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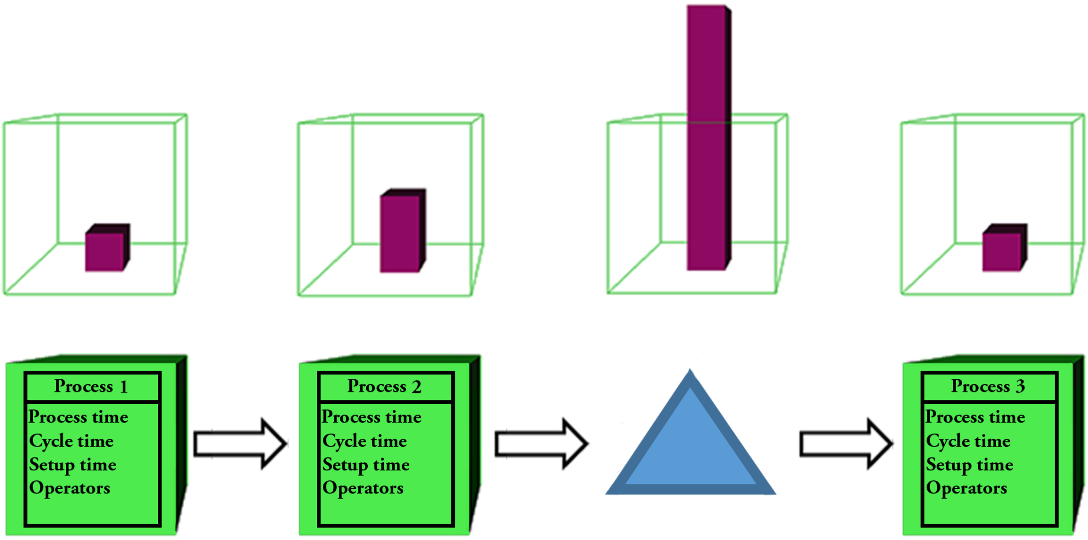

Improving a production flow using Value Stream Mapping and Discrete Event Simulation

Master's thesis in Production Engineering

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Cover: Improving a production flow using Value Stream Mapping and Discrete Event Simulation

Abstract

The purpose of this master's thesis was to analyze the capacity and to evaluate if discrete event simulation should be used to support future analyses at the company. The scope was partly to determine the current capacity, find what can be made to increase it and also to find and implement improvements.

A method for performing the project by combining discrete event simulation and value stream mapping was developed based on Banks project methodology. By collecting data in the production through interviews and time sampling the value stream mapping and discrete event simulation was conducted. At the side of the value stream mapping and simulation, a layout planning was performed because the production was scheduled to be relocated within the facility. The method systematic layout planning was used to systematically develop the new layout to better support the material flow through the production. The material handling for the production was also analyzed and it was found that both Kanban and kitting is suitable for the production.

The result from the analysis was that the current capacity is 100x (normalized by x) and is possible to increase by 29% with the current machines. To produce more than this it is required to invest in new equipment and further increase the number of operators in the production. Some of the found improvements regarding the material handling were implemented during the project and some were delivered to the company as an implementation guide. The layout of the production was delivered to the company and the area was planned according to this layout. The Kitting of material was implemented in the production were a new kitting box was introduced. A description of how the company should use Kanban for the production was delivered.

Throughout the project, VSM and DES were used in combination to perform the analysis. These methods complemented each other by providing different perspectives to the analysis which enhanced the analysis.

Keywords: Discrete Event Simulation, Value Stream Mapping, Capacity, Kanban, Kitting, Systematic Layout Planning

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Albin Goodwin & Daniel Pantzar, Gothenburg, June 2017

Contents

Glossaries - Production Engineering terms

In this section, some production engineering terms which are used in this thesis, are explained.

Backflush
Backflush is a system when the products material cost is calculated and inventory levels are updated when a product is finished, compared to preflush when cost and inventory levels are updated at the order start.

Bottleneck
The constraining process in a production. The whole systems capacity is limited by this process.

Capacity
The capacity in a production is the maximum volume of a product that can be produced in a certain time period.

Cycle time
The cycle time is the amount of time it takes for a certain operation or station to process a product in the production flow.

ERP-system
ERP is an abbreviation for Enterprise Resource Planning. It is a real time IT system to keep track of management processes such as product and production planning, inventory levels and materials management.

FIFO
First in first out is a principle to for managing inventory. The material that arrives first is also used first.

Flow oriented layout
A flow oriented layout is when the equipment in the production is organized so that the material travels the shortest way through the production.

Functional layout
In a functional layout the equipment is organized according to function so that all machines of the same kind are placed in the same area.

Lead time
The lead time is the time it takes for a product to be produced, from the product is started until it is finished.

MPS
Master Production Schedule.

Steady state
Steady state for a simulation is when the behaviour of the system is invariable over time and the resources can work in a regular manner. The steady state is preferably used for analysing simulation models because the utilization of resources and output data is equally used from the beginning of the measurements.

Takt time
The takt time is a measurement of how often a new product must be produced in order to meet the customer demand.

Warm up time
The warm up time of a simulation model is the time it takes for the model to reach a steady state.

1
Introduction

This Chapter introduces the thesis, providing a background to company and project. The purpose and objective of the project are also presented, as well as the delimitations.

1.1 Background

The project was performed at a company producing world leading products for military defense and civil security. The production and development facility in Gothenburg is specialized in radar and laser equipment. The company has in total around 14000 employees in Sweden whereof around 2000 are located in Gothenburg. Most products are generally produced in a low volume with high variation and high demand for quality.

The company sees a possible increase in demand for one of their products. To be prepared for an eventual increase in demand the company wants to investigate the capacity of this product. The company is also interested in knowing if there are any improvements that can be made to increase the capacity. Further, the company is interested in using discrete event simulation to analyze the production, since this has not been done before at the company.

The production is planned to be relocated within the facility later this year. In conjunction with this relocation, the company wants a proposal for a new layout to better support the flow in the production.

1.2 Purpose and objective

The purpose of the project is to analyze the capacity and to find improvement potentials in order to reduce costs and lead time for one of the company's productions. This is a low volume production. The improvement potentials will be analyzed and evaluated to find how much different solutions will improve the production. The solutions for the implementations will be given to the company and as many solutions as possible will be implemented starting with the easiest to implement with the biggest effect. The solutions that do not clearly give enough value compared to the cost of implementation will be analyzed further to see if an implementation is beneficial. The areas that will be analyzed are the material and information flow, buffers, capacity and layout of the system. The analysis of the layout will provide the company with knowledge for the future relocation of the production.

From the above purpose and objective, three research questions are proposed.

Research questions:

- What is the current capacity of the production?
    - What can be done to increase the capacity?
- What are the main benefits of using discrete event simulation when analyzing and improving the company's low volume production?
- What are the main benefits of using discrete event simulation in combination with value stream mapping when analyzing and improving the company's low volume production?

1.3 Delimitations

The project focus is only on one product in the production but there are other products in the production that shares resources with the product that has to be considered in the project. The production that will be analyzed is limited to the production that is made within the facility.

Since there is a lack of opportunities to collect data, partly of the low volume production, it is of big importance to take every possible opportunity to measure process times. The production can not be compared with a high volume production where production is running smoothly every day and data can be collected at any time. Data collection must be planned ahead and every opportunity there is must be taken to collect data. An attempt to collect enough and reliable data was made with the requirement that maximum five weeks is spent on gathering data. The breakdowns for the machines in the production are not measured and are assumed to be equal to zero. The down times are usually scheduled maintenance which is planned in advance and therefore actual breakdowns are rare and can hence not be measured within the limited time of the project.

There was already a scheduled relocation of the production. Because of this relocation, no major analysis of the current layout was necessary, more focus was spent on analyzing the alternatives for a new layout.

Due to the confidentiality of the products and the processes concerning the project no real data can be published. Therefore all data in the project is normalized in order to prove the concept without revealing any secrets.

2

Theory

In this chapter the literature study is presented as well as literature of the methods used in the project.

2.1 Value stream mapping

Value stream mapping, hereafter referred to as VSM, is a method that is used for mapping information flow and material flow from the supplier to the customer (Abdulmalek and Rajgopal, 2007). The method originates from Toyota but was further developed and introduced to the western world by Rother and Shook (2003). The purpose of the method is to get an overview of the value stream including value adding time and non value adding time. The value adding time is the time that a value adding process is spent on the product. The total time is the lead time which is determined by the number of products in the system. The more products that are in the system the longer the lead time becomes. The process consists of two major parts, the creation of current state and future state maps. The current state map is a snapshot in time showing how things are currently being done, the buffer sizes and process times are not sampled in this method (Abdulmalek and Rajgopal, 2007). The method will hence not give a perfect picture of reality but it will be faster to perform which makes it a favorable method. The future state is a proposal of how the material and information flow should be.

To create the current and future state map there is a need for symbols to simplify the interpretation and making of the map. Some of the most common symbols used in VSM can be seen in Figure 2.1.

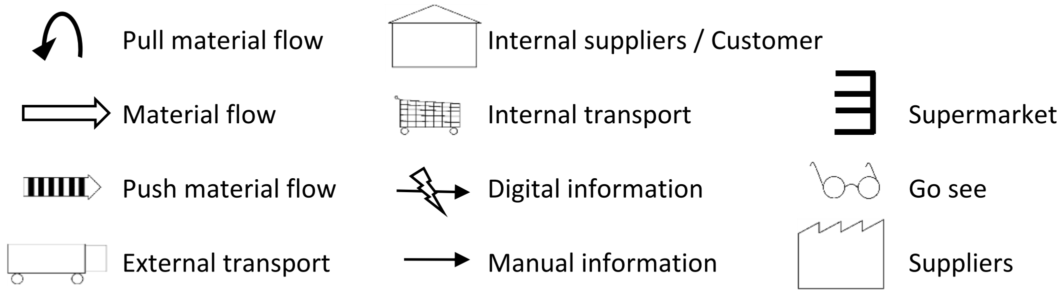

Figure 2.1: Description of VSM symbols.

2.2 Discrete event simulation

Discrete event simulation, hereafter referred to as simulation, can be used to simulate a production for analysis. Simulation can be used for analyzing and understanding a real world system such as a production. The simulation model can be built based on the real world data, collected data and historical data but it can also be a conceptual model for analyzing a new system or changes to a system. The model should then be verified and validated in different ways as a proof that the model is realistic and can be used as a tool to improve the production. To find improvement potentials simulation can be used to find bottlenecks, optimize buffer sizes and calculate the cost for the production (Banks, 1998). When analyzing a production system there are different things that can be done, for example, check the utilization of different resources and see if any processes are starved or blocked (Larborn, 2015). Further, there are some disadvantages of using simulation, it is time consuming and expensive to build a model. The accuracy of the model cannot be any higher than the data that is used as input, which makes the data collection and analysis just as important as the model itself (Banks, 1998). A known method for performing a simulation project is Banks project methodology, Figure 2.2. This methodology is suitable for all kinds of simulation projects because it contains all the important steps in a simulation project.

