# Maximizing productivity in paint industry

# - Using lean philosophy and virtual simulation

*Bachelor Thesis for Mechanical Engineering*

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Abstract:

The purpose of this thesis was to assess the productivity of Hydrodip AB in the paint industry and determine how discrete event simulation in conjunction with lean production could be used to make improvements. In the future, the case company hopes to have lean production and discrete event simulation (DES) as a standard approach to all their manufacturing. The scope of the project included determining the current productivity, identifying current wastes, and identifying improvements to increase the productivity. The question answered in this project was how productivity can be improved through lean production and simulation in the painting industry.

The selected method to perform the project included on-site observations, interviews and data collection to conduct a current state value stream map (VSM). The future state map was then developed using lean philosophy to reduce the wastes identified, in conjunction, DES was used to verify the improvements from the future state VSM.

The report uses traditional methods used in all types of manufacturing such as the automotive one and implements it in a job-shop paint industry. This report could thus be used as a template for paint companies that are looking for an approach to increase productivity, using the thesis as a guide to a new area to explore with lean production and simulations.

The authors chose the simulation program Tecnomatix plant simulation for their project because they have previously worked with it. The software is complicated, making it possible to design and visualize any production system. Nevertheless, it takes time to implement all the elements necessary for the system to accurately depict reality.

It was determined that without any investments for the case company, it is possible to reduce the production lead time with 46% or 26 hours by implementing improvements produced in the future state VSM. It was further discovered that investing in a new heat lamp, a different primer and an additional grinding room could decrease the production lead time with 87%. This will contribute to an efficient and profit-driven production if implemented. Due to limitations such as time and budget constraints, the authors will not see the implementation of the recommended improvements produced by their work at Hydrodip AB.

Keywords: Lean production, Discrete event simulation, Value Stream Mapping, Paint industry, DES, VSM

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# Wordlist

**Andon:** Is a visual control that shows status. The Andon could be used to show the status of a machine at work, work processes or similar.

**Bottleneck:** Occurs when some part of the production, usually certain processes, is not efficient enough for some reason and creates queues, halts or delays production leading to higher production costs and lower outputs.

**Genchi genbutsu:** Direct translation to English is “go and see for yourself”. It is a principle from the Toyota way that indulges one to go and observe a location and its conditions in order to understand processes and problems among other things.

**Kaizen Lightening:** Activity that solves an issue.

**Lead time:** Is the amount of time passed from the first process to the last one. It includes total times such as transport between processes and buffer times.

**Poka yoke:** Is a control system to ensure that there is no human error. In assembly lines it is used to ensure that the operator has picked the right materials. In material handling it is a mechanism that leaves no room for human error in terms of picking materials as the human must confirm the item has been picked for the poka yoke to not stop the assembly line.

**Pull system:** Is a strategy to reduce waste in processes. Components used in manufacturing will only be replaced once consumed in order to eliminate overproduction, which is a waste according to lean.

**Supermarket:** Is a location where determined supplies are stored to aid and supply downstream processes. It minimizes lead times by eliminating transport time between processes and unnecessary material handling.

**Takt time:** defines the rate of which a product needs to be finished to match customer demand.

**5S:** A methodology used to keep a workplace/worksurface clean, organized and safe. Usage of this methodology can result in waste reduction, higher quality of products and employee safety. 5S stands for sort, set in order, shine, standardize and sustain.

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# 1 Introduction

The thesis work is introduced in this chapter, which includes a background on the company and project. The project's goal and objective, as well as the delimitations, are also presented.

## 1.1 Background

In today's manufacturing companies look for ways to perform certain tasks at the lowest costs possible, to maximize income. This can be done by hiring multiple suppliers to secure different components, all working towards assembling one product. Hydrodip AB is a company that offers different options for industrial and personal paint jobs to different components and market targets. The painting industry is a specialized one, with few studies being conducted to improve productivity. As a result, this work will concentrate on increasing productivity in the painting industry using lean and DES as tools.

Hydrodip AB was founded in 2014 and is situated in Gothenburg, Sweden. It is a fast-growing company that has already had to change locations twice, and now is working on expanding their current production to twice the size (Hydrodip AB, 2019). They offer industrial painting among other things. Their main expertise is in wet painting and hydro dipping, but they are now working on expanding their current production to powder coating to meet other customer targets. Their customers vary from painting kitchen fans to gun holsters and phone cases, they can paint any component they wish in one way or another, and according to customer demand. The factory located in Partille, Gothenburg, is a typical job shop environment. Due to the organization of manufacturing function and the material flow is adapted to it.

One of the items Hydrodip paints has a consistent demand. The company wishes to evaluate manufacturing capacity to be prepared for a possible increase in demand. The organization also wants to know whether there are any capacity-enhancing changes that may be made. Furthermore, the suggested changes will be considered in their other production projects/lines. Furthermore, as this has never been done before, the company is interested in using discrete event simulation to analyze the manufacturing capacity.

## 1.2 Aim

The aim of this bachelor thesis is to conduct and investigate ways to optimize and increase the production efficiency in Hydrodip AB's current production facility. We aim to thoroughly investigate and determine flaws in the current facility and find ways to improve them with the help of various research and our knowledge in production processes obtained through our education within our bachelor's degree.

## 1.3 Research question

The project will focus on the efficiency issue from two main angles.

- How can productivity be improved through lean production and simulation in the painting industry?

## 1.4 Goal

The goal is to increase the productivity of the company with help from various methods. By the end of the project a list of changes in the way of working that will contribute to an efficient and profit-driven production will be delivered to the company. Such changes could reduce waste based on lean philosophy and implementing tools such as 5S in their production. If successful, a seed will be planted in the company's mind and show them the benefits of working with lean philosophies. The 7+1 wastes according to lean philosophy will be eliminated, identify bottlenecks within production and hopefully introduce a standard way of working in various processes.

The list of improvements provided to the company will be based on observations regarding their main product, Fjäråskupan and all the processes that it includes. However, the recommendations and improvements can be used as a template in their new upcoming factory and in future processes. In addition, an approach that have been developed and implemented for this research area will be presented.

## 1.5 Limitations

The project will utilize virtual simulation to illustrate the improvement changes suggested from VSM. Due to time limitations the project will produce a list of recommended changes that will improve the productivity, but the authors will not get to see the changes implemented in real-life and the results are only theoretical at this stage. The real effects of the changes have on the production can only be confirmed once they are implemented.

# 2 Theoretical framework

The literature study, as well as the literature of the methods used in the thesis, are presented in this chapter.

## 2.1 Lean philosophy

Lean manufacturing is a well-known production system management philosophy that originated at Toyota Motor Company after WWII. Its primary purpose is to decrease and eliminate waste, hence enhancing the end product's value and lowering expenses (Abdulmalek and Rajgopal, 2007). Lean philosophy is wild spread and is used in many areas today. One of the first steps to investigate when looking for improvements on production floors is the principle of waste reduction and the utilization of tools such as standardization and 5S.

Lean can also be used in management and personnel in conjunction with manufacturing, which also nourishes production. The Toyota way consists of 14 principles in two key areas: continuous improvement and respect for people. By implementing these 14 principles (or the principles relevant to the system) one will achieve among other things a better production flow, better morale in the company and higher quality of products. The first principle emphasized in the book Toyota Way is that long-term solutions by managers are more beneficial than short-term financial goals, which require investment in both equipment and employees (Liker, 2013).

Lean philosophy is a term that focuses on the reduction of waste, one way of doing this is the so called 7+1, which are listed below. By reducing or eliminating these wastes production flow, quality of product, production cost (cost per product), cost for maintenance and many other factors have can be improved drastically (Gourley, 2020).

*Table 2.1 7+1 Waste*

| | |
|---|---|
| 1. Defects | Faulty products that require additional resources to function |
| 2. Overproduction | Producing more than selling, thus leading to inventory |
| 3. Waiting | Wasting time by waiting to begin the next step of the production |
| 4. Transportation | Transporting products or materials unnecessarily without the movement benefitting the process |
| 5. Unutilized talent | Assigning high skilled employees to perform tasks below their skill set, thus not using the employees to the fullest. |
| 6. Extra-processing | Doing tasks that are not needed or does not further the products function or goal. |
| 7. Motion | Unnecessary movement by employees, for example to search for missing tools or not having enough space on worksurface |

| | |
|---|---|
| 8. Inventory | Storing products or materials (finished or unfinished) without processing them |

### 2.1.1 Standardization

The concept is the most well-documented working method in terms of quality, efficiency, and safety. It includes the order of the work steps, as well as the times for the labor steps, are all described in detail (Fager and Olsson, 2021). And is also the foundation for continuous improvement and quality in a business. If the process is shifting from here to there, every enhancement will just be another variant that is used infrequently and ignored most of the time. Before continuous improvements can be made, the process must be standardized and thereby stabilized (Liker, 2013).

However, standardization may be the most misunderstood and misused principle of all the lean ideas. This principle may have its origins in Frederic Taylor's early research and the goal to increase revenue by meticulously defining work components and holding staff responsible for completing them. In some businesses, work standards have a long and tumultuous history, with the goal of "beating up" personnel for mediocre performance. As a result, there are certain well-known "games" and ways to get around the system. Due to this dilemma, there is a competitive climate between operators and higher-ups. This is problematic because there must be a common purpose of high quality, but instead we are left with a competitive environment. (Liker & Meier, 2006).

### 2.1.2 Continuous flow

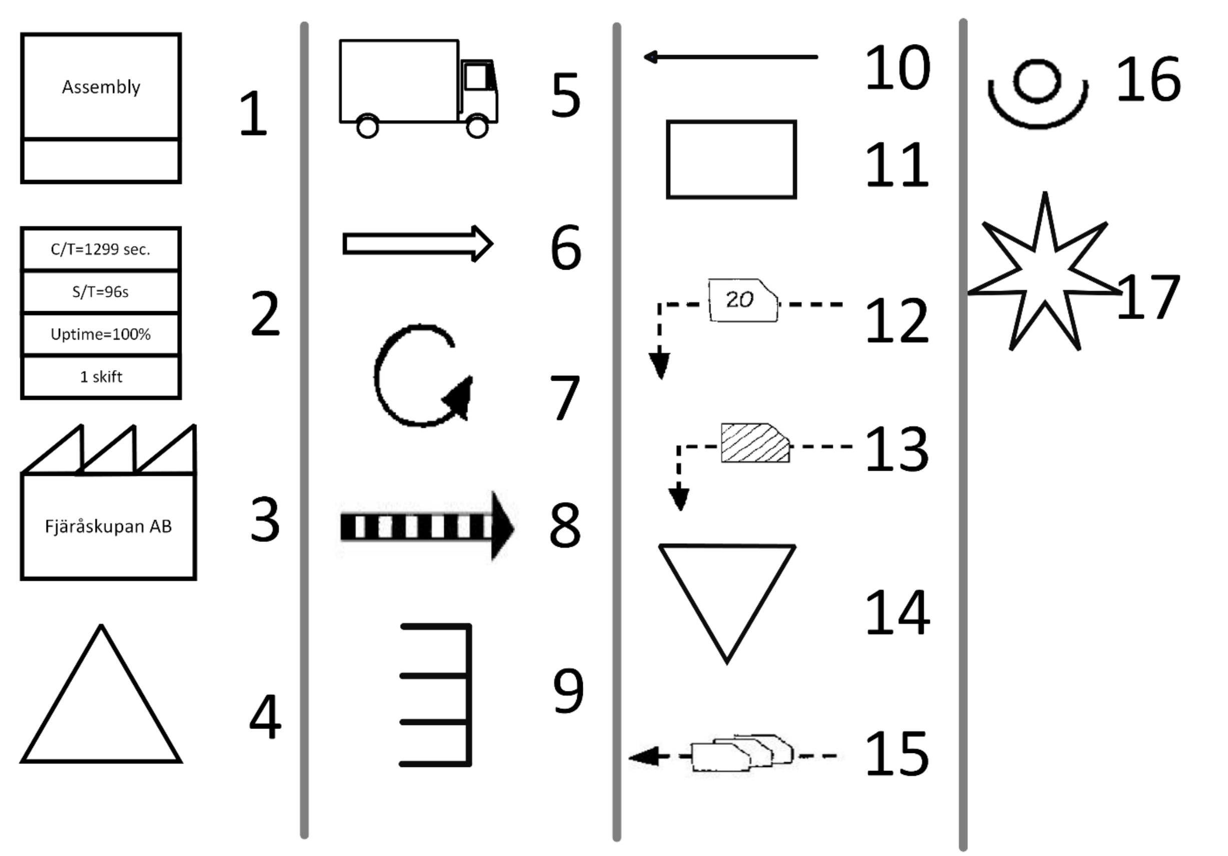
Continuous flow means the production of one item at a time, with each item moving seamlessly from one process step to the next. Continuous flow is the most efficient way to produce and achieving it will require a lot of innovation (Roother & Shook, 1999).

