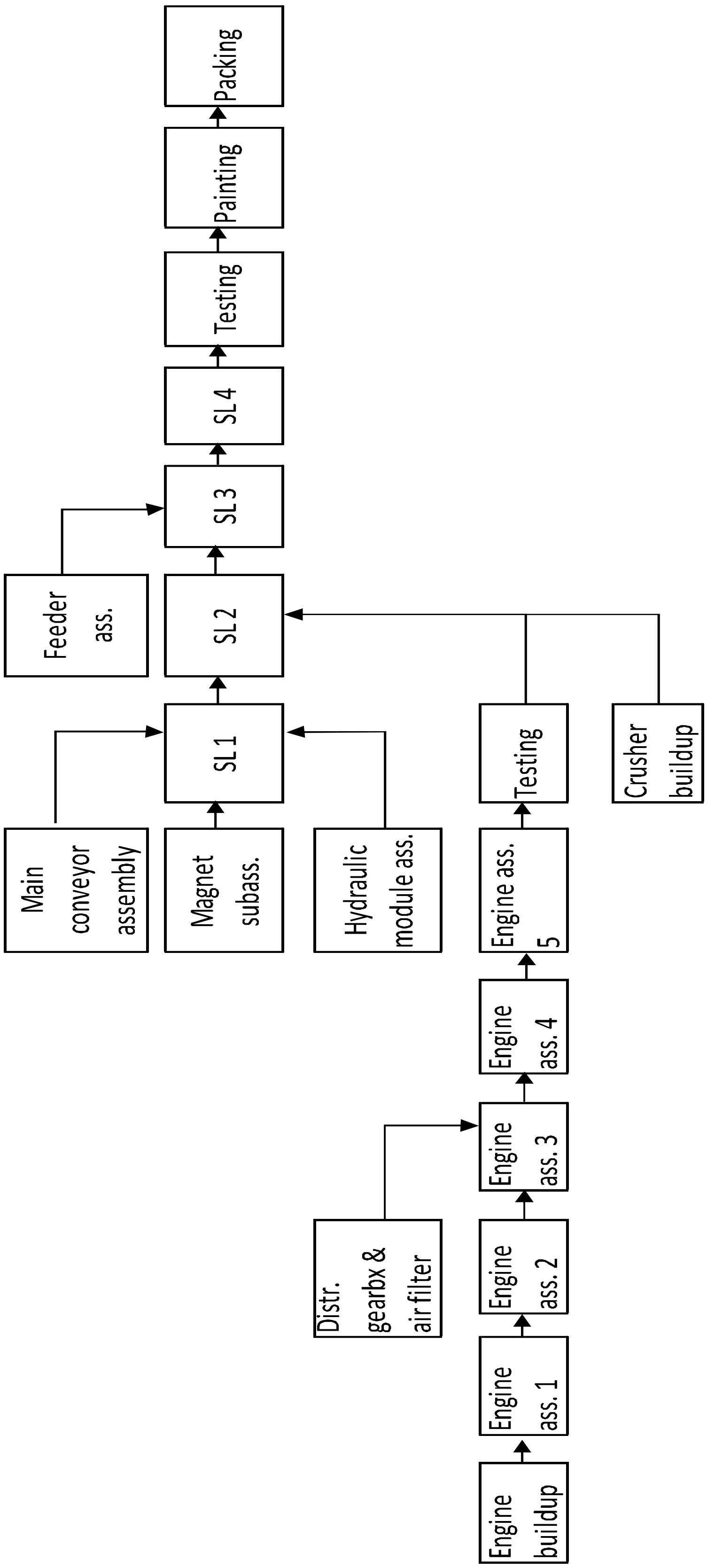
Interview with the assembler: Current production process and required resources

1. How do you become aware of the complete production process? What type information would you like to get more?
2. What type of material is needed in the area where you work?
3. What resources (tools, workers, cranes, racks e.g.) do you need in each station? Describe process and tools.
4. How much space or height do you require to perform at each station?
5. What are the most common problems in production and how would you improve production?
6. Is there anything you would like to add?