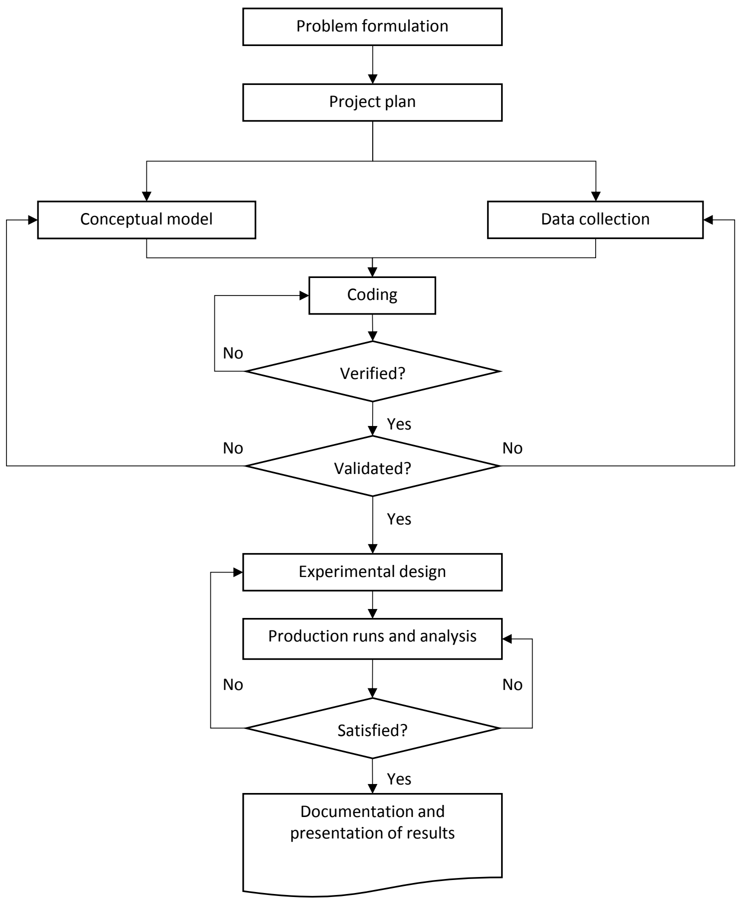

Figure 2.2: Banks project methodology for conducting a simulation project (Banks, 1998).

2.2.1 Verification and validation

When a simulation model is built it is necessary to make sure that the model gives an accurate picture of the reality. This is called to verify and validate the model (Sargent, 2013). If the model is not verified and validated it can be difficult to convince the audience that the model is correctly built, and the model can not be used for drawing conclusions and decision making (Sargent, 2013). Verification of a model can be described as to make sure that each element in the model is behaving correctly and that it is correctly coded (Sargent, 2013). Validation of a model is made on a higher level in the system. It is made to make sure that the behavior of the model is an accurate representation of the real world (Sargent, 2013). There are many possible methods for verifying and validating that a model is behaving correctly. Some of the different techniques that were found in the literature are presented in the bullet list below. Generally, more than one of the methods should be used to increase the trustworthiness of the verification and validation.

Verification:

- Observing animations when the model is running (Larborn, 2015)
- Look at variables during and after the simulation (Larborn, 2015)
- Print messages while the program is running (Larborn, 2015)
- Run the code step by step (Larborn, 2015)
- Follow a specific load (Larborn, 2015)
- Follow the principles of structured programming (Banks, 1998)
- Make the operational model as self-documenting as possible (Banks, 1998)
- Have the code checked by more than one person (Banks, 1998)

Validation:

- Compare simulation data with historical data (Banks, 1998)
- Use historical data as input (Banks, 1998)
- Degeneracy test. Test the model in the extreme conditions. The model should be able to handle any extreme conditions such as very high input of products or zero inventory in the system (Sargent, 2013)
- Turing test. Display data from the test and from reality and let an independent person tell which one is the model and which one is a reality. If it is not possible the system is validated (Sargent, 2013)

2.3 Combining VSM and DES

Several articles were found regarding combining VSM and simulation, all of them saw positive effects from using this combination when analyzing a production system (Lian and Van Landeghem, 2007; Lu et al., 2011; Lian and Van Landeghem, 2002; Abdulmalek and Rajgopal, 2007; Esfandyari et al., 2011).

Lian and Van Landeghem (2007) and Abdulmalek and Rajgopal (2007) describes in their articles how they used VSM to map a production and thereafter used the eight questions in Table 3.1 to develop a future state for the VSM. Both of them used the simulation as a tool for validating the VSM's future state. The conclusion from the articles is that simulation and VSM are a good combination for developing a future state VSM. The simulation will add a fourth dimension, time, to the VSM which is valuable because the results will be less static (Erikshammar et al., 2013).

2.4 Softwares

Mainly two different softwares have been used in the project. These are AutoMod and Minitab and are explained in this section.

2.4.1 AutoMod

AutoMod is a discrete event simulation tool in which it is possible to build, simulate and visualize any production system. The software consists of two major parts where one of them is called AutoMod. In this module, it is possible to build models and execute them (Muller, 2013). The other module is called AutoStat in which it is possible to do statistical analysis and test different scenarios in order to optimize the model (Muller, 2013). Advantages with AutoMod are according to Muller (2013) that the simulation can be run in real time and that there is no limitation to the size of the model.

2.4.2 Minitab

Minitab is a statistical software that can be used to analyze data. Data sets can be plotted in different graphs and histograms which will facilitate the interpretation and analysis of the data. Besides plotting the data it is also possible to analyze it in a wide range of statistical analysis tools such as distribution fitting, the design of experiments and control charts etc. (Minitab, 2017).

2.5 Theory of constraints

The theory of constraints is a framework for how to find and eliminate constraints in order to reduce lead times and increase capacity. The theory of constraints is a five step method explained and introduced by Goldratt (1999). The five steps are shown in Table 2.1. The reason to use this method can be explained by a quote from Cox et al. (2011): "An hour lost on the bottleneck is an hour lost on the entire system; an hour gained on a non-bottleneck is a mirage." Actions must be taken to improve the constraints.

2.6 Implementation of continuous improvements

To continuously implement improvements is one of Toyota's and lean manufacturing's main pillars (Toyota, 2001). Continuous improvements are necessary in order

Table 2.1: The five step method to resolve constraints (Goldratt, 1999).

1. Identify the system's constraint.
2. Decide how to exploit the system's constraint.
3. Subordinate everything else to the above decision.
4. Elevate the system's constraint.
5. If in previous steps a constraint has been broken, go back to step 1.

to stay competitive. There are two main types of improvements. One is continuous improvements that are small and easy to implement and comes with a low cost. The other is radical improvements that require more planning and comes with a higher cost. Radical improvements are sometimes necessary, but continuous improvements are always necessary. The structure for implementing continuous improvements are often made using the PDCA (Plan-Do-Check-Act) cycle which is a well known tool for making continuous improvements (Liker and Meier, 2011). The tool consists of four steps. Plan - Identify the problem and determine a goal for the changes to be made and come up with a method for implementing the change. Do - Perform the changes according to the method proposed in the previous step. Check - Evaluate the result of the changes that was made. If the goal was reached, continue to the next step, if it was not reached, go back to plan. Act - Standardize the solution.

2.7 Kitting

Kitting is a way of presenting material to the assembler. Instead of having separate boxes for each material at the workbench, one pre-sorted box is used for all material used in the assembly sequence (Hanson and Medbo, 2012). This way of presenting the material to the operator have several advantages. The material has the same position in the box every time which reduces or eliminates the time the operator is looking for material. It is easy to spot if any part is missing in the assembly because the kitting box should be empty when the assembly sequence is finished. The learning time will be reduced since the material is presented in the same sequence every time and the next piece of material will be picked without using much cognitive capacity. One disadvantage with kitting is that the material preparation will be more time consuming.

2.8 Data collection

Both quantitative and qualitative data is needed for research projects. Quantitative data typically consists of sampling process times and qualitative data typically consists of interviews and observations. For simulation there is a high demand for quantitative data and a lower demand for qualitative data. For VSM there is a higher demand for qualitative data and lower demand for quantitative data. The purpose of the data must be considered so that the data is as accurate as it is required to be (Robinson, 2002).

2.8.1 Time sampling

Time sampling of the production gives quantitative data, and when analyzing the collected data it is important to verify that it is reliable. This can be made by calculating the confidence interval and by visualizing the data's prediction intervals. Depending on the distribution of the data different equations for calculating the confidence interval should be used. Manual work has a distribution that is skewed to the right in a way similar to a lognormal distribution (Knott and Sury, 1987).

For a lognormal distribution Equation 2.1 should be used to calculate the confidence interval. The equation will give an estimation of the confidence interval, where samples are likely to be. The size of the confidence interval depends on a number of samples and the confidence level that is used. Any confidence levels can be used, but the most commonly used confidence level is 95% (Moye, 2007). When the confidence interval is calculated a determination of whether the interval is small enough and the data is reliable or not is made. If the interval is too big further samples are needed or a lower confidence level can be used. A smaller confidence interval with higher confidence level is always preferable, but it will require more samples which are both time consuming and costly.

$$CI = \bar{x} + \frac{s^2}{2} \pm Z_{(1-\alpha/2)} \times \sqrt{\frac{s^2}{n} + \frac{s^4}{2(n-1)}} \tag{2.1}$$

Equation 2.1 shows a calculation of confidence interval for lognormal distributions using Cox's method. $\bar{x}$ is the mean, s^2 is the variance, s^4 is the squared variance, Z is a value form the Z-table based on confidence level and n is the number of samples.

2.8.2 Interviews

There are several techniques for performing interviews which will give different outcomes. Interviews can in general be divided into three main categories these are structured, semi-structured and unstructured (Gillham, 2005). Structured interviews are prepared ahead and no side steps from the protocol are made. Semi-structured interviews are similar to structured interviews, but side steps are allowed. Unstructured interviews do not follow a protocol, questions can arise as the interview progresses and the interviewee has a possibility to steer the interview. For the purpose of gathering qualitative data, it is preferable to use unstructured or semi-structured interviews since structured interviews often create qualitative results (DiCiccoBloom and Crabtree, 2006). Unstructured interviews are preferable in an exploratory initial phase of a project when the interviewer does not fully know what is needed to be known (Gillham, 2005). Unstructured interviews can be a good step before performing a semi-structured interview.

2.9 Systematic layout planning

To rearrange the layout in a production plant is often a costly effort. It will most likely result in lost production time, idle time and disruption of personnel (Muther, 1974). Therefore it is of big importance to get it right the first time so that further rearrangements can be avoided. One proven method for planning layout is systematic layout planning by Richard Muther (Muther, 1974). The method is based on determining the relations between different processes to systematically come up with the most suitable placement of each process to reduce the traveling distance for operators and material.

2.10 The Hawthorne effect

The Hawthorne effect comes from a series of studies performed from 1924-1932 that was developed to test the effect on productivity when the illumination is improved. The result from the test showed that productivity increased with more illumination, but it also increased with less illumination. The conclusion from this was that the effect from being studied was greater than the effect from changes in illumination (Freivalds and Niebel, 2013).

3
Method

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

3.1 Project methodology

The methodology that the project was performed according to can be seen in the flow chart in Figure 3.1. The project started with the creation of a planning report including the scope of the project and a time plan for the completion of the project. Thereafter the current state of the simulation and VSM was created simultaneously. The simulation model and the VSM was compared to make the simulation model more realistic. As a side track to the VSM, a layout was planned using the method systematic layout planning. This layout was then used for the future state of the VSM.

The future state from the VSM worked as inspiration for the improved simulation model. The VSM and simulation were then compared and evaluated. The improvements that were implemented in the simulation model was analyzed to see the effect from each improvement. A plan for implementing the improvements was suggested for each improvement, some of the improvements were implemented during the project.