Creating flow whether of materials or information reveals inefficiencies that need to be addressed right away because the process will shut down if the faults and bottlenecks are not fixed. Everyone involved is incentivized to correct them. Traditional business processes on the other hand can hide significant inefficiencies from a clear view. In the manufacturing industry, some processes take days or weeks to complete, with a lean process may achieve the same result in a couple of hours if not minutes. This is one of the shortcomings of traditional company operations, where massive inefficiencies can go unnoticed (Liker, 2013). Leadership commitments where all employees are informed to be involved in continuous improvement could be key to eliminating these inefficiencies.

### 2.1.3 Value stream mapping

Value stream mapping (VSM) is a lean tool developed by Toyota. The method maps how the material flows through the factory and how the information flows through departments. The purpose of value stream mapping is to see what the nonvalue adding activities are and eliminate them. Value adding time is time spent on the product that contributes to the result, for example grinding. Nonvalue adding time is for example when the product is waiting in a buffer for the next process. The method has a useful feature where it closes the loop from costumer order to manufacturer. The state that is given by VSM is static and therefore cannot analyze capacity and loading and this is a shortcoming. First the current state map is drawn with symbols shown in table 4, where current material and information flow is mapped for the chosen product family. VSM presents the current situation and gathers first-hand data. When mapping, a stopwatch can be used to measure data that is not available (Bärring, M et al., 2006). Most manufacturers have a waste margin of 95-99%, some WorldClass manufacturers achieve 90% or less (Holweg et al., 2018). The future state map is where creativity comes in place to decrease nonvalue added time. When analyzing the future state map eight questions shown in table 5 were created by Roother and Shook (1999) to guide in making decisions. This map then serves as the foundation for making the necessary system adjustments (Abdulmalek and Rajgopal,2007).

*Table 2.2 VSM Symbols*




| | |
|---|---|
| 1 Manufacturing process | 10 Manual information flow |
| 2 Data box | 11 Information |
| 3 Outside Sources | 12 Production Kanban |
| 4 inventory/Buffer | 13 Withdrawal Kanban |
| 5 Truck shipment | 14 Signal Kanban |
| 6 Movement of finished goods | 15 Kanban arriving in batches |
| 7 Withdrawal | 16 Operator |
| 8 Movement of production material by Push | 17 Kaizen Lightening |
| 9 Supermarket | |

*Table 2.3 Questions for the future state map based on Roother and Shook (1999).*

1. What is the Takt Time?
2. Will you build to a finished goods supermarket from which customers pulls, or directly to shipping?
3. Where can you use continuous flow processing?
4. Where will you need use supermarket pull systems in order to control production upstream processes?
5. At what single point in the production chain (the "pacemaker process") will you schedule production?

6. How will you level the production mix at the pacemaker process?
7. What increment of work will you consistently release and take away at the pacemaker process?
8. What process improvements will be necessary for the value stream to flow as your future-state design specifies?

## 2.2 Discrete event simulation

DES, often known as simulation, is a useful tool utilized in a variety of sectors. Simulation allows you to simulate the operation of real-world processes or systems over a set period of time. This has been proven useful for solving many real-world problems. The behavior of the system and testing different scenarios regarding real world system can be simulated. When simulating a system, for example, artificial history is generated based on input data, and then that artificial history is observed to draw conclusions about the operating characteristics of the real system that is represented (Banks,1998).

There are numerous advantages and disadvantages to simulation, identified by Banks (1999). Some of the advantages and disadvantages are presented below.

+ You can test every aspect of a proposed change or addition without spending money to its acquisition by using simulation.
+ You can save time by simulating one day in a matter of minutes
+ Experiment with new operating procedures and methods without causing any disruptions to the real-world system.
+ Simulating complex factory systems can help you better grasp the interactions between the various variables that make up the plant.
+ Identifying the cause of bottlenecks, for example WIP (work in process) and processes.
+ Instead of displaying an individual's assumptions about how a system would run, simulation studies aid in gaining a better knowledge of how a system works.
+ Simulation is a smart investment because the estimated price of a simulation study is less than 1% of the entire cost of implementing a design or redesign.
– It might be difficult to tell if an observation is the consequence of system interrelationships or chance because most simulation outputs are essentially random variables.
– If you cut costs on modeling and analysis, you can end up with a simulation model and/or analysis that is not up to the task.

A well-known strategy for carrying out a simulation project is the Banks project approach Figure 2.1. This technique is suitable for most types of simulation projects since it contains all the key procedures demonstrated by Banks (1999) in a simulation project.

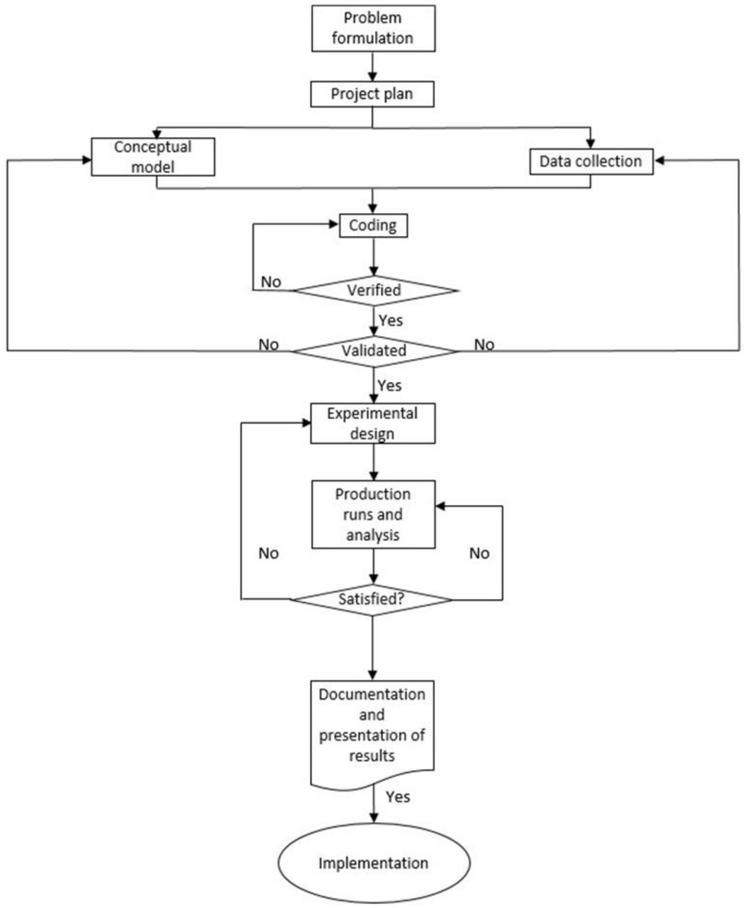



Figure 2.1 *Banks project model for carrying out a simulation project (Banks, 1998).*

## 2.2.1 Data Collection

Data collection is an important factor of the simulation project's quality. If the simulation model is provided with inaccurate data/wrong data, the result will be wrong (Chen, 2021). In the best-case scenario, the customer has been gathering the necessary data in the right format and is able to submit it to the simulation analyst. Frequently, the client confirms that the requested data is in fact available. When the data is supplied. However, it is discovered to be significantly different from the data that was expected (Banks,1999).

*Table 2.4 Sources of input data by Chen (2021)*

| |
|---|
| • Production technicians` own documents<br>• Automated logging system<br>• Business systems and planning systems: ERP, MESMRP.<br>• Documents from the construction of the production system<br>• Documentation from previous collection of production data<br>• Personal time studies using clock |

- Video analysis
- Interviews
- Historic data from similar processes/machines
- Expert groups
- Data from machine suppliers

## 2.2.2 Verification

Verification is concerned with the operational model and ensuring that the simulation model corresponds to the conceptual model. The verification should be taken place during the building of the model Banks, 1999). Some methods of verification are presented in table 7 below.

*Table 2.5 Methods for verification by banks (1998).*

- Follow the principles of structured programming
- Make the operational model as self-documenting as possible
- Have the computer code checked by more than one person
- For a variety of input-data values, ensure that the outputs are reasonable
- Use an interactive run controller or debugger to check that the program operates as intended
- Animation is a very useful verification tool.

## 2.2.3 Validation

Validating a model is concerned with comparing the outputs of the simulation model to the real-world system and see if they match. The purpose of validating a model is to have a real-world system that you can experiment with (Banks,1999). Some methods of validation are presented in table 2.6 below.

*Table 2.6 Methods for verification by banks (1998).*

- Face validation (The appearance of the system should be decent in the eyes of experts who know the system.).
- Sensitivity analysis (The model should behave in a predicable way when inputs are changed.)
- Consistency checks (Examining the operational model over time to ensure that no changes in the real system need to be reflected in the structural model.)
- Turing test (Experts of the system should compare the output of the model to the real system output.)
- Validating using historical input data (Running the operational model with actual historical records and analyzing results.)

## 2.3 Software

Using different types of software gives great advantages when executing projects of improvement nature. Software such as Tecnomatix Plant Simulation and Visual components gives the opportunity to easily simulate and predict production flows, continuous flows, machine breakdowns, possible future output and compare them to the current state of the factory. Other software could also investigate the ergonomically aspects that affect operators over a long period of time. This is without a doubt a more effective and optimal economical solution, compared to making the changes in real life before running the software and predicting where the changes will prove to be beneficial or when the improvements will become a liability (Siemens, 2014).

## 2.4 Merging VSM and DES

The goal behind integrating VSM and simulation is to use it for production system analysis. Several articles on the subject have all reported positive outcomes system (Lian and Van Landeghem, 2007; Abdulmalek and Rajgopal, 2007; Esfandyari et al., 2011).

In general, we require a VSM-complementary tool that can evaluate the improvements during the early planning and analysis stages. Simulation is an obvious tool that can generate resource requirements and performance statistics while remaining adaptable to different organizational details. It can be applied to manage uncertainty as well as produce dynamic views of inventory levels, lead times, and machine usage for different future state maps. (Abdulmalek and Rajgopal, 2007).

The conclusion drawn from Esfandyari et al., (2011) is that using simulation as a complementary tool for VSM is unquestionable: the power of imitate visualizing investigates the interaction of production flow elements, cost, and time savings, and it is an instant alter attempt for trial and error for different scenarios. Furthermore, setting up the developed model for different scenarios provides a valuable tool for managers in terms of employee and customer training, reliability issues for lean transition, and evidence the practical applicability of 'lean operation' at the company are a working principle for associating simulation modeling with VSM.

## 2.5 Interviews

Lean philosophy teaches that the operators and employees opinions play a vital role in improving the manufacturing system (Liker, 2013). The operators of processes have the best knowledge and experience with what does and what does not work. Studies have shown that including employee's involvement when trying to improve a process, one can boost employee morale, product quality and process times.  (Liker, 2013).

Conducting interviews with employees is a way to document their input on the question at hand. It is important to document and get a variety of answers, meaning that the interviews should include a variation in gender, working experience and age (Holt-Jensen, 2013).

There are different approaches to collect qualitative data for an interview such as textual, oral and observational. The most common one is structured oral interviews. To determine the most beneficial method, the research question of the study is to be taken into consideration. The combination of both oral and textual methods is often used, with focus on the oral tools. The emphasis and high quality of the oral method is because it gives direct access to reliable informants such as employees, in comparison to textual documentation that were written in the past (Yin, 2009).

## 2.7 Productivity

In the manufacturing industry, measuring productivity performance has always been critical. This is an ongoing or long-term measure. This data is necessary for benchmarking and improving the performance of a business. Human and system behavior are guided by measurement. The findings can be used to track changes in productivity and suggest ways to improve it. As a result, the appropriateness and precision of productivity assessment are critical. Manufacturing companies have been experimenting with various approaches to create various productivity indicators for a long time. The outcomes of productivity measures, on the other hand, have not always been able to accurately reflect actual performance. A manufacturing plant's poor productivity performance is frequently caused by inaccurate productivity assessment (Wazed & Ahmed, 2008).

Most manufacturing firms would prefer to discover a solution for improving overall productivity. Manufacturing facilities looking for improvement strategies, on the other hand, are likely to find that they are unable to fully utilize new approaches and processes. Part of this can be due to a fear of change, a complex working culture, a lack of management engagement, and a lack of people competency in terms of productivity appreciation and comprehension (Wazed & Ahmed, 2008).

The measuring of productivity is a component of the diagnostic process for determining where improvement efforts should be focused on. It's critical to measure as a foundation for analysis, as well as to monitor progress and change throughout the improvement process. The goals of productivity measurement are to help company understand their production processes, ensure that decisions are based on facts, show where improvements are needed, show if improvements have been made, and determine whether the company are meeting customer's needs (Matebu & Shibabaw, 2015).