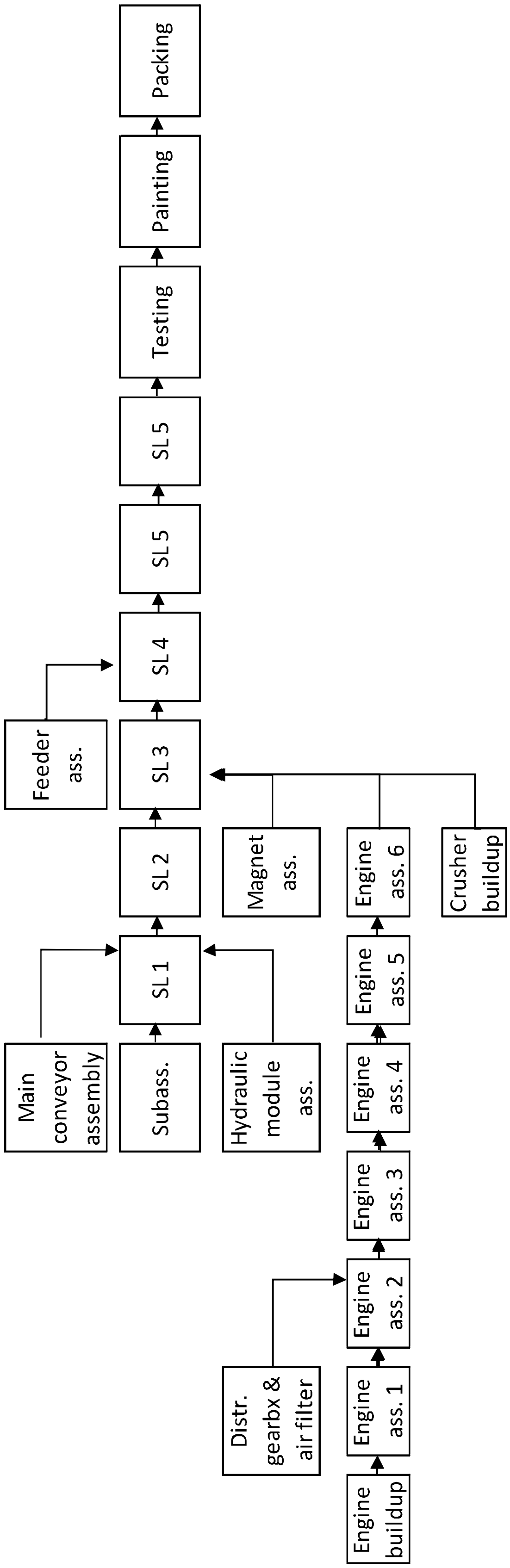
APPENDIX C: BENCHMARK RESEARCH STRUCTURE

1. What type of daily routines do you have? Who is responsible and what tools and methods are in use?
2. What kind of standard work do you have for each employee and how is it visualized?
3. How does the material delivery work and how is it visualized?
4. How do you maintain 5S state? Who is responsible for maintaining the state and updating?
5. How does the visualization support your production management and production development?
6. How do you follow production flow and make sure that takt time is achieved?

APPENDIX D: PRODUCTION PROCESS BEFORE CHANGES



APPENDIX E: PRODUCTION PROCESS IN NEW PRODUCTION AREA



APPENDIX F: SKILLS TRAINING MATRIX

Starting situation with different types of assemblers. Matrix describes different possible scenarios and situations of assembler's skill levels at starting point of the matrix. In this situation, all assemblers know their current tasks very well.

SKILL	NAME	Assembler 1	Assembler 2	Assembler 3	Assembler 4	Assembler 5	Assembler 6	Assembler 7	Assembler 8	Assembler 9	Assembler 10	Assembler 11	Assembler 12
Station 1	E												
	M												
Station 2	E												
	M												
Station 3	E												
	M												
Station 4	E												
	M												
Station 5	E												
	M												
Station 6	E												
	M												
Station 7													
Engine buildup													
Engine station 1													
Engine station 2													
Engine station 3													
Engine station 4													
Engine station 5													
Engine station 6													
Sub assembly 1													
Sub assembly 1													
Feeder ass.													
Magnet ass.													
Hydraulic ass.													
Crusher buildup													
Testing													
Packing													
Painting													
Conveyor ass.													
Material handling													
Fixing/welding													
5S													
Development													
Hose/pipe making													
LT7150													

Different assembler scenarios described:

Assembler 1: Electrical assembler from Speedline. Can do electrical assembly LT7150.

Assembler 2: Working in seventh station and fixing products. Can also perform welding and make pipes and hoses as well as participate in development work.

Assembler 3: Engine module assembler. Can assemble LT7150 engine module.

Assembler 4: Assembler can perform subassembly in two different subassembly areas.

Assembler 5: Can only do hydraulic assembly.

Assembler 6: Mechanical assembler that can also do welding. Can do mechanical assembly for LT1750.