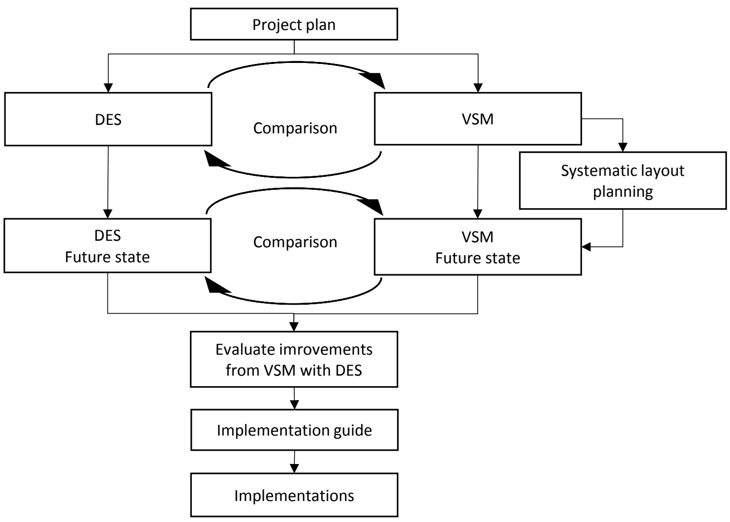

Figure 3.1: Visualization of the project methodology.

3.2 Value Stream Mapping

The value stream mapping was performed as an initial part of the project. The mapping started with observations of the production and interviews with production staff. The interviews were performed with people from production to get their opinion regarding the information and material flow. The interviews were of the unstructured type, which is suitable when the researcher does not know what there is to be known (Gillham, 2005). This initial step was performed when the production had not fully ramped up to a stable process pace but it increased the understanding of how the production process works so that the construction of the simulation model could be started.

The next step in the VSM was to find out more about the customers, suppliers and control points by answering the questions in the book *Learning to see* (Rother and Shook, 2003). The questions can be found in Table 3.1. When the questions were answered the mapping of the current state was performed. A map of all the information flow, material flow, processes, suppliers and customers was drawn on an A3 paper. To get feedback and another view on the current state map an interview was performed with the master production scheduler. Later a digital copy of the map was created to get a good overview to be able to discuss the map with the key persons in the production.

Further, a future state map was created based on collected information and input from different operators with the goal to reduce waste. The map was later used as a map for creating the future state of the simulation model to test the effect of the suggested improvements. To get ideas of things to improve for the future state a brainstorming activity was performed using the eight future state questions in Table 3.1 by Rother and Shook (2003) as inspiration. Both good, bad, possible and impossible suggestions were proposed and added to a copy of the current state map.

Table 3.1: Eight future state questions by Rother and Shook (2003).

1.	What is the takt time?
2.	Will production produce to a finished goods supermarket or directly to shipping?
3.	Where can continuous flow processing be utilized?
4.	Is there a need for a supermarket pull system within the value stream?
5.	What single point in the production chain will be used to schedule production?
6.	How will the production mix be leveled at the pacemaker process?
7.	What increment of work will be consistently released from the pacemaker process?
8.	What process improvements will be necessary?

3.3 Discrete Event Simulation

The simulation of the production was performed in different stages based on a modification of Banks project methodology, Figure 3.2. The first step was to create a conceptual model which was made as the current state VSM. With the VSM as a basis, the simulation base model was coded. This model was adjusted several times to better represent reality and also verified each time that it was correctly coded. The available data was added in the code even though the data collection was not fully completed. When more data was collected it was added to the simulation model and the model was validated by comparing to historical data and testing the model in extreme conditions.

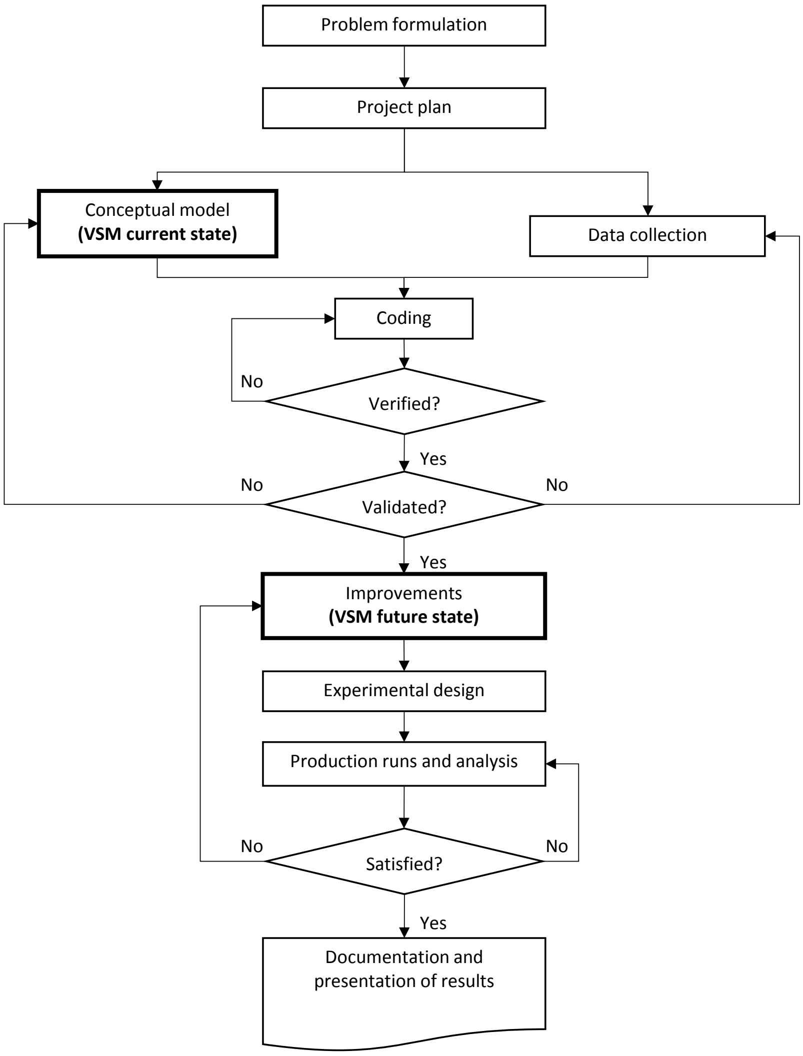

Figure 3.2: Banks project methodology for conducting a simulation project with modification for combining with VSM (Banks, 1998).

The first simulation model was developed based on information from interviews with production staff. This model was constructed when no actual production was in progress. Therefore some assumptions had to be made, which were corrected when the information was confirmed. When the production started the flow became clearer which made it possible to correct the current state model to match the real production.

Data from the production were gathered and analyzed in Minitab to determine what distribution the data followed. It was assumed that the data was positively skewed and followed a lognormal distribution, but it was analyzed in Minitab to verify that this assumption was correct. This data was added to the simulation as distributions that were returned from the statistical software.

To make the simulation more realistic, breakdowns were added to the operators, such as lunch, coffee breaks, meetings and toilet breaks. These breakdowns were based on collected data regarding the operators and machines behavior. The simulation model was built to have real work hours with 24 hour days and each operator working 8 hours per day. It was necessary to have 24 hour days because some resources were able to run these hours without any operators monitoring.

When analyzing the simulation data AutoStat was used. The model was simulated 20 times in a set time period, and for each run, a warm up of the system was performed for the model to reach a steady state before making the analysis of the simulations.

To build the future state of the production the future state VSM was used. The VSM improvements were one by one built into the simulation to be able to analyze each improvement step. Each step, as well as the final sum of the improvements, were used for evaluating the future capacity.

3.3.1 Verification and validation

The verification and validation of the simulation were performed according to the bullet list below. The simulation model was verified several times during the construction. The first stages of the simulation were primarily verified by observing the animation of the simulation and by checking buffer sizes and utilization of the different processes. A comparison between the lead time for the simulation and the real production was made.

Validation of the simulation model was made by comparing the output of the simulation to real data from production to make sure that it is realistic. The model was also validated by testing the model in extreme conditions, both when the system is full of products and when the system is empty it should work as expected.

Verification:

- Observing animations when the model is running. (Larborn, 2015)
- Look at variables during and after the simulation (Larborn, 2015)
- Print messages while the program is running (Larborn, 2015)
- Follow a specific load (Larborn, 2015)

- Follow the principles of structured programming (Banks, 1998)
- Make the operational model as self-documenting as possible (Banks, 1998)
- Have the code checked by more than one person (Banks, 1998)

Validation:

- Compare with historical data (Banks, 1998)
- Test the model in the extreme conditions (Sargent, 2013)

3.4 Implementation of improvement potentials in production

To find possible improvement potentials the VSM was used as a basis. The potentials that had an impact on the lead time, capacity or cost were documented. The improvement potentials were analyzed and the improvements that had an easy and cheap solution were implemented instantly while the more complex solutions were further analyzed, documented and brought to the company. Further, the implemented solutions were compared to the initial state to confirm that the solutions were a better option. Each suggestion was added in a matrix, with the cost on one axis and the benefit on the other, to more easily determine which suggestions to implement.

3.5 Data collection

Data was collected through interviews and observations. This was made in an early stage of the project because the data was needed for both the VSM and the simulation model. The interviews that were performed were all of the unstructured types in order to get the interviewees to share their knowledge (Gillham, 2005).

Numerical data was collected to be used for both the VSM and the simulation, by measuring process times over five weeks. Data was collected from all processes in the production flow separately, which made it possible to balance the line for the capacity analysis. The samples were analyzed in Minitab with a goodness-of-fit test to see what distribution the data had. To ensure that the data was statistically significant the confidence interval was calculated for each of the processes. Equation 2.1 was used to calculate the confidence interval for the distributions. A confidence level of 95% was used in the calculations. The confidence interval was then assessed to determine whether enough samples had been gathered or if more samples were needed. Some of the processes needed more samples which lead to another cycle of data collection.

3.6 Systematic layout planning

Systematic layout planning is as described previously a method for determining the most suitable placement of each process in a production. The first step in the process, to collect data, was made through the value stream mapping activity. The value stream map gave understanding over the material and information flow. When the flow was known the activity relations between all processes were determined as a matrix, Figure 3.3. The connection between the processes was assigned a letter A, E, I, O, U, X according to Table 3.2 depending on the closeness that is required between the processes.

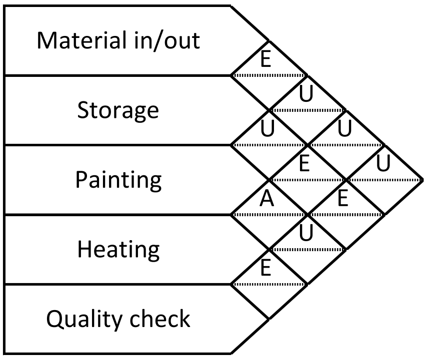

Figure 3.3: Example of relationship matrix.

Relationship	Closeness	Value
Absolute Necessary	A	4
Especially Important	E	3
Important	I	2
Ordinary closeness	O	1
Unimportant	U	0
Not desirable	X	-1

Table 3.2: Ranking of closeness between different process.

Further, the functionality requirements for each of the processes were mapped. In the functionality requirements table the special requirements were mapped, such as if there was a maximum floor loading, if water drains or compressed air or similar was required. For a visualization of the different steps of the method see Appendix A.

The next step was to create a diagram over the functions relations starting with the ones that were classified as *absolutely necessary* to be close to each other. Thereafter the relations classified as *especially important* were added and so on. When all of the processes were added rearrangements were made to reduce the materials and operators travel distance.