# 3. Methodology

The method for combining VSM and simulation is presented in this chapter, along with the other methods used in the project.

## 3.1 Method

The project began with a project report that detailed the project's scope as well as a timeline in the form of a WBS. Several discussion sessions with Hydrodip AB were conducted to gain more knowledge about their production system and where the focus should be. A tour of the factory was taken to visualize the different processes. Immediately after approval of the project plan, literature studies and data collection from on-site visits were conducted simultaneously. Due to lack of data provided from the company, the data collection phase extended for a longer period than expected. Simultaneously with data collection, a Value stream map was created. It analyzed the current state of the factory, followed by a future state map with improvements. The VSM included tools such as spaghetti charts to investigate and track operator movement.

Interviews with all personnel, including the personnel on the work floor and higher-ups were carried out in conjunction with the data collection and on-site visits. The interviews were then used to analyze and compare with the current state map, as a way of 'validation'. The interviews were also used to investigate possible solutions or improvements in the future state map. The answers and notable observations were documented after each visit.

After the VSM a simulation model of the factory was created based on the future state map and to simulate the effects of the changes. Simulations were also carried out to compare both the current and future state map and the changes were backed by further literature studies. The Simulation was conducted according to banks methodology, verification and validation were done on the current system. Main purpose was to simulate the improved state of the factory.

Following, the VSM analysis was compared to the simulations to conclude and present a list of improvement suggestions that would better the production. The production lead times, and process bottlenecks were investigated thoroughly through on-site visits and simulations.

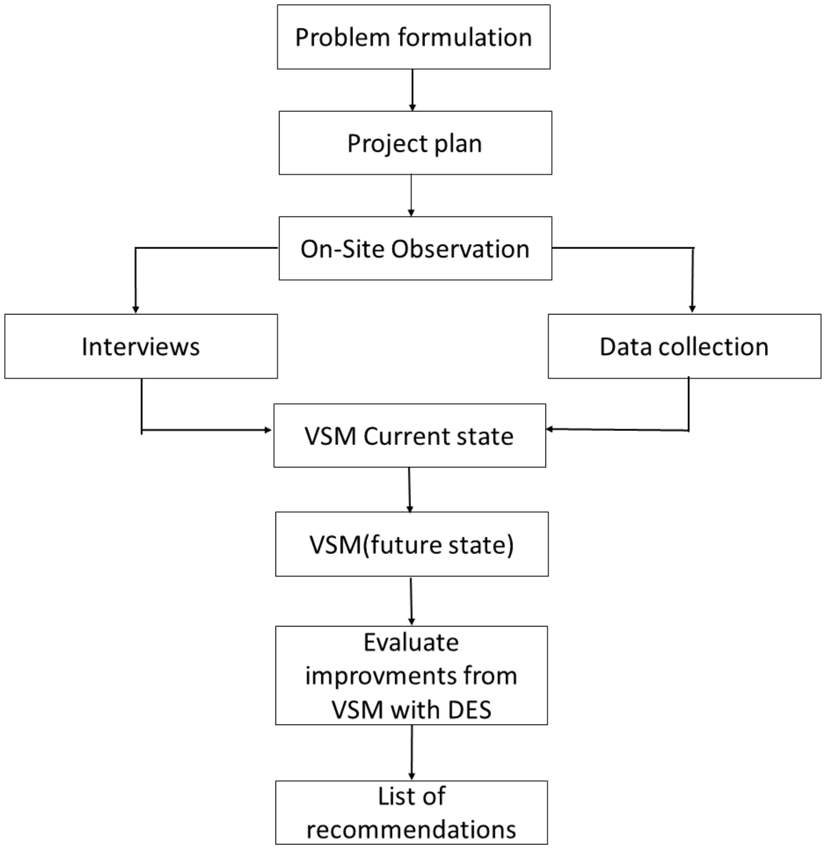



*Figure 3.1 Project's method flow.*

## 3.2 On-site observation

Initially, various observations of the production floor were made to gain an overview without disturbing the operators or the flow. It also allows for a better knowledge of operator movement patterns and the flow of materials through the manufacturing process. Observations were also carried out on a regular basis during data collection to keep knowledge of the production up to date.

## 3.3 Data collection

Numerical data was collected through multiple on-site visits with phone timers. All the data that was collected was documented with pencil and paper. Observing and timing all processes in a 6-week period with 1-2 visits per week, with multiple process time to validate and calculate the average process times. This was done at the initial stages of the project because data such as process times and cycle times were needed to create the value stream mapping and simulation model. Multiple data collections for each process were done to get a more accurate average.

Statistical variation should be included in the model because there are multiple outcomes that can produce various results. The operator was timed while they were unaware of our presence, for example, when obtaining operator grinding cycle times. As a result, there was no concern of being compelled to perform or vice versa, which could affect the times. The failure of a model is frequently caused by data that does not correlate to reality.

Some processes had extremely high processing times which made it difficult to take the time manually due to the project time plan. The missing data from such processes were collected through interviews with operators and production manager, in conjunction with material technical data sheets (such as technical data on harden times for primers).

Some lead times, such as certain buffer or queue times were estimated through interviews and partial manual timing, in conjunction with historical data from working times from the company.

## 3.4 Interviews

The interviews were conducted continuously from the first on-site visit until roughly the last where more formal interviews took place. The first interviews were semi-structured with the purpose of gathering information about the processes, process flow and all things relevant to the production, specifically following one product. At the early stages of the project, the questions were asked to the 3 staff members working on Fjäråskupan and two managers on the factory floor.

The participants of the final, formal interviews were targeted based on their relevance to the production of the certain product. The interviews were documented with pen and paper and carried out in the factory floor. The questions, which can be found in appendix D, were answered by all three operators of the processes included in this report, and the production manager. They were all asked the same questions and given the same amount of time to answer them. The questions focused on working standards and environment.

## 3.5 Value stream mapping

The value stream mapping was created in the preliminary stages of the project. The mapping process began with on-site visits to observe the material and information flow. Due to the company having flexible manufacturing, many on-site visits to observe the flow and interviews with majority of production members were carried out to gather as reliable and useful information as possible for the VSM. Interviews with production manager and experienced operators gave a step-by-step overview of all the processes in the production flow in conjunction with observations and timers. The information gathered from the interviews with experienced operators where very useful in getting an in-depth view of the operations.

The on-site visits increased our understanding of the production layout and processes which was needed to produce an accurate VSM and begin the simulation layout. The VSM was initially drawn on a piece of paper and then in the software Microsoft Visio. Once all necessary processes information were gathered, information about customer needs and product details were gathered to calculate takt- and lead times.

The last step in VSM was to create a future state map with improvements that could possibly decrease the waste in the business. The future state map was later used as a foundation for creating simulation cells for the various stages of the process in order to test the impact of the suggested improvements. By answering and brainstorming the eight questions by Roother and Shook (1999) which are shown in table 2.3, a future state map could be created.

## 3.6 Simulation

It was decided to perform a virtual simulation of the production to analyze the production flow, possible bottlenecks and test different scenarios. The simulation model was created based on the gathered data and the factory layout together with the observations and interviews of operators. Banks methodology was used as a template for conducting the simulation work, with the addition of VSM. The experimental design was replaced with the VSM future state map. A value stream map of the current state of the factory was analyzed upon which improvements were made which resulted in a future state map. The simulation was used as a tool to validate and verify said improvements and to analyze possible outcomes in comparison between the two state maps.

When the future state map was done the simulation work begun. A clear understanding of the different process steps was key to get a realistic model. That is why the simulation model was done after gaining a lot of knowledge about the process. This also made the verification step smoother.

Several simulation models of different cells in the factory were created and analyzed separately. This was made because some buffers had a dwell time that was around 20 hours and simulating this would give a misconception on other bottlenecks. The different processes in each cell were created as “machine” in the program with the collected data. The distance between the stations were put in by using conveyors with walking being the average walking speed measured.

To determine which machines were bottlenecks, a tool called a "bottleneck analyzer" was utilized, which allows you to retrieve information on how much capacity a machine has. Several different values, such as machine availability, cycle time and setup time, have been checked using manual simulations, and by keeping track of them in Excel. Visual observations have also been beneficial in determining where the flow produces buffers and stops.

### 3.6.1 Verification and validation

Numerous times throughout build up, the simulation model was verified and validated. The first stages of the simulation were primarily verified by observing the animation of the simulation and checking buffer sizes and process utilization.

The simulation model was validated by comparing the simulation output to real data from collected production to ensure that it was realistic. The model was also validated by testing it under various settings, ensuring that it works as intended both when the system is full of items and when it is empty. The methods are presented below.

Verification

- Have the computer model checked by more than one person
- For a variety of input-data values, ensure that the outputs are reasonable
- Animation is a very useful verification tool

Validation

- Face validation (The appearance of the system should be decent in the eyes of experts who know the system.).
- Sensitivity analysis (The model should behave in a predicable way when inputs are changed.)
- Consistency checks (Examining the operational model over time to ensure that no changes in the real system need to be reflected in the structural model.)
- Validating using historical input data (Running the operational model with actual historical records and analyzing results.)

### 3.6.2 Program

The software Plant Simulation was chosen being one of the most appropriate for this degree project. Because the program is part of a school course, some prior familiarity with it was also available. When you use simple software, you can construct higher complexity in your models in less time than if you use more advanced software, which takes longer to learn and makes it more difficult to interpret the model's outcomes. Because the simulation is being utilized as a tool for VSM, a detailed simulation of operators performing various tasks is not feasible. A detailed simulation of the workforce would also shift the focus of theses work away from the larger perspective of the businesses and into more specialized practices. Due to the simplicity of the simulation model no programing in simtalk was needed.

## 3.7 Potential Capacity/recommendation

The VSM was utilized to identify potential areas for improvement. Potentials that could affect lead time and capacity. The potential for improvement was evaluated, and the improvements that had a simple and inexpensive solution were incorporated in the list right away, while the more difficult options were further analyzed. The implemented solutions were also compared to the initial state to ensure that they were the superior alternative.

An investigation into the current capacity of the production was conducted, as well as what changes in the production could do to increase capacity in anticipation of future demand increases. The simulation and VSM were used in this investigation. The analysis was carried out concurrently with the simulation's improvement. When a change in the simulation model was made, the outcome for a certain time could be seen. Each solutions capacity was recorded to compare and identify which alterations had the greatest impact on the production. Because some changes require many adjustments to have an effect, a variety of alternative changes were implemented and assessed.

# 4. Current operations

This chapter describes the case company's production to give the readers an understanding of the production layout, different processes and the products flow from incoming delivery to finished goods.

## 4.1 Production facility

Figure 3 shows how the manufacturing is organized across nine processes spread over six different locations. The six different areas are 2,3,5,6,8 and 9. Because of the other items produced at this location and the complicated flow, the stations are set up in a job shop arrangement. Some of the processes are related, and different operations in the production flow are performed at the same location. Because of the quality criteria, most activities necessitate skill and precision. Most of the low-volume production examined is done by hand. The only automated procedures are the oven and spackle hardening. The gray part of the factory is not used in the process of Fjäråskupan.

The manufacturing process resembles that of a job shop. The manufacturing function characterizes this type of layout, and the material flow responds to it. As a result, the flows are somewhat complicated. Job shop layout usually results in semi-finished or finished objects. The job shop provides a wide range of products, although the manufacturing quantities are lower. This reflects the actual Hydrodip situation quite well, due to Fjäråskupan's high product variety.