Assembler 7: Conveyor assembler. Is learning to assemble LT7150 conveyor.

Assembler 8: Conveyor assembler who can also do material handling tasks.

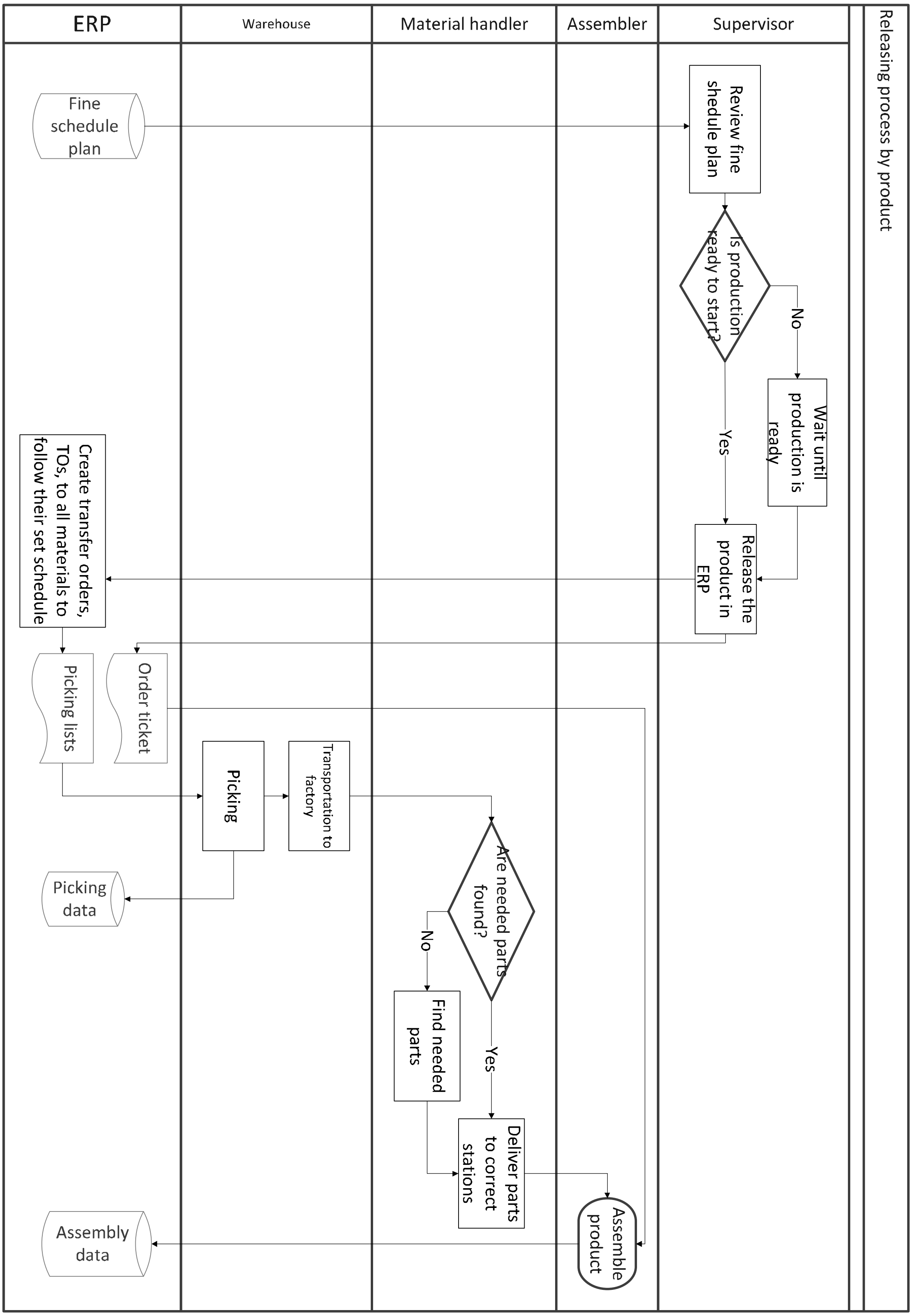
Assembler 9: Assembler from production end who can do testing, painting and packing.

Assembler 10: Crusher assembler

Assembler 11: Feeder and magnet assembler that is learning LT7150

Assembler 12: Can do subassembly 1 and hydraulic assembly

APPENDIX G: RELEASING PROCESS BEFORE CHANGES



APPENDIX H: RELEASING PROCESS BY OPERATIONS