After this, the processes were added into a drawing of the available area. Two different alternative solutions were drawn, see Appendix B for the whole process. These solutions plus one that was made previously by an employee were all evaluated using seven different factors that were important for the specific layout such as material flow, work environment and cost of implementation. The most important factor was assigned a weight of 10 and the others were assigned a weight in relation to the highest from 1-10. Each solution was rated on each factor from A to X where A gave 4 points and X gave minus 1 point in descending order according to Table 3.2. The factors were multiplied by the rating and summed up. When this evaluation was made for all solutions, the one with the highest sum was considered to be the best. A more detailed drawing was made of the chosen solution so that it was clear to everyone how it is supposed to look and that it is possible to build according to the layout. This should have been the final step in the process, but more information was revealed after the final step and another cycle of the layout planning process had to be done. The second cycle of the process generated two new layout proposals, see Appendix B.

3.7 Capacity analysis

An analysis of the capacity of the production was made to investigate the current capacity and to see what changes in the production could do to increase the capacity for an eventual increase of demand in the future. This analysis was based on the simulation and VSM in combination with the Theory of Constraints. The analysis was made along with the improvements of the simulation. When a change was implemented in the simulation model the output for a certain time could be seen. The capacity was documented for each solution in order to compare and determine what changes had the biggest effect on the output. Some changes require more changes in order for an effect to be seen, therefore combinations of different changes were implemented and tested.

4
Current state

In this chapter, the current state of the production as it was at the time of the study is presented.

4.1 Production

The production is structured in nine processes located on six different stations, Figure 4.1. The stations are located in a functional layout because there are other products that are being produced in this area and the company wants to group similar machines close to each other. Some of the processes are similar and are using the same station for different operations in the production flow. Most operations require high skills and precision due to the high quality requirements. The analyzed low volume production consists mostly of manual work but there are some automatic tasks performed by machines which have to be loaded and unloaded manually. The learning time to be able to perform the manual work independently is fairly short thanks to the detailed instructions, but it takes some time to master all the tasks at a high pace.

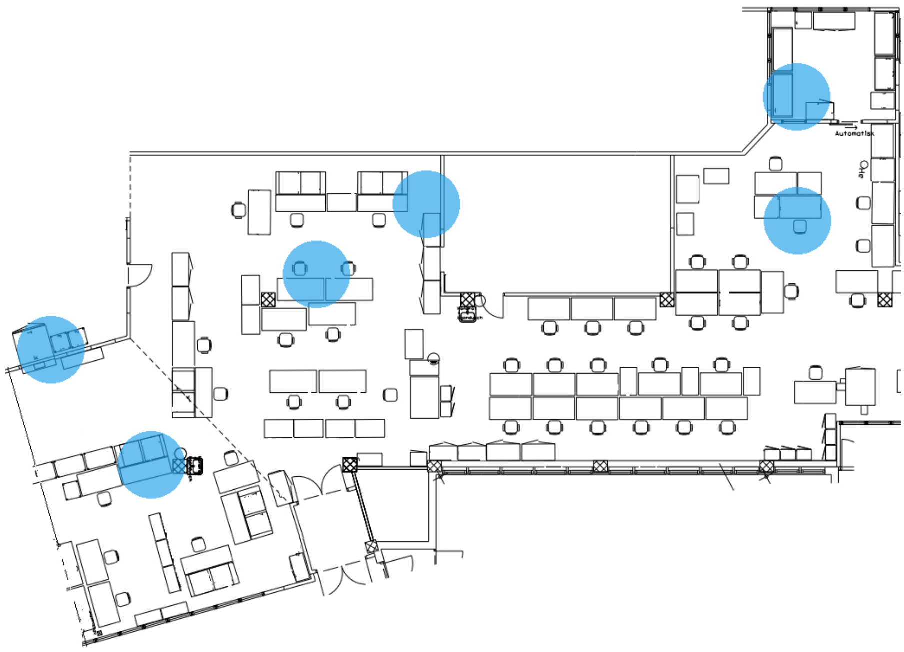

Figure 4.1: The current layout with the used stations marked.

4.2 Organisation

In the production, there are daily meetings every Monday, Wednesday and Friday for 15 minutes to plan each operator's upcoming tasks. There is also a $5-10$ minutes meeting these days where the employees can come with improvement suggestions.

The work hours are flexible and the operators can start from $6-9$ in the morning and should work until 15 in the afternoon. The operators should work 8 hours per day in average as long as they are in production from 9 to 15 every weekday. The flexible work hours makes the production run more than 8 hours per day in total because the operators usually starts from 6:30 to 8 and the last person usually stays until 16:30.

All operators within the production have the same competence which makes everyone able to do all tasks. This is favorable and makes the production robust in case one or more operators are absent. Also, the operators have the opportunity to rotate the tasks within the production or produce a whole product by themselves if they like to, they just have to coordinate the tasks within the production at the morning meeting.

The production planner has many tasks to handle, such as starting orders, registering finished orders, taking care of faulty products and he is authorized to handle changes in serial number traceability when necessary.

The production planner starts each order when there are operators and material available. The operators are not able to start producing before the production planner has started a new order, and there is only one production planner in the production area that is able to start new orders. This makes the system vulnerable if there are operators without work and the production planner is not in the production. To overcome this problem the production planner starts orders further ahead, but when there is a lack of material there is a risk to get into the situation where the operators do not have any work to do. The production planner also register completed orders in the ERP system (Enterprise Resource Planning). By doing this it is possible to keep track of statistics such as lead time, value adding time and costs, also other persons in the company can easily track the progress.

There are also production technicians in the production which help the operators with machines and faulty products. The technicians are specialized in different areas and help the operators with different tasks when there is a need. The technicians also make sure that everything within the production works as it is supposed to.

4.3 Material handling

All material that is used in production is first received at the warehouse. After the reception of the material, it is inspected to assure that the requirements are fulfilled and then it is stored in the warehouse until it should be used in production. The material for one order is picked and moved from the warehouse to the production when an order is started by the production planner. When the order is started a picking list is automatically generated to be picked at the warehouse. Some of the components used in the product are manufactured in-house and this storage is kept at the production area, but most of the components comes from external suppliers and are received and stored in the warehouse.

At the workbench in the production, there are bins with cheap and small components that are used for assembly. There is a stock of components that are used for assembly, but these components are as mentioned previously picked in the warehouse anyway. When the material arrives at the production area in bags with components some of the material is laid aside. The material is not used for the specific order, but the operators open the bags to refill the bin when they have some time over. The other components are stored in the material storage in production. These components are kitted in a $400 * 600$mm box without any fixed places for each component, Figure 4.2. This makes it difficult for the operators to find the right component when it is needed in the assembly.

Figure 4.2: The currently used kitting box. Both with material and empty.

4.4 The production presented through Value Stream Mapping and Simulation

To get an understanding of the current state production, simulation and VSM was used as support. The combination of these two tools was supporting each other by providing different types of information about the production. In Section 4.4.1 and 4.4.2 the current state production is presented by the VSM and simulation.

4.4.1 Value Stream Mapping

The current state VSM is shown in Figure 4.4 and presented in detail in this section. An overall production plan is made in the ERP system that is available to the production planners. Each week's production is planned based on the final delivery date for the customer and is updated continuously if any problems arise such as lack of material or problems with any of the processes. Based on this plan the purchaser orders material and stays in contact with the suppliers to make sure that the materials can be delivered as promised. If there are material and operators available the production planner can start new orders, which initiates a kitting process from the warehouse to the production. The production requires this delivery of material before it is possible to start producing. However, some of the cheap components are buffered in the production area and do not require to be kitted in the warehouse, but due to cost allocation, the components are connected to the order and automatically printed at the warehouse staff's pick lists.

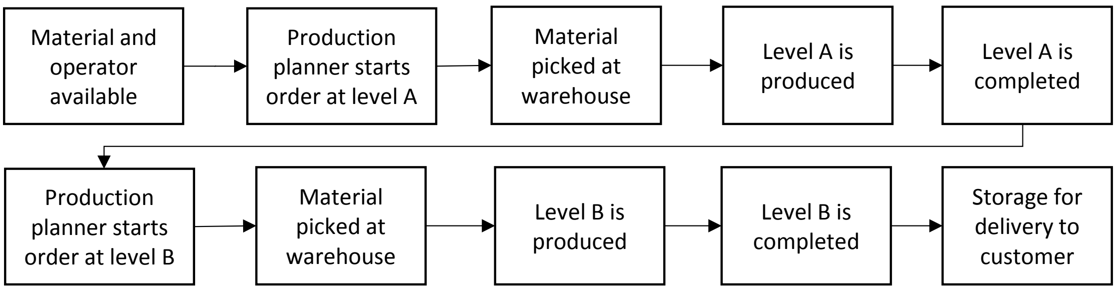

Figure 4.3: A simplified flow chart of the production.

The production is currently divided into two separate levels, A and B, where both levels consists of assembly and functionality testing. When level A is started the material from the warehouse is being picked and transported to the production. When the material arrives it is received and unwrapped. The level A production is then performed. When level A is complete and the product is approved level B can be started. This leads to a waiting time in the middle of the production when waiting for material from the warehouse. When the material for level B arrives it is received and unwrapped just as in level A. See Figure 4.3 for an overview of the production flow.

Process times were measured and a value adding and process time ratio was calculated. This ratio was 10.5%. The operators traveling distance was also mapped in the VSM and this distance was a minimum of 220 meters for each product.

Material flow

The material flow is represented by the wide arrows in the current state VSM. It is transported from the warehouse to the production using a truck. This delivery is made two times every day to supply the whole production plant. In this delivery, the material used for level A and level B arrives. There are also components produced in-house, the delivery of these components are symbolized by the shopping cart. There are four places in production where it is possible to detect errors. Most