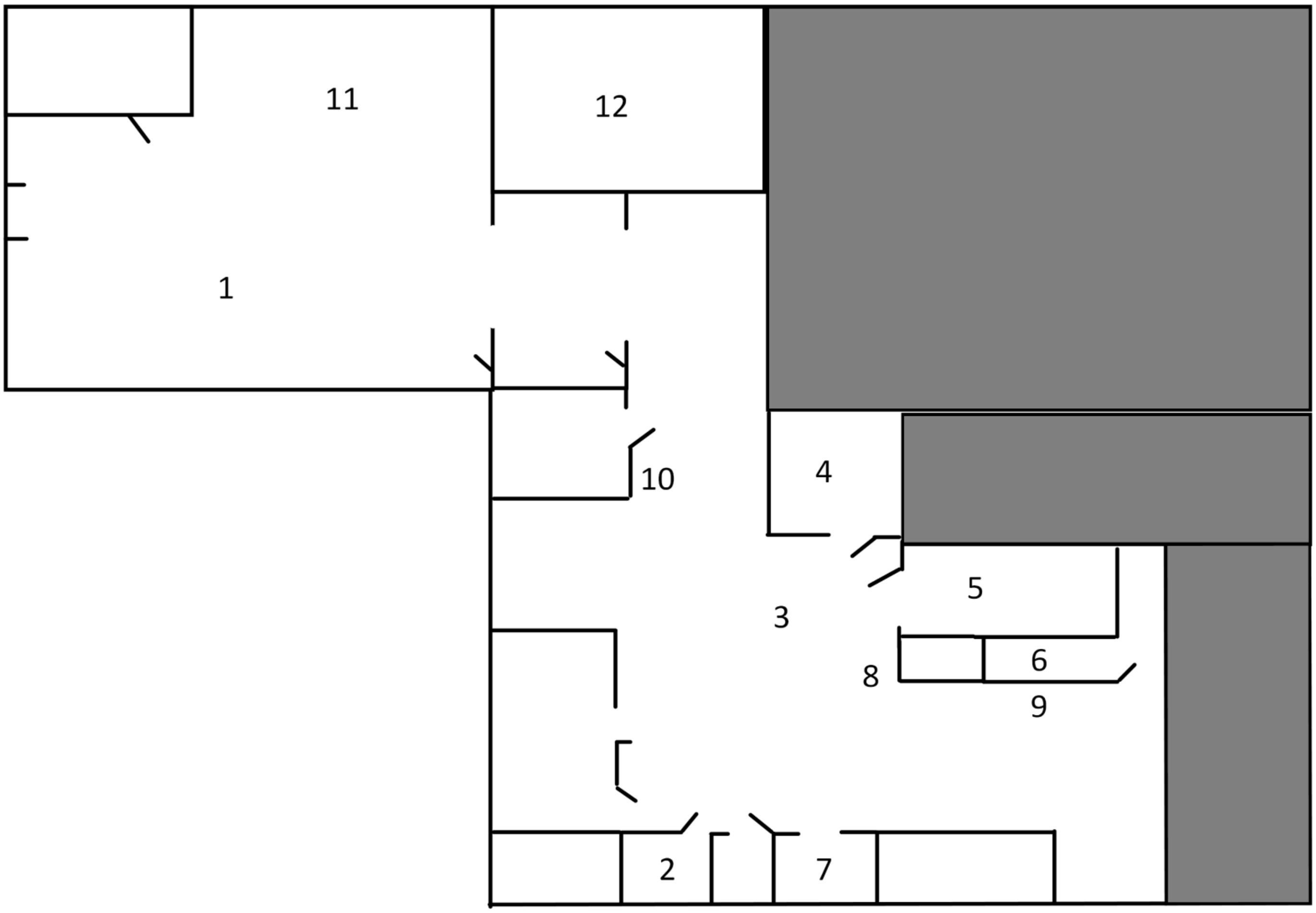



*Figure 4.1 The current configuration, with the stations that have been marked with numbers.*

1. Storage
2. Grinding room
3. Cleaning and preparation for painting
4. Paint mixing and storage room
5. Painting room
6. Oven
7. Toilet
8. Packaging
9. Quality control
10. Incoming product waiting for processes
11. Part of storage mostly used for shipping put ready products
12. Free space (mostly used for storing unnecessary objects)

## 4.2 Organization

In the production, daily 15-minute meetings are held in the morning to plan each operator's upcoming tasks. Workdays begin at 6:30 a.m. and end at 3:30 p.m. Every weekday, the operators work an average of 8 hours. Not all operators in the production possess the same level of expertise and knowledge, thus making the production vulnerable if one or more operators are absent. Additionally, the operators who can paint have the option of rotating tasks within the production process or producing an entire product on their own if they so desire.

The production planner is responsible for a variety of tasks, including starting orders, registering completed orders, and dealing with faulty products. When the production planner arrives at the Fjäråskupan factory to bring the products, he receives each order. The production planner also performs practical work to assist operators in the manufacturing process.

The Company's standard strategy is made to order, where the final manufacturing is done for consumers, in this case Fjäråskupan. The level of integration with production and customer orders is lower, and the order decoupling point is located higher up on the product bill of materials.

## 4.3 process steps

After the factory manager has brought the items from Fjäråskupan, an operator goes to the storage location where the items have been placed. Each item has a barcode number that the operator manually writes down and then hands over to the manager's department. Due to the operator's other commitments, the items usually sit for a couple of hours. Between all these steps are inventories/buffers.

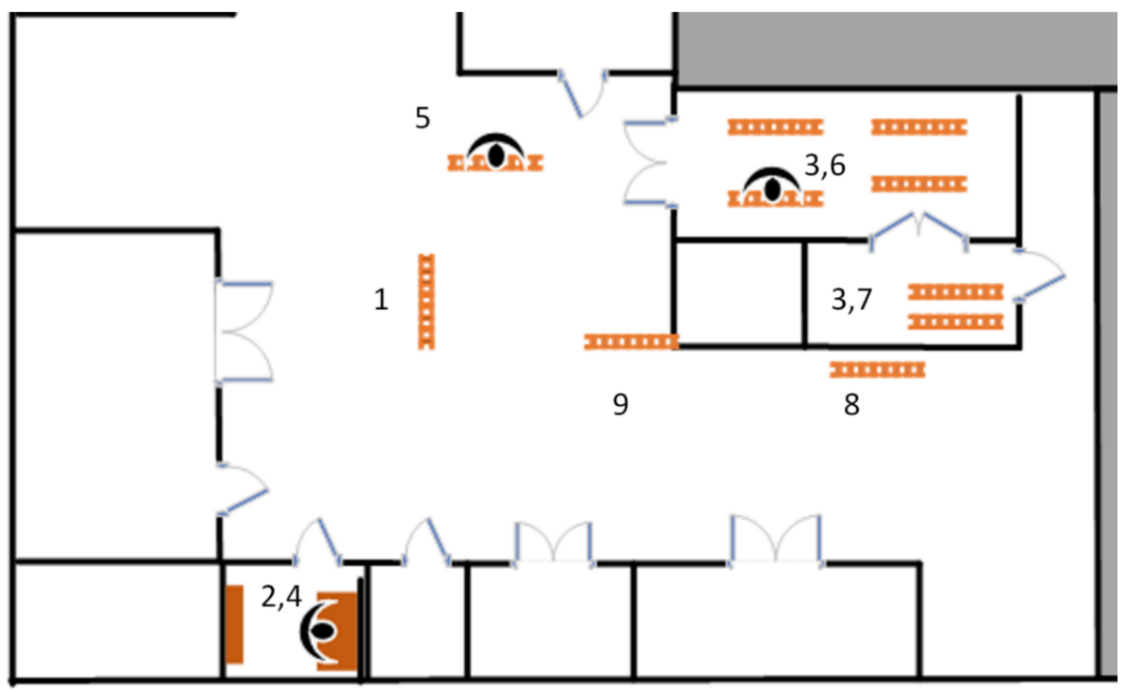



*Figure 4.2 Process steps in factory*

1. **Spackle**

This step is divided into three sequences. The items are first chemically washed and cleaned. After that, masking tape is used to mark the area where the sanding putty will be applied. The operator then combines the chemicals to make the putty and applies it to the targeted area. The putty is used on the kitchen hood's edges. The putty is then hardened.

2. **Grinding 1**

After the putty has hardened, the items should be grided to achieve a specific surface finish. The operator grinds near the edges of the putty where it has been applied. In the grinding room, this is usually done by one operator. The components are ground one by one.

3. **Primer and hardening(oven)**

The items are ready for Preparatory Coating immediately after the first grinding. This step is completed in batches, with approximately 12 items placed on trolleys and then placed in the painting room. The painter prepares the coating and equipment before pushing the product into the painting room with the assistance of another operator. The coating goes directly into the oven to harden.

4. **Grinding 2**

After the coating has dried, the item must be ground again to achieve a specific surface for painting. The entire item is now grinded, not just the edges. This step is completed by a single operator in the grinding room.

5. **Cleaning**

The items must be cleaned before they can be painted. The operator places the items on trolleys and uses high-pressure air to clean them. After that, a chemical is placed and cleaned.

6. **Painting**

The items are painted in identical batches. The operator who paints mixes the colors and prepares the painting equipment. The operator waits for the color to dry after applying the first layer of paint. The items are then given a second layer.

7. **Oven**

The operator places the items in the oven after the second layer of paint has been applied. If the oven has space, this is completed. The oven is emptied once it has reached its maximum capacity. Items that have been removed from the oven are placed outside the oven.

8. **Quality control**

Using a flashlight, the operator inspects the items for damage in this step. Items that pass quality control are placed on a trolley; if an item is damaged, it is placed in a designated location.

9. **Packaging**

The items on the trolleys are checked for the correct barcoded number and color. Then taped and secured on the trolley for delivery.

## 4.4 The production presented through Value Stream Mapping

The thin arrows show the flow of information. There is no digital data transfer. The production planner handles all information, such as starting new orders and registering completed orders. The production planner and other parts of the business are currently being rebuilt and a new ERP system is being installed.

In the current state VSM shown in appendix A, the material flow is defined by arrows. It is moved from the warehouse to the production area by an operator pushing trolleys. This delivery is made after the barcode number has been written down. Each kitchen hood has a couple of components, which are treated separately with fewer processes. There is currently no system in place to control buffer sizes. If the processes are not balanced to have equal cycle times, the material is pushed to the next station, resulting in high buffers.

In figure 4.3 a balance chart of the current production is presented with y-axel representing time in seconds. The red dotted line represents the takt time which is 1440 seconds(24min). The x-axel represent the different processes beginning with first process at spackle.

The reason for early separation of the painting and oven processes was due to their management telling us that the painting is the main problem (bottleneck). This is understandable given that the oven and painter are next to each other with no buffers in between, making differentiation difficult. The primer and hardening were combined for simplicity, and the biggest contributor for the long process time in this process is the hardening(oven).  The average total lead time for one product is 44 hours 5 minutes, which results in 95.2% waste and 4.8%value added time.

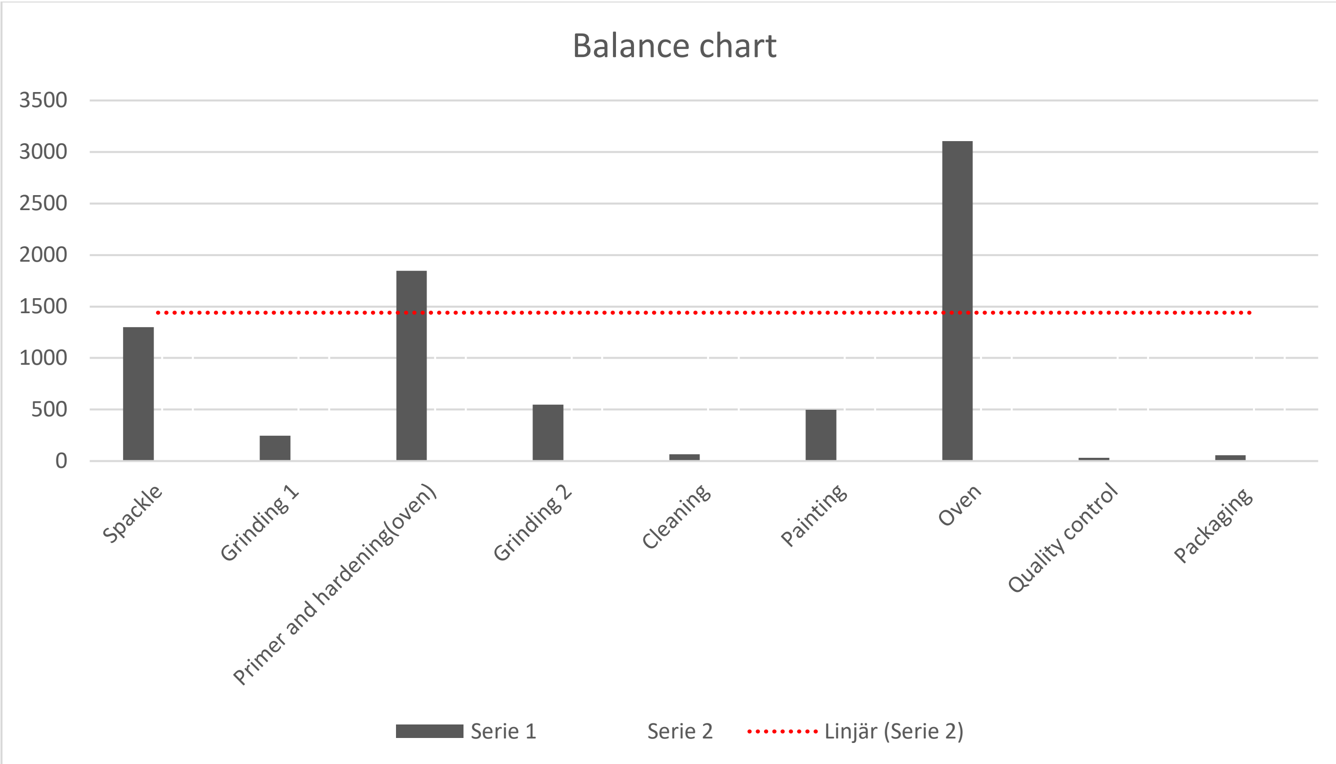



*Figure 4.3 Balance chart of the processes*

# 5. Results

In this chapter, the results of the studies are presented, and the different solutions are explained and compared with the current state of the production.

## 5.1 Future state VSM

Lead time through buffers can be calculated by dividing the inventory quantity by the daily customer requirement. Users can get a good estimate of total production lead time by adding the lead times for each process and inventory triangle in the material flow (Rother and Shook, 2003). A different way of calculating buffers was tested, by timing them manually which in some cases were time-consuming and other cases impossible where the WIP were idle until next day. Due to the previous statement, calculating the buffer manually gave more accurate times. This resulted in the following calculations, thus providing the required parameters which are also found in the VSM in appendix A.

- Takt time = 480min/20=24min
- Leadtime through buffer = 12/24min=0.5= 30min
- Lead time measured manually = 1h

Network communication, most preferably a digitalized one, should be established between case company and supplier to plan the production in an optimal way. Communication between supervisors and operators on the production floor should also be strengthened to have a more efficient flow. The future state VSM is presented in appendix B and the changes are highlighted with green. Multiple changes have been made which all affect production in diverse ways.

A Kanban signal is a way to visually make operators aware of the state of a process, and that should be implemented in the oven. The Kanban should signal to the support personnel every thirty minutes, thus leading to maximized oven capacity. The wasted 25 minutes each product goes through in the oven will also be eliminated with the Kanban signal. Furthermore, the operator in the paint room will not have to wait for the oven to be emptied before moving the next batch into the oven, thus decreasing the lead time and non-value-added times.

A supermarket pull system is to be implemented between the paint process and the last process before painting, the “blow drying” process. By doing so, the movement waste and waste of transport are both reduced and no downtime in the paint process due to lack of products will occur.

Standardized work should be suggested throughout the whole factory. In conjunction with that, it is also strongly recommended to implement 5S, especially in the grinding room.

## 5.2 Simulations

The simulation was conducted as a tool to visualize the changes made in the future state value stream map. By dividing the different process steps into cells and simulating only parts of the production process with the implemented changes. The simulation models can be found in Appendix E. The conveyors represent the walking distance between processes. The simulation model was validated with on-site observations, for example the grinding process could handle 12 items in one hour which corresponds to the simulation.

The current order size that Hydrodip handles from Fjäråskupan varies from 10-30 kitchen hood fans per day. Some fans can contain sub parts which varies from 1-4 parts. On average a big order could be a total of 65 parts, which would take Hydrodip 48 hours to complete. By simulating the different cells with the improvement suggestions an estimation of the capacity was found. The capacity of the different cells was then to be combined with a working day to see the potential improvement in lead time.

*Figure 5.1 Kitchen hood fan*

The following figure present how different improvements can lead to an increase in productivity. The improvements that were implicated in this first scenario almost zero investments.  When studying the technical data of the spackle that the company uses the drying time in air 20 minutes, they currently wait over an hour. The items need a minimum of 30 minutes due to materials properties of the pant reaching a certain temperature.

The batch size in figure 5.2 is 65 items of which 25 should go through the grinding process. It should be noted that for simplicity reasons all process steps are not written in the schedule. For example, the painting process includes cleaning, painting, oven time and quality control. The machines break very seldom, therefore they are negligible and not included in the machine times. The following recommendations do not require any major investments beside a clock.

- Start grinding on the item after 20 minutes of the spackle drying.
- Operator who works with Fjäråskupan should not do the packaging of the products, writing barcode number on new items and making the quality control.
- Emptying the oven after 30 minutes with the help of a Kanban signal system.

| | | | | |
|---|---|---|---|---|
| Concerns "support" personnel, those who do not paint; | | | Item= Kitchen hood fan that needs to be grinded | |
| **Time** | **Operators** | **Task** | | **Number completed** |
| | | | | |
| 06:30-07:00 | 1 | Personel packs yesterdays finished goods for delivery | | |
| 06:30-09:00 | 1 | Grinding products that has been treated with "primer" = slip2 | | 16 items |
| 09:00-09:30 | | Break | | |
| 09:30-09:50 | | New products incoming from supplier + writng down barcode number, Done by the driver | | |
| 09:30-11:00 | 1 | Grinding products that has been treated with "primer" | | 9 items = All items done |
| 11.00-12.00 | 1 | Perform process "spackla" on new Items | | 25 items= Al new items done |
| 12:00-12:30 | | Lunch Break | | |
| 12:30-14:45 | 1 | First grinding on new products | | 25 items= Al new items done |
| | | | | |
| 14.45-15:30 | | All focus on support processes for the paint room | | |
| | | for example emptying the oven and helping to setup for the painting | | |
| | | | | |
| Concerns the operator in the paint room; | | | | |
| | | | | |
| **Time** | **Operators** | **Task** | | |
| 07:00-07:30 | 1 | Prepare for the painting, eg. process/mix colors | | |
| 07:30-09:00 | 1 | Paint | | 22 items |
| 09:00-09:30 | | Break | | |
| 09:30-12:00 | 1 | Paint | | 44 items = all items done |
| 12:00-12:30 | | Lunch Break | | |
| 12:30-12.45 | 2 | Prepare for the primer | | |
| 12:45-14:45 | 1 | Use primer on grinded products | | All done |

*Figure 5.2 Work schedule*

During the onsite visits notation on the durability of the workers were made. The individuals that grind can perform this process for a maximum of 1 hour due to the vibrations caused by the grinding machine. That was considered when making this schedule and the grinder would have 10 minutes of resting between every 1-hour session. The person that paints need someone that feeds products into the oven.

The outcome of these improvements will be that the products would be ready after 26 hours which is a decrease of 22 hours. The problem is that when the items has gone through the last process, they are still drying. One solution to this would be to inform Fjäråskupan that the items are still drying and that they should wait before delivering to the costumer.

The technical data sheet from the supplier of the material used to fill in the corners (putty) was requested. Upon further inspection it was found that a massive decrease of the waiting time for the material to harden can be made. It currently idles for an hour before proceeding to the grinding process for the material to harden. According to the supplier, the material can be grinded after 10 minutes when put in an oven in 40 degrees Celsius. Further research was made and an alternative method of drying the putty was discovered, by using heat lamps called IR. By using this method, the material is hardened after 4 minutes. This would decrease the idling time from 1 hour to 4 minutes, thus gaining 56 minutes per product. When validated with simulation it proved to increase the output of the process from 4 products within 2 hours and 30 minutes to 31 products within the same period.

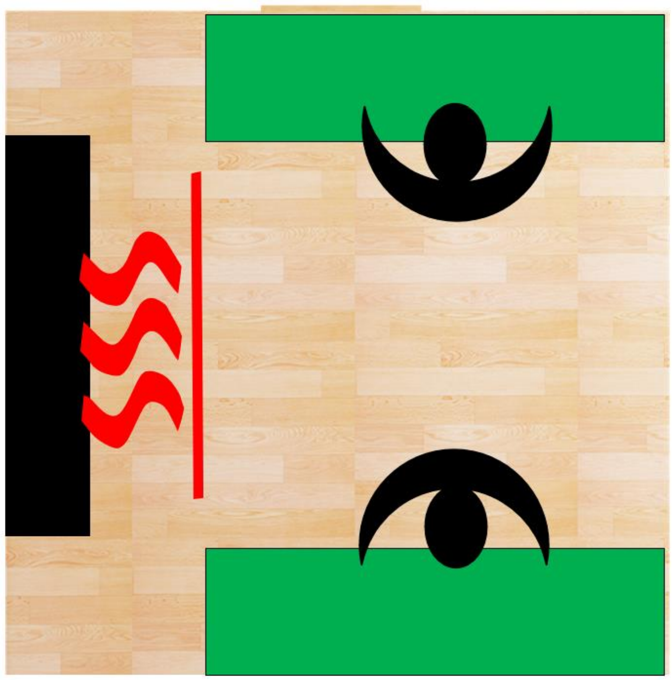


*Figure 5.3 Illustration of workplace*

As illustrated in figure 5.3 above, the green rectangles represent the work bench which the two operators should work on. The speckled items should be put in the shelf which is the black rectangle. The IR lamp heats the objects while the operators are working to get a continuous flow.

The different primer brand dries in about 15 minutes with the help of an IR lamp. This lamp could be installed outside the oven, requiring no oven time for the parts treated with primer. As a result, there is more room in the oven.

The second alternative presented in figure 5.4 generates the best outcome. With this method a batch of 65 items will be processed in 6.5 hours, which is a reduction of 41.5 hours. On top of that the operator would have free time from 9.30, where company could rearrange the workforce to do other tasks. It should be noted that the process steps are done at 16.00, and the delivery of the product will be done the day after. However the following recommendations require investments.

- Utilization of the spackle that’s ready after 4 minutes with IR
- Grinding room relocated with 2 operators
- Operator not doing the packing and writing down barcode number

- Emptying the oven after 30 min and 15 with the primer
- Support personnel Mix/prepare color for the painter according to order specification
- Using IR on different primer reducing the drying time to 15 min

| Concerns "support" personnel, those who do not paint; | | | Item= Kitchen hood fan that needs to be grinded | |
|---|---|---|---|---|
| Time | Operators | Task | | Number completed |
| 06:30-07:00 | 1 | Free time | | |
| 06:30-09:00 | 2 | Free time | | |
| 09:00-09:30 | | Break | | |
| 09:30-09:50 | | New products incoming from supplier + writng down barcode number | | |
| 9:30-12.00 | 2 | Perform process "spackle" and first grinding on new Items | | 25 items=All new items done |
| 12:00-12:30 | | Lunch Break | | |
| 12:30-13:00 | | Prepare for grinding/help painting process | | |
| 13:00-14:00 | 2 | Grinding products that has been treated with "primer" = slip2 | | 25 items = all done |
| | | | | |
| Concerns the operator in the paint room; | | | | |
| Time | Operators | Task | | |
| 07:00-07:30 | 2 | Free time | | |
| 07:30-09:00 | 1 | Free time | | |
| 09:00-09:30 | | Break | | |
| 09:30-12:00 | 1 | Paint | | 44 items = all items done |
| 12:00-12:30 | | Lunch Break | | |
| 12:30-12.45 | 2 | Prepare for the primer | | |
| 12:45-14:00 | 1 | Use primer on grinded products | | 25 items=All done |
| 14:00-14.30 | 1 | Prepare for the painting, eg. process/mix colors | | |
| 14.30-16:00 | 1 | Paint | | 25items=all done |

*Figure 5.4 Work schedule with maximum productivity*

The black line indicates a continues flow between the different stations. Due to the painting stations working in batches of around 10 items, the operator in grinding process will be preparing the until the first batch gets dried. After the lunch break, the parts that have been grinded for the first time will be treated with primer. The operators that will grind will receive their first batch and complete it until the next one comes in and send it back for cleaning and painting. The operators that are grinding could act as support personnel after the last batch of items.

## 5.2.1 Standardized work

A new standardized way of operations was produced withing the timeframe of the workday which can be found step by step in figure 5.5. The flow was simulated according to the standard way of working which was based on lean philosophy to reduce waiting times and movement. The results were a decrease of the lead time. The new standard enhances and optimizes the operating hours to work in the most efficient way possible. By using this way of working, the operators will perform the necessary tasks at the necessary times to avoid long waiting times for products to be processed.

The figure shows an overview of the best order to perform the tasks and the times can be changed by the production planner as seen fit, although the order of the tasks needs to remain the same. Not shown in the figure are details concerning support operations such as emptying the oven, which can be neglected due to the short times it takes to perform the tasks. As shown in the figure the support personnel have their tasks and the painter has his/hers, but it should be stated that all personnel who are not painting are regarded as “support personnel” and are to deviate from the standard (if needed) to perform supporting operations for the painter. Said operations are all tasks that divert the paint operator from the painting process, whatever they may be. The main and most time-consuming ones, which were confirmed by on-site observations and interviews with the operators, are listed below.