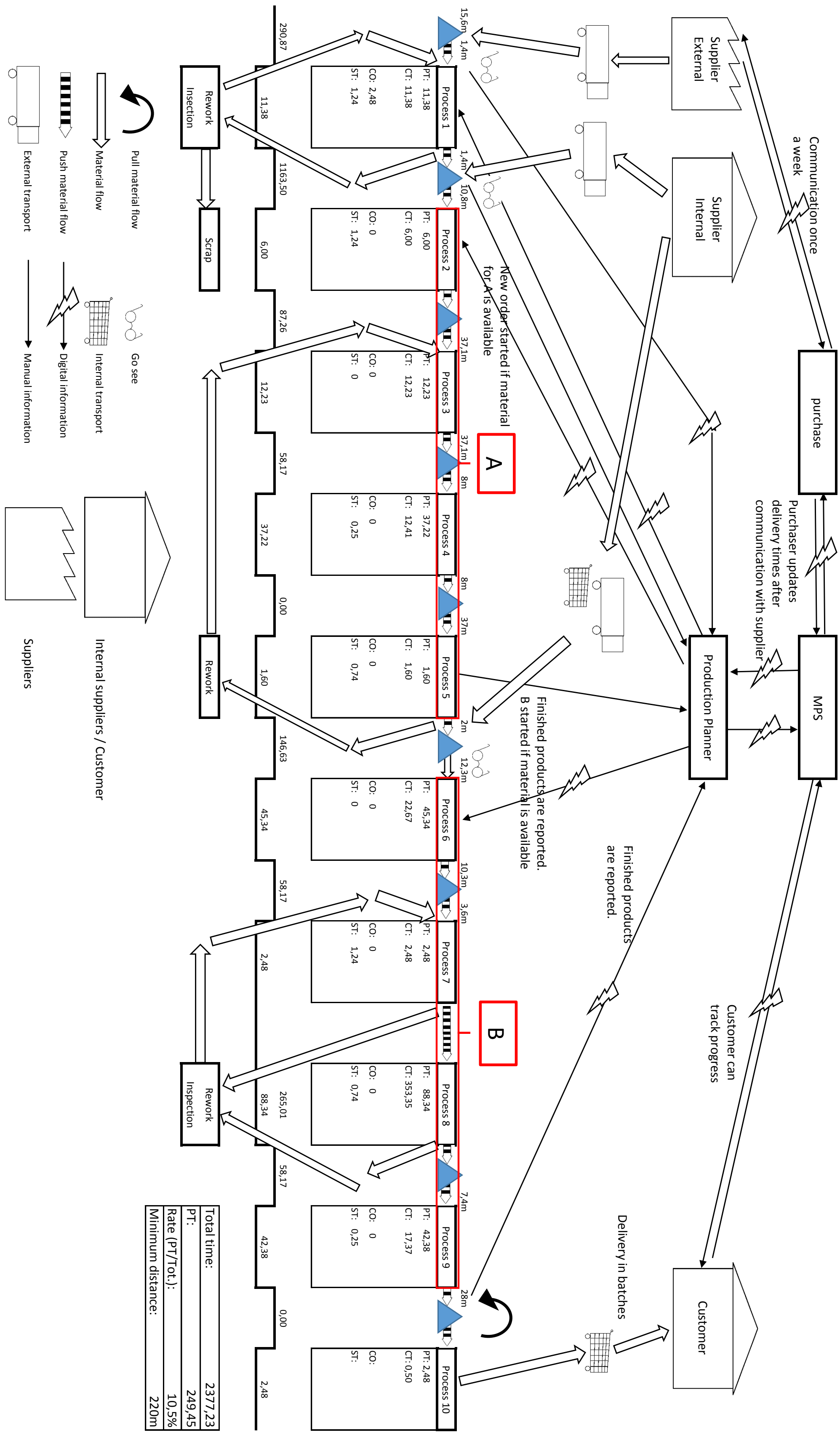

Figure 4.4: Current state VSM.

times it is possible to fix the error but when the cost of repair exceeds the cost of the product it can be scrapped.

There is currently no system to control the buffer sizes. The material is pushed to the next station which leads to high buffers if the processes are not balanced to have equal cycle times.

Information flow
The information flow is represented by the thin arrows. The information that is electronic has a lightning and manual information does not. Much information is handled by the production planner such as starting new orders and registering finished orders. The production planners and purchasers work with a software called IFS, which is an ERP system, on a daily basis and updates production times regularly.

Every time there is a material whose delivery is late the production is rescheduled. This makes it difficult to keep track of how late a product is since it can be rescheduled several times.

The production process starts with the arrival of material before Process 1. When this material is received an order is started to perform Process 1. When this process is finished the production planner registers the finished order and starts level A. For the production planner to know when Process 1 is finished the operators should put up a label on a board that is visible to everyone and also sends an email to the planner. It is the same process when level A and level B are finished and should be registered. The ERP system is available to the customer which can keep track of the progress of production.

4.4.2 Simulation

The simulation of the current state is presented where a basic graphical representation can be seen in Figure 4.5. The results from the simulation are presented in Table 4.1.

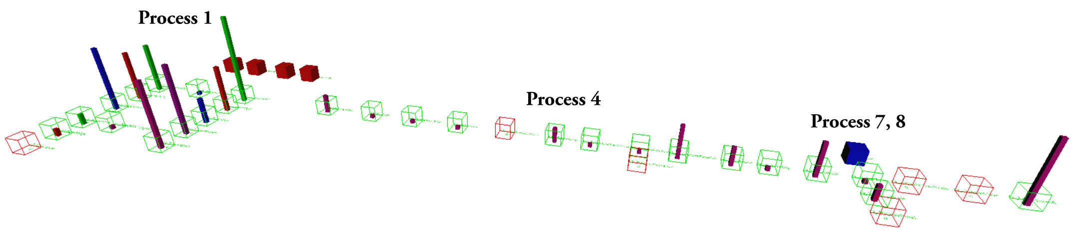

Figure 4.5: The graphical representation of the current state simulation.

The current state simulation results given in Table 4.1 shows the current production output, normalized to the scale (x), for a known time period. Processes 1, 4, 7 and 8 where there is a machine required is presented with the amount of produced products, utilization and idle time. The output from the production is 100x which is the same as the number of produced products in Process 7, 8. The utilization of Process 7, 8 is 55% which is the highest utilization of the machines in the system. Process 7 and 8 are using the same machine for their process, Process 7 is the pre-process for Process 8. Therefore, Process 7 and 8 is represented together because it is the same machine. The mean utilization of the operators is also shown. The measurements are calculated with the available time for the different processes, the available time for Process 8 is different from the others because it can be used 24 hours a day. The others can be used the regular work hours, 8 hours per day. The lead time is normalized as a certain time unit (TU). These results are used as a reference for the improvements of the simulated production.

Table 4.1: Current state simulation results.

Measurement	**Current state**
Output from the production	100x
Products produced in Process 1	110x
Products produced in Process 4	110x
Products produced in Process 7, 8	100x
Utilization of Process 1	43%
Utilization of Process 4	18%
Utilization of Process 7, 8	55%
Mean utilization of Operators	78%
Idle time for Process 1	57%
Idle time for Process 4	82%
Idle time for Process 7, 8	45%
Mean idle time for Operators	10%
Lead time	100 TU

The model is based on the collected data, it is used for simulating the operator's work and the machine times. The model can not be more accurate than the collected data. The collected data for the different processes are presented in Table 4.2. 95% of the time the mean will be within these intervals, meaning that there is a 95% confidence interval.

Table 4.2: 95% confidence interval for the collected data, where μ is the mean value for each data set.

Process 1	$\mu - 9.8\%, \mu + 10.9\%$
Process 2	$\mu - 9.7\%, \mu + 10.7\%$
Process 3	$\mu - 9.8\%, \mu + 10.8\%$
Process 5	$\mu - 12.2\%, \mu + 13.9\%$
Process 6	$\mu - 18.4\%, \mu + 22.5\%$
Process 9	$\mu - 6.6\%, \mu + 7.0\%$

4.5 Layout

The production is currently performed in an area shared with several other products. It can be seen in Figure 4.6 that the processes are spread out in a functional layout. For products produced in large batches this is of little importance but to have a continuous flow in a layout like this will result in long traveling distances for both material and operators. It also makes the communication between the operators more difficult because they cannot see each other at all times. The shortest possible distance that the operator must move is 220 meters per product in the current layout. However, most of the times the distance is much longer due to human errors. The operators are not stationary at one station, they can move between different stations and sometimes complete the whole production process for one product.

Figure 4.6: Current layout with the material flow drawn.

5
Current state analysis

In this chapter, the analysis of the production that was conducted through VSM and simulation is presented along with identified issues that were observed. The collected data for the analysis is also analyzed and presented.

5.1 Data collection

The interviews that were performed turned out with different results. Depending on the interviewed persons work tasks the information given by them was different. In general, the operators had a good picture of the material flow, the production planners had good knowledge about the information flow and the production technicians had good knowledge about the processes. The interviews with all these different persons gave the analysis of the production a kick start. It provided a basis for the current state VSM and was later supported by the author's perception of the flow. Interviews were also performed with the product planner to verify the current state VSM.

The numerical data collection was performed by a time study. The processes in the production were timed and the data were gathered for further analysis. Each process got a different sample size, this was because the production was not running in regular pace when the data collection was performed and all opportunities that were given was used. The data was then analyzed in Minitab to determine the characteristics. A distribution fitting was performed to compare the data to different kinds of distributions. Since most of the work are manual the distribution was expected to be right skewed. The analysis concluded that the data with higher sample size had characteristics that converged towards lognormal distributions. The data sets with fewer samples were more difficult to determine the most accurate distribution, therefore these sets were assumed to follow lognormal distributions as well. The distribution fitting for the processes is presented in Figure 5.1.

5.2 Material handling

The material handling at the warehouse is performed in such way that the operators in the production do not benefit the packaging. The components are picked in the warehouse and placed in small plastic bags. This is made for all components at the warehouse including basic components such as screws. This does not facilitate the operators in the production because they already have a bin for each of the basic

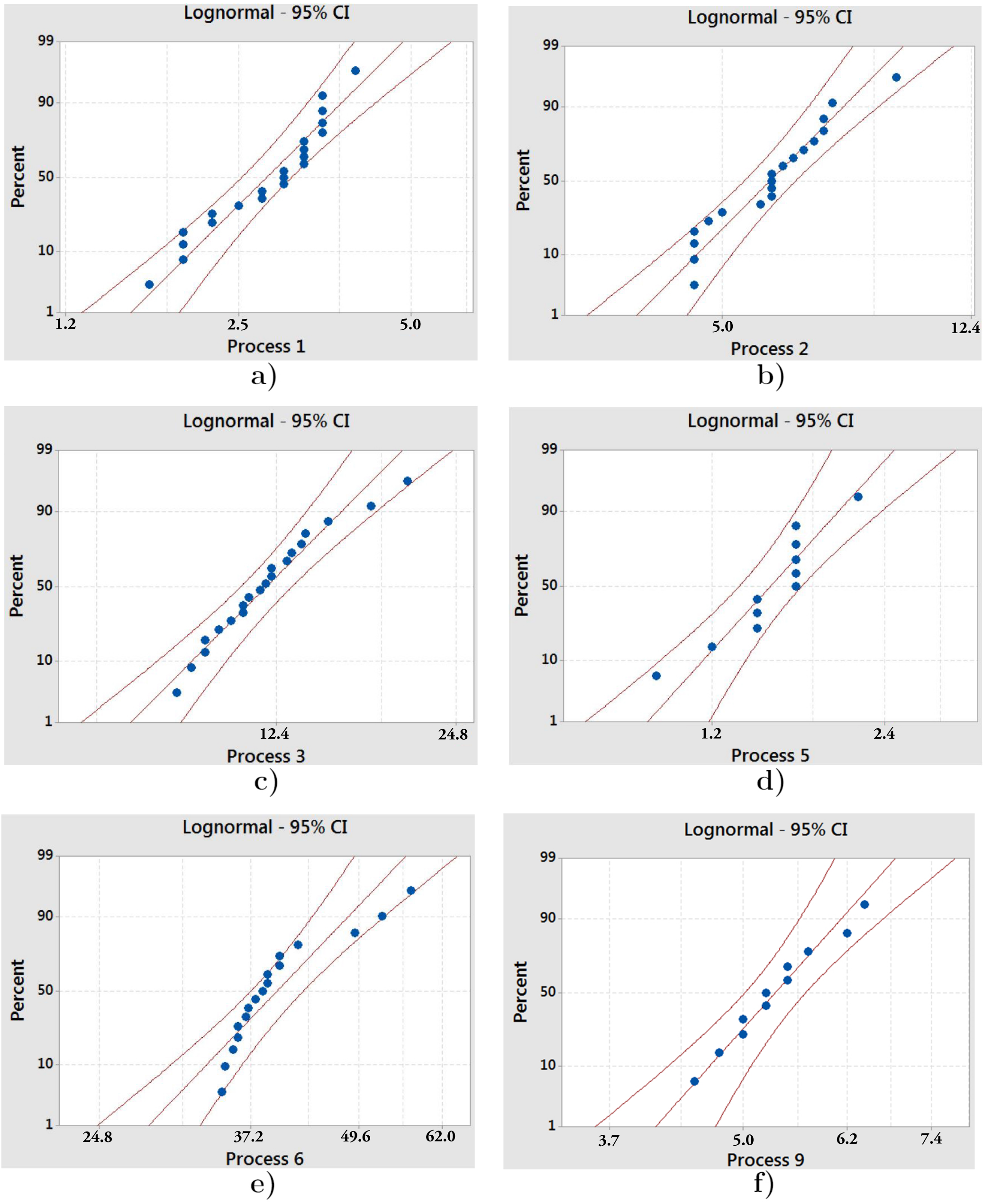

Figure 5.1: Probability plots of the data for Process 1, 2, 3, 5, 6 and 9. The time is normalized.

components at the workbench. They do not use the packaged material from the warehouse for the specific order, it is used to fill the bins at the workbench when there is time available. This makes all the extra packaging of these components at the warehouse unnecessary and time consuming for both the operators in the warehouse and in production.

The cost for the current material handling of the picking of components for both level A and B could be reduced by implementing a two bin Kanban system and combining the levels. There are costs for operators in the warehouse, operators in production, transports of material and order starts for the production planner. These implementations would reduce the cost of material handling by 84%. Because of a high work burden for the production planner, it is required to do some work tasks during the weekends. By combining the two levels a bigger part of the work tasks could be managed in regular work times and costs would hence be saved.

The components that are stored in production are currently kitted in a box without compartments for each component, see Figure 4.2. This makes it difficult for the operators to find the correct component when it is needed in assembly. To have a kitting box that is suited for assembly will decrease the risk of not using all components for each product because if the box is empty when the order is finished it will be easily spotted. It will also result in less time needed to get components during assembly and while kitting.

5.3 Value Stream Mapping

From the current state VSM, some good and bad things with the production process were visualized. One thing that should be avoided is to have a stop in the middle of production between level A and level B. This stop results in either waiting time for deliveries or a requirement for a bigger buffer in between these levels. To have higher buffers in between the levels will result in longer lead times and is therefore not preferable. The stop between the levels also results in an extra transport of material from the warehouse. By combining level A and level B there will be a reduction of lead time, less resources required for material handling and the production planner will have fewer tasks to complete. There are no advantages in keeping the two levels as they are.

Another thing that was noticed through the VSM was the material handling. The material is currently kitted at the warehouse for each order, for both level A and level B. When the production planner starts an order a signal is sent to the warehouse that material is required. The material is then picked for the order and sent to production. A problem with this is the lead time from the warehouse to production which directly adds to the lead time for the production. The kitting made in the warehouse has to be made twice since one kit is prepared for each level. The solution to this is as mentioned above to combine level A and level B.

The material is currently pushed through the system and the level of the buffer sizes are not controlled. In a push system, there is a risk of having too many products in the system which will lead to a longer lead time. By having a pull system, which means that products are not produced unless the next process requires them, the buffer levels can more easily be controlled. The buffer levels should be as low as possible without risking the performance of the system.

The value adding ratio is determined from the total number of products in the system and the total process time. This ratio was 10.5% which is high compared to most production processes. It was this high because there were fewer products in the system than it usually is.

The production planner currently has a lot of tasks to complete to manage the order starts and completion of orders. These are processes that might be necessary for a single piece production but for this production when there is a flow of products it should not be necessary. The production planner should have control of the process, but the operators should not be limited by the production planners presence. The system may not be mature enough for this right now, but it is a state to aim for.

From the VSM it can be seen that Process 8 has the longest process time. This is an indication that this process might be the bottleneck in the system, but this process can run over night. The second longest process time is the one for Process 6. This process does not run overnight and is hence the slowest process. The simulation is a good tool to more easily determine where the constraint of the system is.

5.4 Simulation

From the current state simulation Process 8 was determined as the bottleneck. This is because the process had the highest utilization, as can be seen in Table 5.1. It blocked the stations before and starved the stations after. The utilization of the operators is higher than the utilization of Process 7, 8. However, Figure 5.2 shows that the operators are not constraining the output since the output from the system is not increasing if the number of operators is increased. Further, the output from the system never became higher than the output from this process, see Figure 5.3, which conforms with the theory of constraints described in Section 2.5. As a principle from the theory of constraints, it is important that this process has minimal idle time. To decrease the idle time there is a requirement that the process always has products in the buffer before the process and space in the buffer after the process. Therefore the buffer sizes were analyzed to find the minimum buffer size that could supply the process and still avoid it to get starved.

Table 5.1: Idle time for the processes where a machine is required and operators.

Process	Utilization
Process 1	43%
Process 4	18%
Process 7, 8	55%
Operators	78%

From the current state VSM, it could be seen that the production is divided into two levels, level A and level B. These two levels could be merged to eliminate the waiting time. The change was analyzed in the simulation model to see how it affected the lead time of the production.

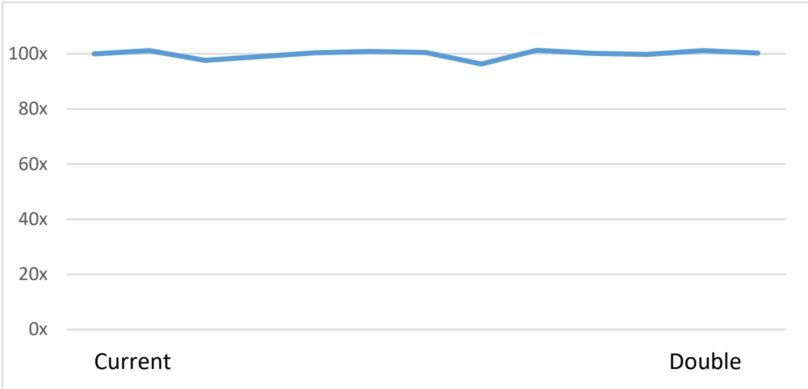

Figure 5.2: The simulated output from the system when increasing the number of operators from current to double.

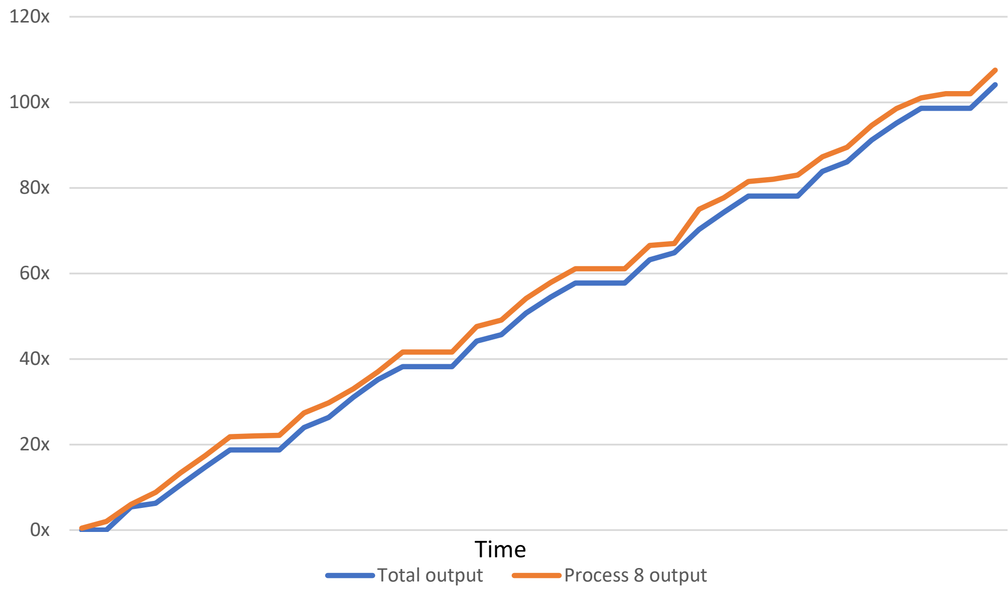

Figure 5.3: The simulated output from the system and Process 8.

5.5 Layout

An issue with the current layout is the long traveling distances for material and operators. This is due to the current functional layout where processes are ordered according to function instead of flow. This results in losses in terms of unnecessary movements and transports. In the current layout, there are some benches that are shared among different products, and the operators do not always have a workbench that is suited for the work that is performed. However, a positive aspect is that there is a planned relocation of the production which gives possibilities to make changes to the layout without high additional costs. The new layout was developed using the method systematic layout planning. The different steps and results from the method can be seen in Appendix A. To improve the layout when it is not implemented can be made to a fraction of the cost compared to when it is already used in production.

6
Future state

In the following chapter, a future state of the production is presented. There are multiple changes that can improve the production in different ways, these changes are presented along with the possible effect to the production.

6.1 Material handling

The material handling for the components that are used in the production should be made as described in this section. For the picking of standard components from the warehouse, like fastening material and similar, a two bin Kanban system should be used. The material handling in the production should use kitting of the components for assembly.

6.1.1 Kitting

The kitting of material in the production should be customized and there should be a new kitting box where the components have an allocated space so the operators easily can find the right component during the assembly, see Figure 6.1. The material storage should also be reorganized so the kitting process follows the assembly order, the components should therefore be placed in the same order in the storage as in the kitting box as visualized in Figure 6.2. The time for kitting with the new kitting box will be the same as before. The kitting box will increase the quality of assembly because the right components will end up at the right place in the product. With the kitting box, it will be easy to see if all required material is picked because each component has a separate compartment.

6.1.2 Two bin Kanban system

A representation of how the Kanban system will work is shown in Figure 6.3. To get around the problem of picking cheap and small components for each order at the warehouse a two bin Kanban system should be used. By using this system there will be less time spent for operators at the warehouse picking components and the operators in production will not have to open the plastic bags for each order.

Two bins are stored in the production area and each of them contains components for three weeks of production. One smaller bin is stored at the workbench containing

Figure 6.1: A prototype of the kitting box that should be used in the production. Both with material and empty.

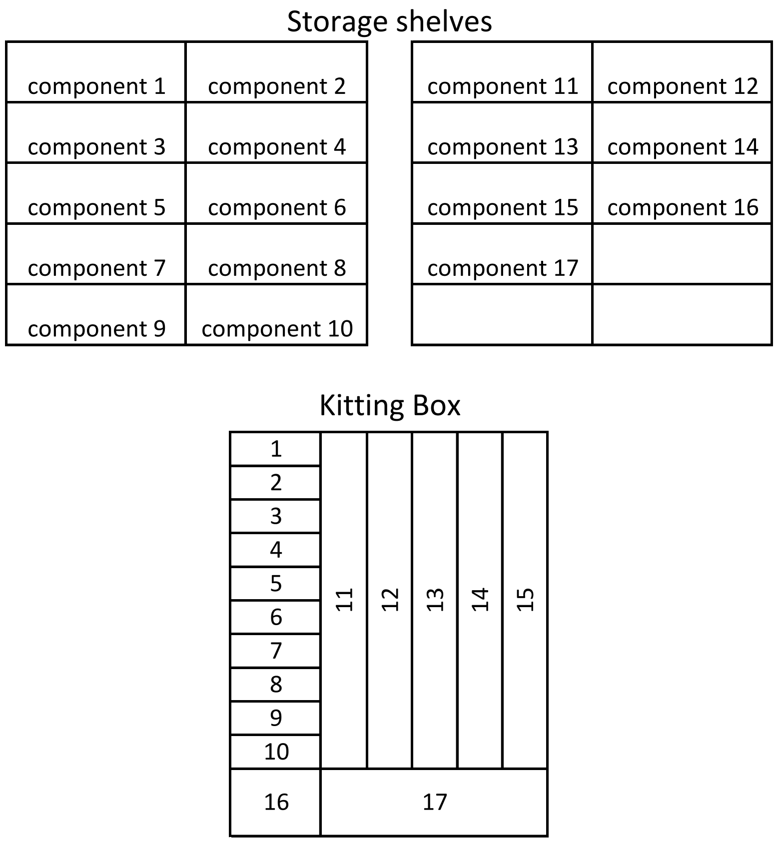

Figure 6.2: A visualization of the storage compared to the kitting box.