- Transport products ready for painting to the front of the painting room
- Push products into painting room once painter is done with previous batch (whilst the painter moves the finished batch into the oven which is connected to the painting room)
- Empty the oven every 30 minutes
- Transport products to packaging area
- Support personnel Mix/prepare color for the painter according to order specification

## 5.4 Relocation of current grinding room

Not shown in the future state is the suggestion to add an additional grinding room or relocate the current one. The current grind room is located far from the warehouse where the products await processing, thus the walking distance is far. Observations were made on the on-site visits that showed that the current grind room is small and contains one work bench, thus proving difficult to improve the process without development of the workspace. By either moving the grind room or adding another one, the grinding process can be optimal by having more than one operator performing the task at once, thus enabling the output to be doubled according to the simulation results. The operator must collect the materials from carts and transport them one by one to the grinding room, thus making the trip multiple times (depending on how many incoming products). Shown in figure 5.5 is an image illustrating the distance (highlighted with red). The placement of the carts can be seen in appendix F (2).

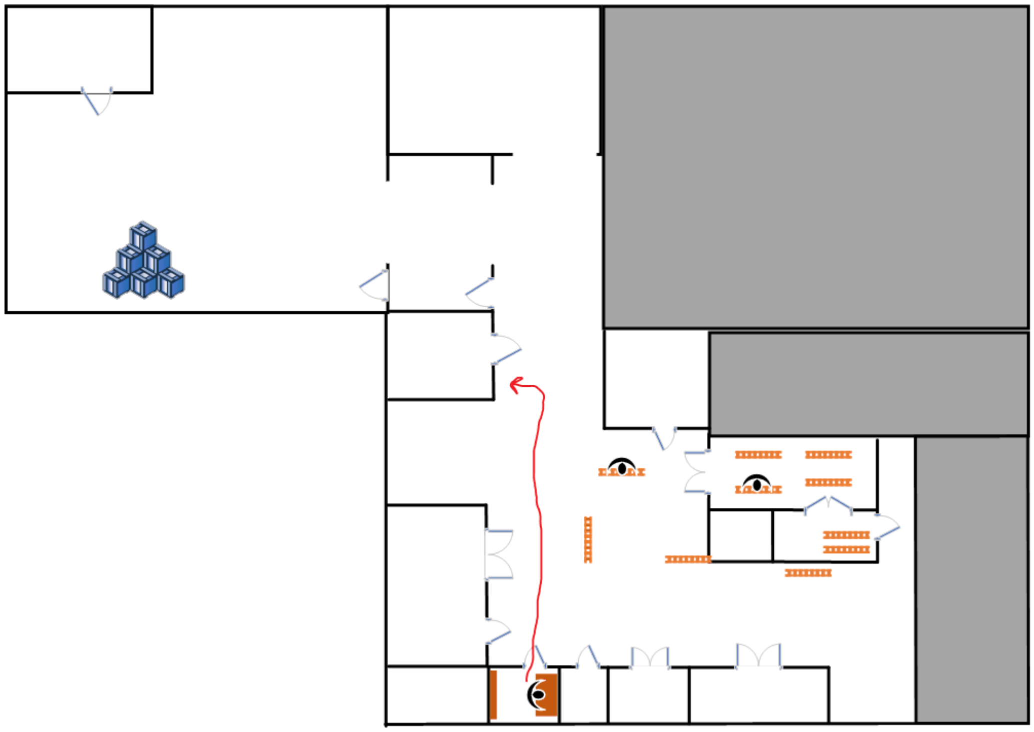


*Figure 5.5 Current path to retrieve materials*

Depending on the sought outcome, the current grinding room could be switched with the storage room as shown in figure 5.6 below. Another possibility is to remove or replace the storage room and creating an additional grinding room in its place. The case company work on several products and could utilize the current grinding room for one of those products whilst the new grinding room is restricted to the studied product (Fjäråskupan).

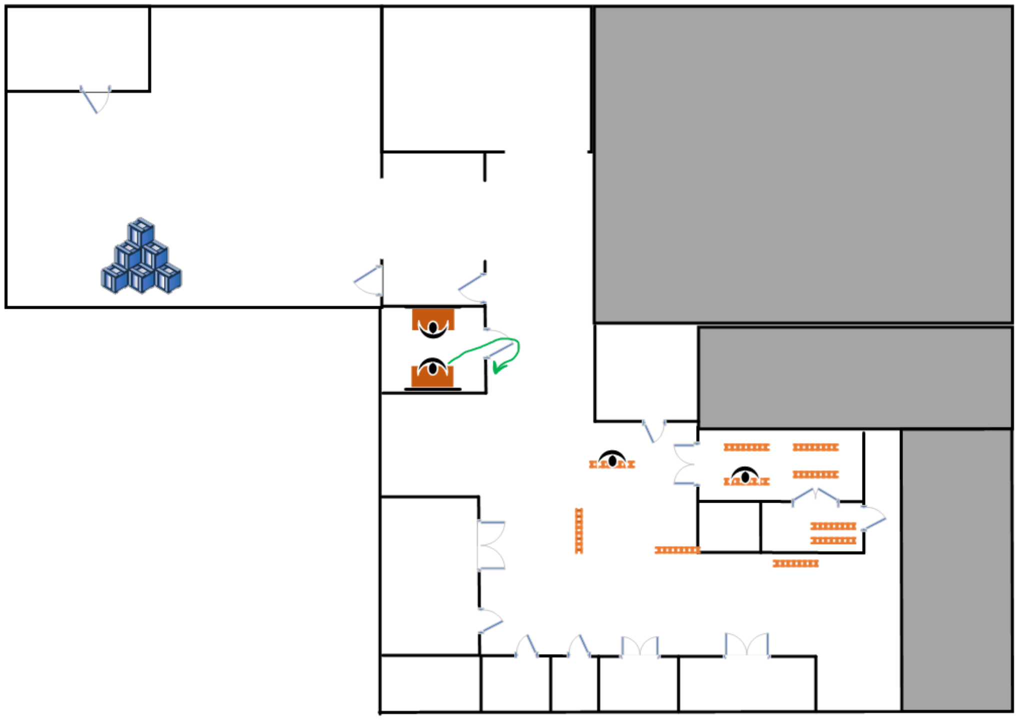


*Figure 5.6 Path to retrieve materials after improvement*

Through measurements and on-site observations, it was found that the walking distance with a straight path and no obstacles on said path is 35 steps one way. The operators walk 70 steps to retrieve one product at a time and must do so until the carts are emptied. Through the same method, it was determined that by placing the grinding room at the suggested space, the number of steps are reduced to approximately 5 steps, resulting in only 10 steps to retrieve one product at a time, which is a reduction of 60 steps (approximately 86% reduction). Furthermore, the carts could be placed in the corridor upon delivery, thus reducing the steps even more. By analyzing and comparing the two figures shown above, one can visualize the changes easily.

## 5.5 5S

Based on on-site visits and recorded times where operator search for items needed to perform the task, the operator wastes approximately 5 minutes by searching for tools which can be reduced by implementing 5S. This occurred on several occasions and the reason why is that there is no clear 5S implemented in the factory and no clear instructions, therefore each operator places tools and protection gear where they see fit for them individually.

As shown in the picture taken whilst on-site that can be found in appendix C (1), there is no clear 5S implemented in the room. This applies to the whole factory, but the focus is on the grinding room to simplify for the reader. 5S could be implemented in said room and used as a template for the rest of the factory. For example, in the paint room were some floorspace could be freed, shown in appendix F (3).

The vacuum that is displayed in the picture should be attached to the wall to avoid operators or trolleys tripping over it. A shelf could be built to the wall in front of the workbench and safety equipment such as masks, goggles and bandages should be placed there. The grinding machine itself should be attached to either end of the workbench using method suitable for the machine, such as hooks or something of that kind, thus making it impossible to misplace the machines and providing easy and quick access to the machines. A cheap and simple way of implementing this is to attach hooks to the workbench on either side, as shown in figure 5.7 (highlighted in green).

*Figure 5.7 Example of suggested workbench*

The gadgets belonging to the machines are to be stored in the built-in shelves under the workbench, preferably in customized boxes, an example of this is shown in figure 5.9.

*Figure 5.8 Example of customized box stored under workbench.*

In figure 5.8, some attachments to the grinding machines used in the case company is presented. The respective color to the side of each gadget is marked with the same color in the box, to illustrate and visualize the suggestion for the reader.

The 5S is to be checked and performed before the first product is transported to the grinding room, and after the last product leaves the grinding process. The operator(s) should also, suggestively, have it within their work tasks to check that 5S has been performed when arriving to work and before leaving the facilities. All operators regardless of their tasks should perform 5S in the room, making it a habit for them. A schedule is to be produced giving each operator the task of 5S each week, as shown in the example in figure 5.9.

| | | | | | |
|---|---|---|---|---|---|
| | 5S weekly schedule | | | | |
| Week 1: | | | | | |
| | Day: | Start | End | Operator in charge: | Task: |
| | Monday | 7:00 | 15:00 | A | Perform 5S |
| | Tuesday | 7:00 | 15:00 | B | Check 5S |
| | Wednesday | 7:00 | 15:00 | C | Perform 5S |
| | Thursday | 7:00 | 15:00 | A | Check 5S |
| | Friday | 7:00 | 15:00 | B | Perform 5S |
| | | | | | |
| Week 2: | Day: | Start | End | Operator in charge: | Task: |
| | Monday | 7:30 | 15:30 | C | Check 5S |
| | Tuesday | 7:30 | 15:30 | B | Perform 5S |
| | Wednesday | 7:30 | 15:30 | E | Clean |
| | Thursday | 7:30 | 15:30 | A | Check 5S |
| | Friday | 7:30 | 15:30 | D | Perform 5S |

*Figure 5.9 Example of dividing the 5S workload.*

By using the suggested method shown in the figure above, all operators get to perform 5S in one way or another. Each day, the task should be changed so that an operator does not perform the same task days in a row. Each week, the operators are switched out, to achieve a habit for all, regardless of gender, age or working experience. The production manager should encourage and be a good example to his/her employees, therefore he/she should be included in performing the tasks. Another way to approach and divide the workload is to assign each employee a room/space where they perform 5S each day, where they are solely responsible for their assigned space, although it could seem unfair if some spaces get more disoriented due to their functions.

An estimated total of 4 operators uses the grinding room each workday. Through the on-site visits it was observed that all operators had to search for some item needed that the previous user had misplaced. Even though this part was not simulated but was calculated manually, misplaced items cost the company 5x4= 20 minutes per day in non-value-added activities on the grinding process itself. It may not appear as an issue when presented as 20 minutes a day, but the calculation implies a loss of 20×5= 100 minutes. Furthermore, as stated before the non-value-added time spent searching for items was only investigated briefly in the grinding process, and the remaining eight processes most definitely faces the same problems.

## 5.7 List of recommendations

Based on the work conducted, the following list of recommendations for how productivity can be maximized through lean and simulation at Hydrodip AB. The fundamental problems, bottlenecks and other wastes, were identified by using lean philosophy as a guide, and the solutions were brainstormed and verified with the same philosophy and simulations. All the recommendations do in one way, or another contribute to the productivity in the facility, some more than others. They are proven to work in theory and the recommendations does not demand vast amounts of money to be invested but are rather cheap and relatively easy to implement. The simplest and most cost-effective change that Hydrodip might make is to empty the oven after 30 minutes. The results of this would reveal how other processes are affected, and new concerns could occur because of this environment change. The suggestions offered below, on the other hand, are not overly sophisticated and might be implemented with minimal effort. The enhancements might be made in a variety of ways, such as installing an alarm system in the oven or simply assigning an operator to keep an eye on it.

*Table 5.10 Recommendations for Hydrodip AB*

1. Utilization of the spackle that's ready after 4 minutes with IR
2. Grinding room relocated with 2 operators
3. Operator not performing support tasks such as packaging and intake of incoming products.
4. Emptying the oven after 30 min and 15 with the primer
5. Using IR on different primer reducing the drying time to 15 min
6. Push products into painting room once painter is done with previous batch (whilst the painter moves the finished batch into the oven which is connected to the painting room)
7. Transport products to packaging area
8. Support personnel Mix/prepare color for the painter according to order specification
9. 5S in the factory

# 6. Discussion

In this chapter, we discuss our findings and any deviations or limitations that occurred. We mainly focus on the simulations, possibility to implement the recommendations and the method used.

## 6.1 Simulations

In the simulations, times wasted by searching for tools were not included. The simulations were also used to compare the theoretical benefits and differences in outcomes when the improvements were to be implemented. Thus, the simulations do not consider factors such as human errors and delivery delays. As of now there is no possibility to confirm the results of the simulations in the real-life factory because the company will not implement said changes immediately. As a result of that, the authors are unable to see if there are any improvements that work in theory and in the simulations but become troublesome in real-life.

Due to the job-shop and the production being manually led, there are no machines or robots to consider down-time. There are however possibilities where the grinder breaks down (although highly uncommon) and those scenarios have not been included in the simulations, thus the results could differ from the real-life.

Scenarios occur where operators speak to one another and differ from their work throughout the day. These “breaks” are not scheduled and has therefore not been included in the simulations, although they could prove to affect the results.

The findings through simulations were that there is plenty of room for improvement with little need for investment. The need for a standard way of working and for example relocating the grinding room alone proved to increase the productivity when investigated using simulations. The simulation program gave a lot of freedom in testing different scenarios in a fast manner to get best output. This proved to be very useful and time saving for the authors.

The authors chose the simulation program Tecnomatix plant simulation for their project because they have previously worked with it. The software is complicated, making it possible to design and visualize any production system; nevertheless, it takes time to implement all the elements necessary for the system to accurately depict reality.

## 6.2 Implementation

The suggested changes are based on research on lean philosophy and the list of recommendations are merely a suggestion to the company. The suggestions were created using lean methods and theories. Whether or not the company chooses to implement these changes are up to them. The authors will not get to see the changes and can only draw conclusions based on the VSM and simulations, thereby they cannot confirm the change of output or lead times in real life.

Although the solutions produced in this thesis are all based on research and confirmed with different methods, there are factors that could prove them insufficient or different from what was predicted. This does not mean that the research is faulty or incomplete, it merely means that due to the unique layout of the production and the company's way of working could disturb or affect the solutions negatively.

The greatest findings in this project are that lean production can be implemented for the better in all industries, such as in the paint industry. A traditional method usually used for industries such as automotive ones has been modified to work in a specialized industry with a job-shop factory layout. This project proves that lean and simulation can be used to improve production flow and productivity in other industries than the common ones.

## 6.3 Method

The used method for this project was based on literature research and studies where VSM and simulations were used simultaneously in similar industries. The method is, by the authors knowledge, the first in the paint industry. There are various studies about the method used in the automotive industry and it is completely different from the paint industry, although the principles and steps are the same. The project plan was followed from start to finish, although some parts proved rather difficult and were more time consuming than predicted.

Collecting data proved to be the most difficult and time-consuming part with the simulations as a close second. This mainly refers to the data collection part where the authors had to time everything manually due to lack of documented data and information such as process times.

When the operators were observed, they sometimes performed their work better and faster. This effect was plainly visible during the project, but the likelihood that it influenced the outcomes was modest, because the authors collected many samples without the operator's knowledge.

Because there are 9 processes where the process times were sampled and only two individuals to do the sampling, the number of samples for each process in the production varied. This, combined with the inconsistent production, made sampling all processes at the same time problematic. During the data collection phase of the project, the production was not always running at a regular pace, thus all sampling chances were taken advantage of. The data that was collected and evaluated seemed to have a good average, so it was used in the study.

Another finding towards the research is the method used and how to make it reliable. Each method used in this study was based on scientifical papers and backed with various research. This was done to ensure that our method would be sufficient and reliable and give a solid outcome of the results. When dealing with a flexible manufacturing and using lean production rather than the traditional line-assembly manufacturing that is backed with much more research, deviations will naturally occur. In this bachelor thesis, we have accounted for these deviations and what to expect. To further this bachelor thesis, one could investigate and develop a general method specifically made for flexible manufacturing or job-shop production.

# 7. Conclusion

*How can productivity be improved through lean production and simulation in the painting industry?*

The lean tool VSM, in conjunction with DES, can be used to research and analyse potential improvements in the painting industry. The primary benefit of combining DES and VSM was that the two methods offered distinct perspectives on production. The VSM will provide a clear picture of the material and information flows, which will be helpful in developing the simulation model. Furthermore, the ability to simulate visualizing the interaction of production flow elements, time savings, and a fast modification attempt for experimenting with different scenarios are undeniable benefits of using simulation as a complementary tool for VSM.

Without any investments, it is possible to produce 25 kitchen hood fans and their 40 subcomponents for a total of 65 items, the contribution reduced production lead time by 46% which is 26 hours, improvements show in chapter 5.2. To increase capacity even further, a new machine called an IR heater, a new grinding room, one additional operator, and a different primer must be purchased. The productivity can then be increased to the point where the batch of 65 items is completed in 6.5 hours using regular work hours. This is a 41.5-hour reduction which equals to the reduction of 87%.

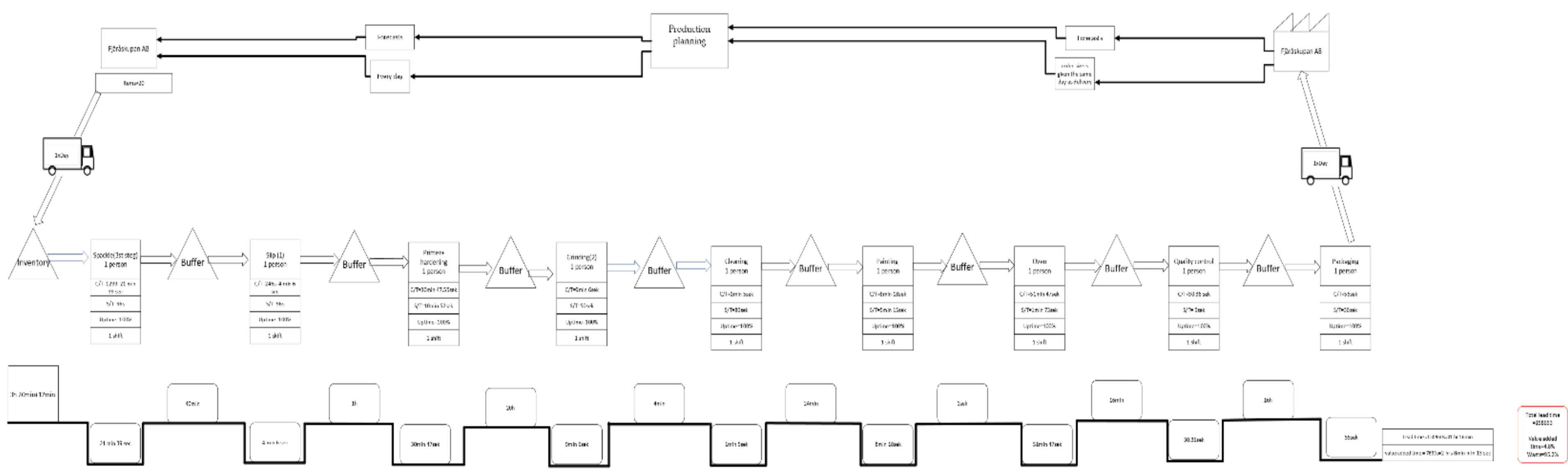
Table 5.10 shows the various steps to achieve the desired results, which can be used by the company in the future if demand increases. Using figures 5.2 and 5.4, the company can determine how much production can be produced based on the size of the increment. Furthermore, the company can analyse production after implementation to determine the next constraint if even higher capacity is desired.

The authors' list of recommendations could be put into practice and evaluated to improve and develop the thesis further. The results could then be recorded. The next step after that would be to further develop simulation model to a more detailed one. This could include simulating the different processes in detail, and even use software to simulate ergonomics on operators over time. However, when making more detail simulations on ergonomics the focus would shift to specific processes.

# Appendices

## Appendix A

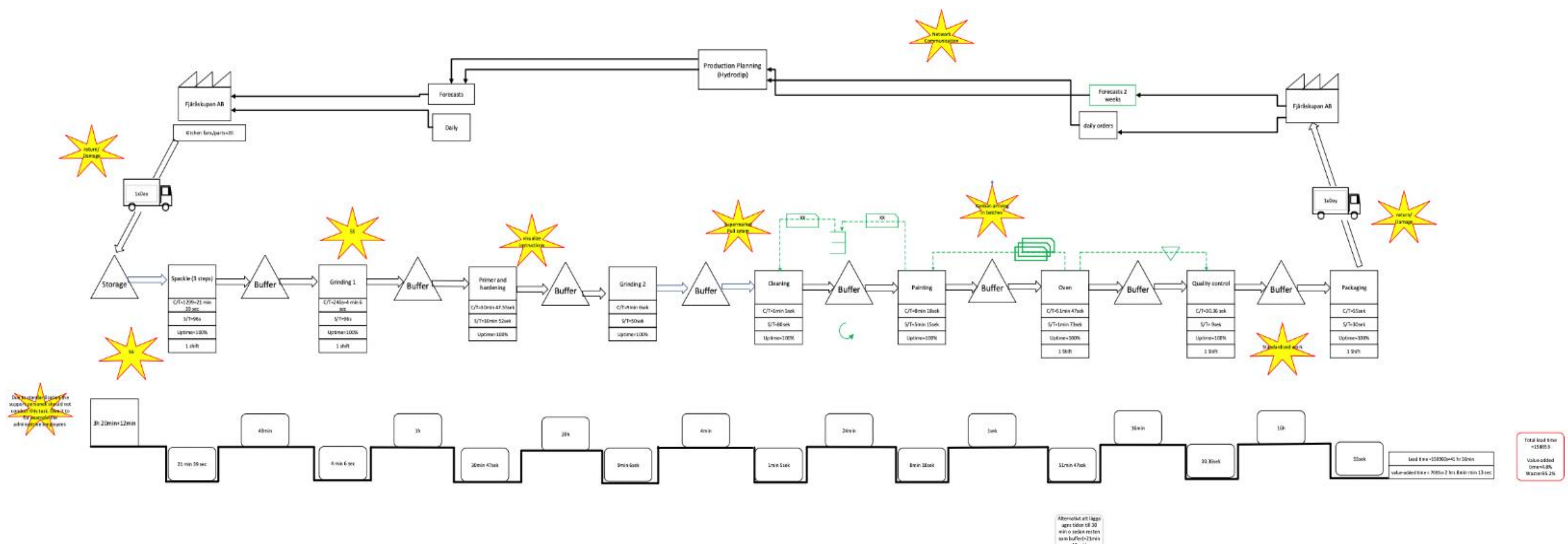
In this appendix, the current state map developed with the program Visio is shown.



Production planning
Fjärskupan AB
Every day
Inventory
Spackle(3st steg) 1 person
Buffer
Slip (1) 1 person
Primer+ hardening 1 person
Grinding(2) 1 person
Cleaning 1 person
Painting 1 person
Oven 1 person
Quality control 1 person
Packaging 1 person
1 shift
40min
1h
4min

## Appendix B

In this appendix, the future state map developed with the program Visio is shown.



Production Planning (Hydrodip)
Fjärilskupan AB
Forecasts
Daily
Forecasts 2 weeks
daily orders
Fjärilskupan AB
Storage
Spackle (3 steps)
Buffer
Grinding 1
Buffer
Primer and hardening
Buffer
Grinding 2
Buffer
Cleaning
Buffer
Painting
Buffer
Oven
Buffer
Quality control
Buffer
Packaging
3h 20min+12min
21 min 39 sec
48min
6 min 6 sec
1h
20h
4min
24min
1sek
36min
16h
55sek

## Appendix C (1)

In appendix C (1) the current grinding room is displayed with the work bench to the left and the shelves to the right.


## Appendix C (2)

In appendix C (2) the current storage room which is suggested to be the new or additional grinding room is displayed.