material for about a week's production. The reason for the amount components in each box is determined from the cost of components, the cost of picking and cost of

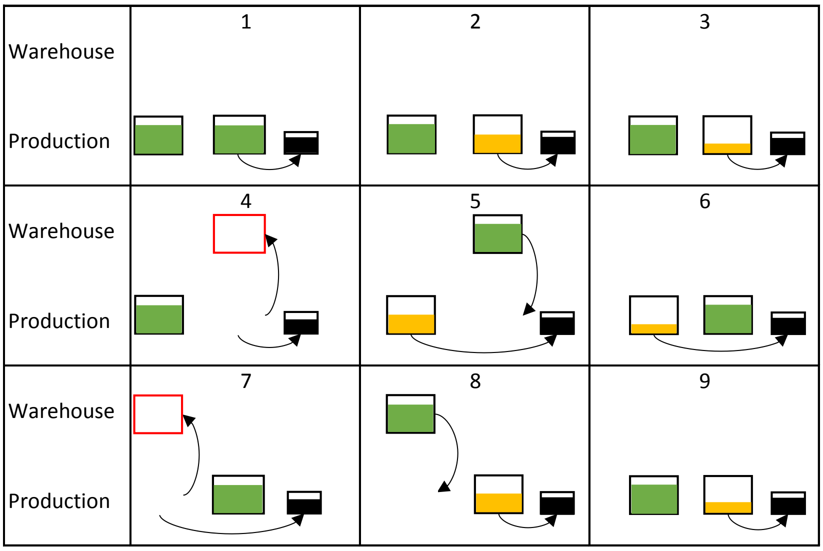

Figure 6.3: Representation of the kanban system. Green bins are full, yellow are not full and the black bins are at the workbench.

transports. One of the larger bins is used to refill the bin at the workbench. When the larger bin is empty it is shipped to the warehouse to be refilled and sent back. In the meantime, the other larger bin is used to refill the smaller bins. When the larger bin returns from the warehouse it is not used until the other larger bin is empty which is FIFO material priority. This is to avoid that both bins are empty at the same time and that material is lacking in the local storage. As mentioned the Kanban system will reduce the material handling time for both the operators at the warehouse and in the production.

6.2 Value Stream Mapping

The future state VSM that was used for improving the production can be seen in Figure 6.4. The main improvements from the current state are the combination of level A and Level B, pull instead of push and supermarket for cheap components. By combining level A and level B the lead time will be reduced, the production planner will have fewer tasks to perform and the operators in the warehouse will only have to pick material once for every product. To have a pull system instead of push will give better control of the buffer sizes and result in a reduced lead time of the system. It will also lead to an increased value adding ratio of 20.5% compared to the previous 10.5%. A supermarket for cheap components will result in less work for the operators at the warehouse and the production. These changes will lead to less information to handle for the production planner since only half the number of orders have to be started. The future state of the VSM will lead to reduced traveling distance for material and operators.

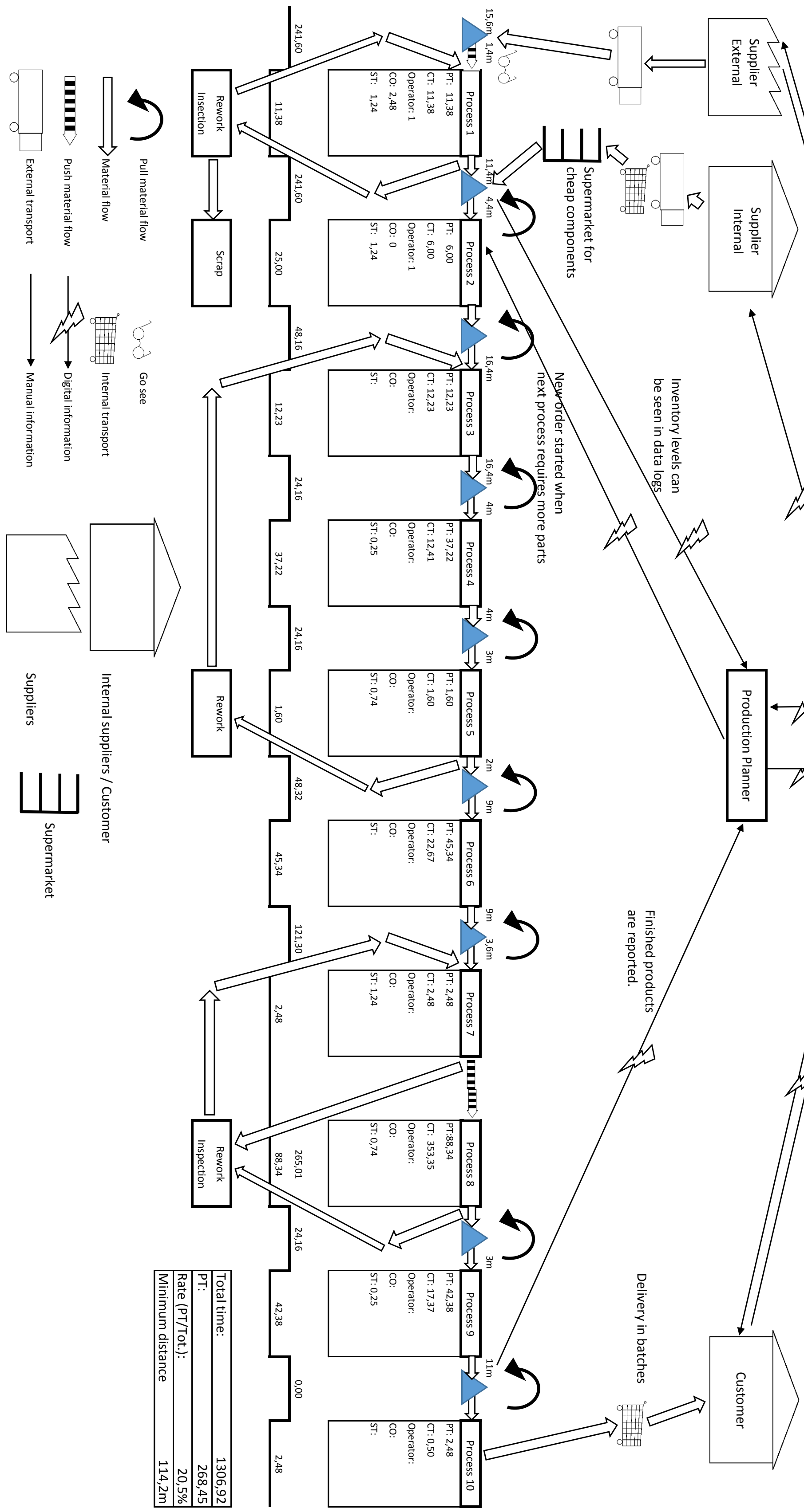

Figure 6.4: Future state VSM.

Table 6.1: Tests that were implemented in the simulation model.

•	Optimize the bottleneck buffer size
•	Remove the waiting time
•	Run the bottleneck during weekends
•	Run the production during weekends
•	Invest in another bottleneck machine
•	Increase the number of operators

6.3 Future state simulation steps

To determine how different improvements affect the production an analysis was performed by implementing and evaluating different alternatives in the simulation model. It was found that the production can either run full time with all operators during the weekend or with one operator focusing on the bottleneck machine. It is also possible to invest in another bottleneck machine. Testing the effect from running production during the weekend with all operators, running the bottleneck machine during the weekend with one operator or running the production only during weekdays but with another bottleneck machine are three possible alternatives that have been tested. According to the theory of constraints, the bottleneck process will move when resources are subordinated to this process. This will force other implementations such as increasing the number of operators which also has to be implemented in the simulation model and analyzed.

The above introduced tests are summarized in Table 6.1. The results from the simulation are presented below and summarized in Table 6.2.

- **Remove waiting time**

When the waiting time between level A and level B in the system were removed the lead time decreased by 12% from 100 TU to 92 TU. The change did not have any impact on the output and utilization of the bottleneck machine but the utilization of the operators increased by 5%. The waiting time is removed for future analysis. The removed waiting time is kept for further analysis.

- **Optimize buffer size at Process 7**

To utilize the bottleneck machine in Process 8 as much as possible without adding too many products into the system the buffer size at Process 7 was analyzed because it supplies Process 8 directly. In Figure 6.5 results of the buffer size's impact on the output from the production and the utilization of the bottleneck machine are shown. As a result of varying the buffer size from "A" to "J" the output from the production follows the utilization of the bottleneck machine. At buffer size "D" the graphs are starting to stabilize, this means that the buffer size should be at least "D". To be able to supply the full capacity of Process 8 the buffer size is set to "E". The utilization of the bottleneck and the operators stays the same as the current state but the lead time is 5% lower. The buffer size "E" is kept for further analysis.

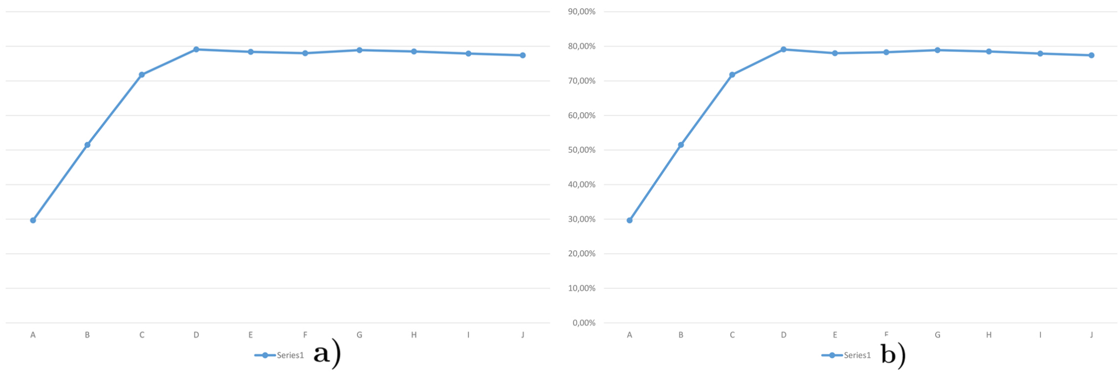

Figure 6.5: Simulated output from the production (a) and utilization of Process 8 (b), when varying the buffer size at Process 7 from size "A" to "J".

Table 6.2: Simulated results for comparison between current state and the improved states; Removed waiting time, Optimization of buffer size, Run the production during weekends, Run the bottleneck during weekends and Invest in another bottleneck machine.

	Output	Utilization of bottleneck machine	Mean utilization of operators	Lead time
Current state	100x	55%	78%	100TU
Removed waiting time	100x	56%	82%	88TU
Optimization of buffer size	100x	56%	78%	86TU
Run the production during weekends	129x	74%	77%	69TU
Run the bottleneck during weekends	111x	62%	71%	45TU
Invest in another bottleneck machine	164x	33%	80%	51TU
Invest in another bottleneck machine and operators	220x	61%	–	29TU

- **Run the production during weekends**

To determine if the capacity could be increased when production is running and using the same machines as in current state but instead extending the work hours to run every day of the week. When running the production during the weekends the output increases to by 29%, the utilization of the bottleneck increased by 35% and the utilization of the operators decreased by 1%. However, the lead time decreased by 31%, this is because there is no lost time when the production is running during the weekend.