Appendix C (1)

In appendix C (1) the work break structure is shown with each stage and their respective time frame.

| Number | Work break down Structure Level | | | | | Time frame | Comment /Deliverables |
|---|---|---|---|---|---|---|---|
| 1.1.0 | 1 | Simulation Project | | | | 12/12-2021-30/5-2022 | |
| 1.1.1 | 2 | Finding a company | | | | 12/12-2021-11/1-2022 | |
| 1.1.2 | 3 | | Researching companies | | | 12/12-2021-11/1-2022 | Searching on websites to find a thesis work and find suitable companies |
| 1.1.3 | 4 | | | Calling | | 12/12-2021-11/1-2022 | Contacting companies by email or phone call. |
| 1.1.4 | 2 | Development and research of Hydrodip AB | | | | 17/1-25/5 | Company named hydrodip. Determine an area to focus on and do research about this problem. |
| 1.1.5 | 3 | | | Specification of issue | | 17/1-7/2 | Talking with the CEO of hydrodip to get an idea of what they need help with. |
| 1.1.6 | 3 | | | Project classification | | 17/1-29/1 | Determine the issue |
| 1.1.7 | 3 | | | Time estimation | | 29/1-14/2 | |
| 1.1.8 | 3 | | | WBS | | 17/1-13/2 | |
| 1.1.9 | 3 | | | Research | | 14/2-30/4 | About the subject and how we can get knowledge from similar studies. By doing litterature studies. |
| 1.1.10 | 4 | | | | Observation | 15/2-28/2 | Observating the factory in motion. |
| 1.1.11 | | | | | Timing operations | 15/2-28/2 | |
| 1.1.12 | | | | | Data | 15/2-28/2 | Getting data from Hydrodip AB |
| 1.1.13 | | | | | Litterature studies | 15/2-30/4 | |
| 1.1.14 | | | | | VSM | 15/2-24/2 | |
| 1.1.15 | | | | | Improving | 24/2-30/3 | Finding different ways of improving process |
| 1.1.16 | 2 | | | Writing | | 7/2-25/5 | This will be done continues during the project |
| 1.1.17 | 2 | | Interview | | | 14/2-18/2<br>24/2-30/3 | To obtain valuable information and in-depth undersetting of the process |
| 1.1.18 | 3 | | | Anita(operator) | | | |
| 1.1.19 | 3 | | | Operator 1 | | | |
| 1.1.20 | 3 | | | Operator 1 | | | |
| 1.1.21 | 3 | | | Operator 1 | | | |
| 1.1.22 | 3 | | | Operator 1 | | | |
| 1.1.23 | 3 | | | Operator 1 | | | |
| 1.1.24 | 3 | | | The boss | | | |
| 1.1.23 | 3 | | | Factory manager | | | |
| 1.1.25 | 3 | | | Maintenance personnel | | | |
| 1.1.26 | 2 | | Simulation | | | 15/2-15/3 | |
| 1.1.27 | 3 | | | Building a virtual twin | | 15/2-11/3 | |
| 1.1.28 | 3 | | | Analysing the results | | 24/2 -30/3 | Verification and validation |
| 1.1.29 | | | | Implementing changes in simulation | | 24/2-30/3 | Compare to current state and our new version. |
| 1.1.30 | | | | Implementing the same changes in real life | | 22/4-1/5 | If possible. If not, suggestions list. |
| 1.1.31 | | | | Documenting result | | 2/5 | Noticing the difference |
| 1.1.32 | 2 | | Compile recommendation | | | 5/5-12/5 | Hydrodip AB |
| 1.1.33 | 3 | | | Creating a list for Hydrodip AB | | 5/5-12/5 | With recommendations of implimenting changes |
| 1.1.34 | 3 | | | Creating a formal list in document | | 5/5-24/5 | Of our achievements or what went wrong |
| 1.1.35 | 2 | | Presentation of results | | | 31/5 | Presenting the results |
| 1.1.36 | 3 | | | Creatin PowerPoint slides | | 25/5-30/5 | For the presentation |
| 1.1.37 | 3 | | | The presentation | | 31/5 | Presentation on our work at hydrodip |
| | Done | | | | | | |
| | WIP | | | | | | |

## Appendix C (2)

The Gantt chart developed in the early stages of the project and the different planned stage and their respective times are shown.

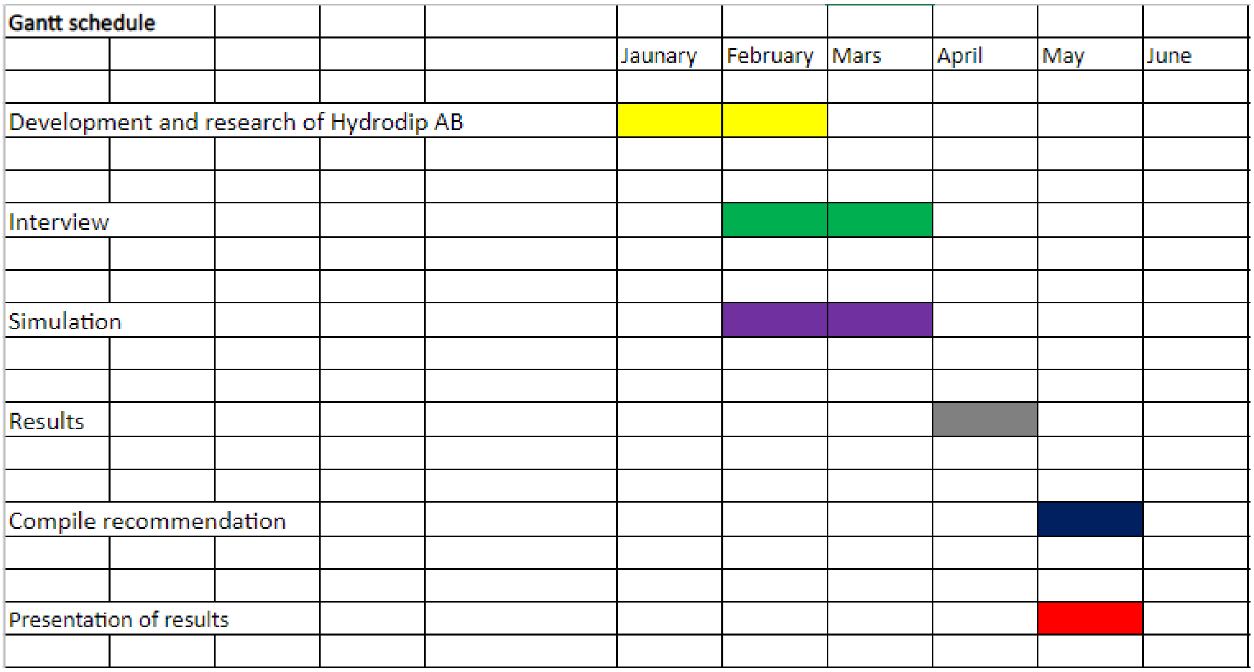



Table 9. Gantt

## Appendix D

In the following appendix the questions asked on-site to the different employees are displayed. The questions were asked in Swedish but are presented in this report in English for the readers convenience. The question highlighted in green was answered by all employees, however the authors were more interested in what the operators thought.

Questions for the interviews:

A) Do you think there should be a standardized way of working?

B) Should there be an assigned place for tools etc?

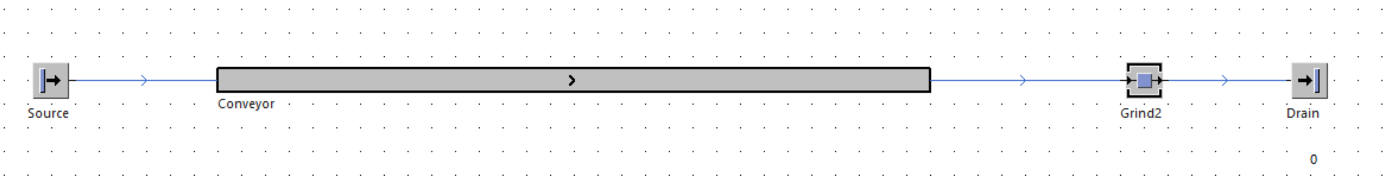
C) How do you percieve your current way of operations, what works, what does not and what could be improved?

D) Can you think of any risks/hazards in your current way of working both regarding yourself or the product?

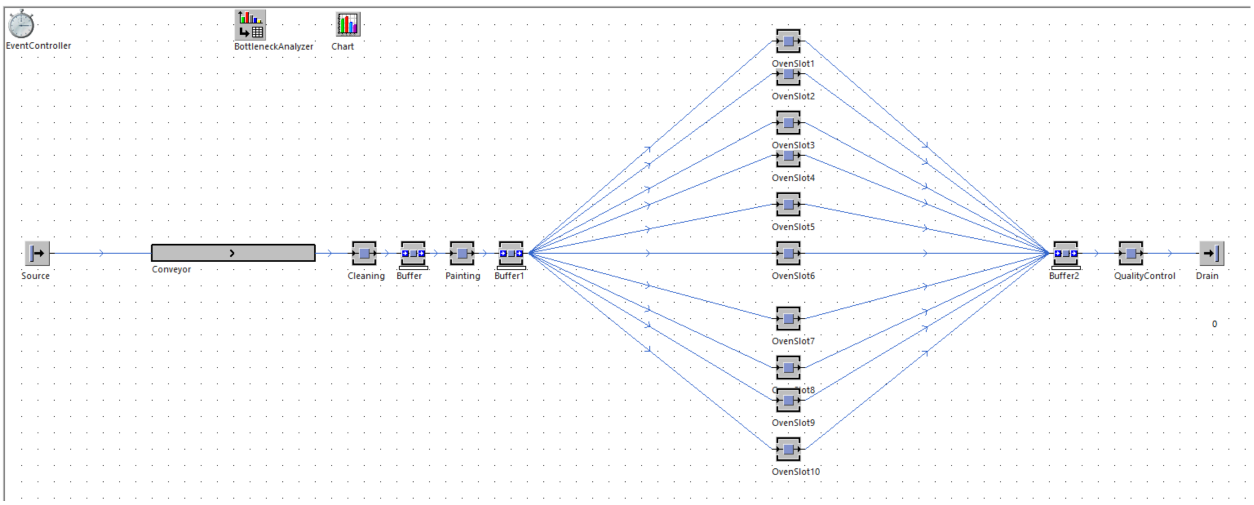
E) How good does operators communicate with eachother?

F) What are your thoughts about the information/communication from higher-ups

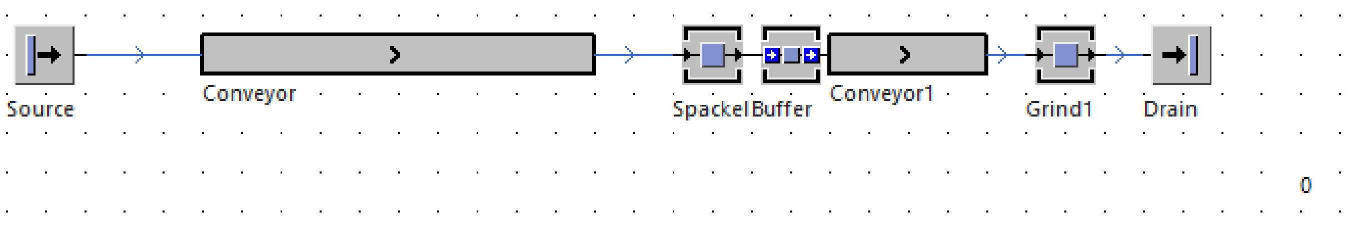
# Appendix E



Source
Conveyor
Grind2
Drain
0

EventController
BottleneckAnalyzer
Chart
Source
Conveyor
Cleaning
Buffer
Painting
Buffer1
OvenSlot1
OvenSlot2
OvenSlot3
OvenSlot4
OvenSlot5
OvenSlot6
OvenSlot7
OvenSlot9
OvenSlot10
Buffer2
QualityControl
Drain
0

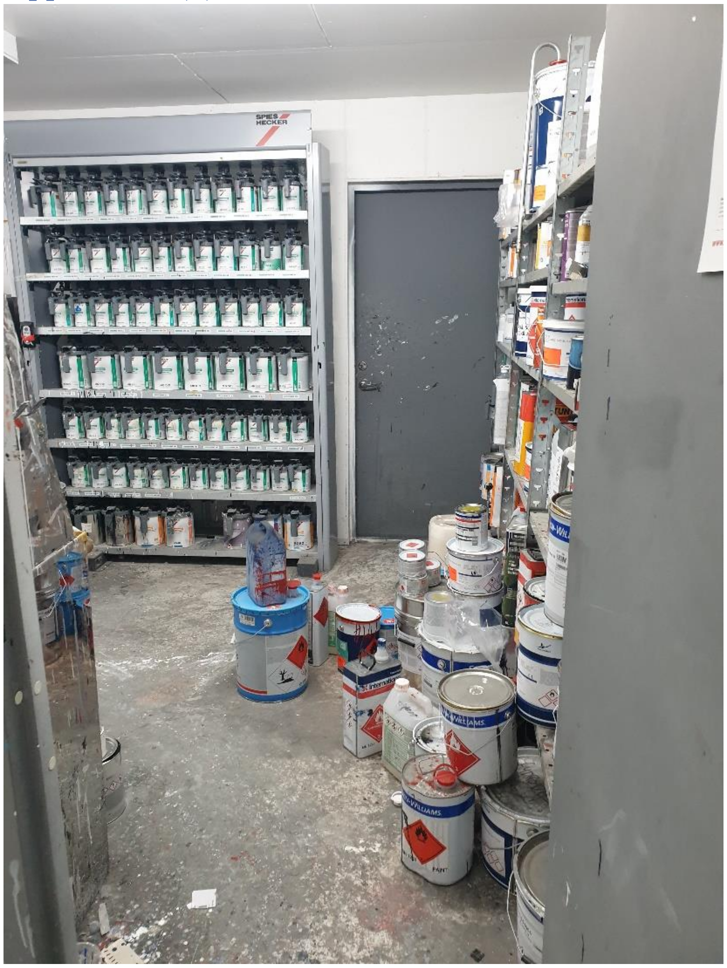



Source
Conveyor
Spackel
Buffer
Conveyor1
Grind1
Drain
0

Appendix F

Appendix F (2)

## Appendix F (3)



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