- **Run the bottleneck machine during weekends**

To compare with running the whole production at the weekends this only uses one operator for half a day during the weekend to start the bottleneck machine. By doing this the output from the production is 5% higher, the utilization of the bottleneck is 13% higher and the utilization of operators is 9% lower, compared to the current state. The lead time is decreased by 55%, this is because the operator that starts the machine does not add any products into the system and the buffers are emptied when only the bottleneck is running.

- **Invest in another bottleneck machine**

To do a long term analysis of the production another bottleneck machine was implemented in the simulation. To keep the characteristics of the machine a buffer was also added to the invested machine with the same size "E" as the first machine. When using the same number of operators in the production and comparing to the current state the output increased by 64%, the utilization of the bottleneck machines were 33% each, the utilization of the operators increased by 2% and the lead time was lowered by 49%. The investment of another machine would elevate the productions constraint. The utilization of the machines of 33% each is not constraining the production anymore. To increase it further, more operators are required.

- **Invest in another bottleneck machine and more operators**

When adding another bottleneck machine the operators are constraining the output from the production. To be able to see the capacity of the production if this investment is made, operators were added into the simulation until the operators was not the constraining factor. The utilization of the operators are therefore not relevant and hence not measured. The simulated output then increased by 120% and the utilization of the bottleneck machines was 61% each. However, the utilization of Process 1 is 84%, which now is restraining the production.

6.4 Layout

The final layout was developed through the systematic layout planning method and the result is shown in Figure 6.6. The advantage with this layout is that it is planned to have a good material flow and it is located in a smaller area with only two different products produced in this area. The lower part of the area belongs to the analyzed product and in the upper part, the other product is being produced. Five different solutions were evaluated in the layout planning, see Appendix B. The first three layouts, A, B and C, were developed and evaluated. When these were finished new information was revealed which forced another cycle of the planning process. In this cycle solution D and E was developed. As seen in Table 6.3 layout B and C were equally good and layout A had some flaws giving this layout a lower score. When developing the new solutions due to the new information layout B and C was used as a base. Layout E was better than D mostly because of the placement of the material storage that leads to shorter traveling distance and better flow. Another difference between these layouts was the placement of a loud process that preferably should be as far away from the workbenches as possible to avoid an unsustainable work environment. These differences resulted in the score 148 for layout D and 174 for layout E. This clearly indicates that layout E is the preferable one to use. In the new layout suggestion, layout E, the approximated traveling distance for the operators has decreased to 114 meters per product compared to the previous 220 meters. It will be easier to communicate between operators and everyone in production can see each other at all times and hence have better control of each other's progress.

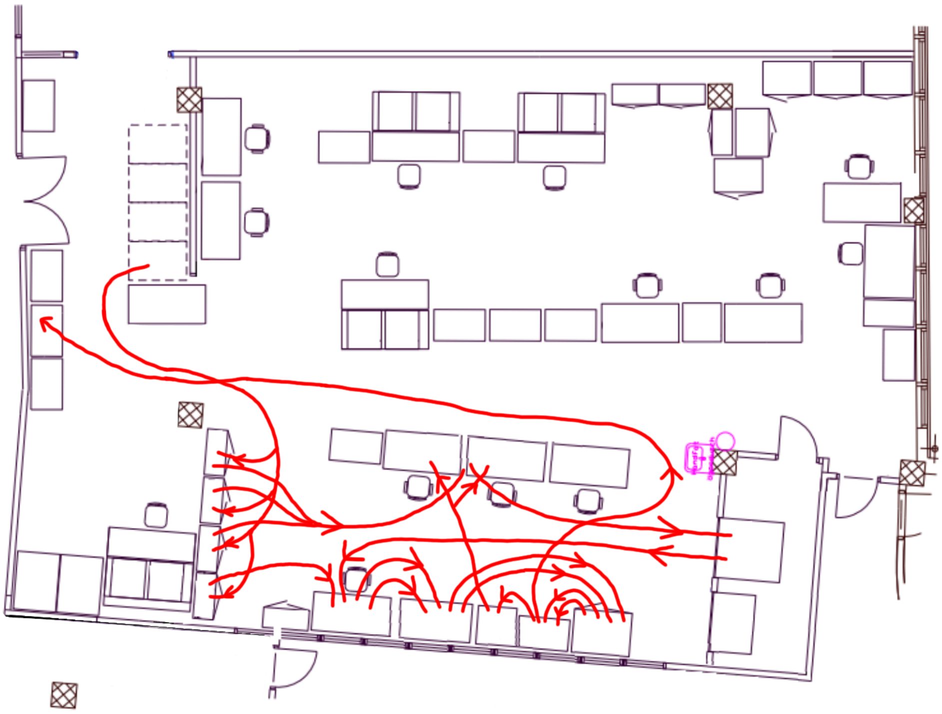

Figure 6.6: Layout E, future layout, with a spaghetti diagram to represent the travelling way for material

Table 6.3: Evaluation of the different layouts.

	Solution	A		B		C		D		E	
Criteria	Weight										
Minimize walking distance	8	I	16	E	24	E	24	I	16	E	24
Maximize space utilization	7	I	14	E	21	E	21	E	21	E	21
Material Flow	10	I	20	A	40	A	40	E	30	A	40
Drain Close to machine	7	O	7	A	28	A	28	A	28	A	28
Work environment (noise/heat)	4	O	6	E	12	O	4	O	4	E	12
Office placement	6	A	16	A	24	E	18	E	18	E	18
Cost, fixed installations	5	E	18	E	15	E	15	E	15	E	15
Storage space	4	E	12	E	12	A	16	A	16	A	16
Totals		109		176		166		148		174	

7

Implementation

This chapter presents how the different changes influences the capacity of the production. Also, suggestions on how the proposed changes can be implemented.

7.1 Planning the implementation

The order in which the different proposals should be implemented is visualized in Figure 7.1. The two bin kanban system should be implemented as soon as possible as well as the Kitting. These proposals will improve the working environment for the operators and also reduce the cost. This kind of improvements should be implemented continuously. If there is a requirement to increase the capacity to more than 100x the weekends must be utilized for production. This can be made in parallel with the implementation of Kanban and kitting. If there is a requirement to increase the capacity to more than 129x another bottleneck machine is required along with increasing the number of operators. The implementation of this should preferably come after the capacity is increased to 129x. Due to that, a new bottleneck machine is an expensive investment the current machines should be used to as far extent as possible and the production should be leveled even if the demand is not.

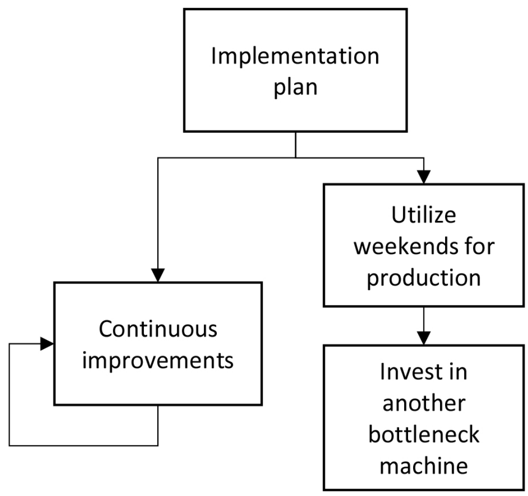

Figure 7.1: Implementation of improvements.

7.2 Capacity

There are two ways to increase the production's capacity, without any investments or invest in another bottleneck machine. To increase the capacity without any investments the work hours for the operators has to be increased. If an investment of another bottleneck machines is made, the number of operators has to be increased to be able to utilize both of the machines and increase the capacity of the production. The number of operators needed for increasing the capacity is visualized in Figure 7.2.

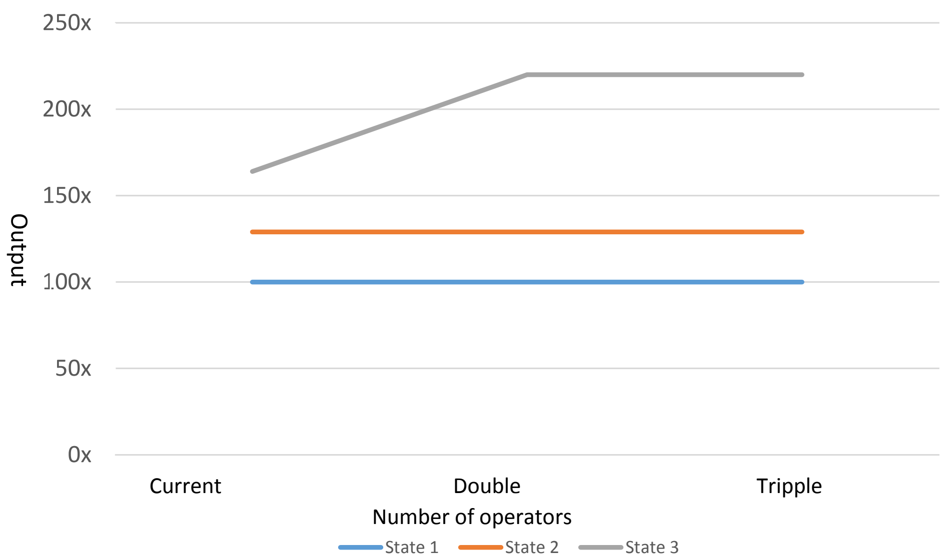

Figure 7.2: Visualization of the output from the production when increasing the number of operators. State 1 is for using the regular work hours, State 2 is for extending the work hours and using the weekends and State 3 is for investing in another bottleneck machine.

7.2.1 Increase capacity without investments

To increase the capacity by using the same machines that are available today and instead extend the working hours and increase the number of operators it is possible to increase the capacity to 129x according to the simulation results. To reach this capacity some operators must work during weekends to operate the bottleneck process. Since the bottleneck is running more than it was before it is also required that the buffer before the bottleneck is increased so that the bottleneck is not starved and can be fully utilized during the weekend. To reach the required buffer level another operator supporting the other operators is required. The waiting time should also be removed by combining level A and level B.

7.2.2 Increase capacity with another bottleneck machine

If there is a need to increase the capacity to more than 129x the only possibility is to invest in another bottleneck machine. If this investment is made the bottleneck would be moved to be the operators. In combination with investing in a new bottleneck machine, the number of operators would have to be increased. This is an expensive investment and a long term solution that could lead to an increase of the capacity of 220x according to the simulation. The capacity of 220x can be reached if the number of operators increases so that the operators does not limit the output of production. This output is possible with more operators when work is performed during business hours only. In the simulated production the operators will not limit the output of production, instead, it will be limited by Process 1.

7.3 Two bin kanban system

Implementation of a Kanban system is in general, not a difficult task. It is basically only to calculate the size and number of boxes required, mark up and put out boxes in production, inform operators and start using the system. However, for the analyzed company it is also required to make changes in the ERP system before the Kanban system can be used. Changes in this system should be made so that material is not picked from the warehouse for each order. Instead, there should be two bins in the local material storage. When one of the bins are empty it should be sent to the warehouse and be replenished. In the meantime, material from the other bin should be used for production as described in Section 6.3.

There are several things that must be made for the Kanban system to function properly. These are listed in the bullet list below.

- There should be a backflush inventory in the production area with the two bins so that the cost will be added when products are completed.
- Production structures must be changed so that the material that uses Kanban are not picked, and that the material uses the backflush inventory.
- When a bin is empty and sent to the warehouse to be replenished the operators at the warehouse should do an inventory transfer to the local material storage.
- The bins must be properly marked with component name and amount to be filled. It is preferable to have the bins in another color to separate them from regular material bins.
- When the bin is replenished it should be stored in the local storage and it should be made sure that this bin is not used until the other one is empty.
- It is required that the staff is informed about the system and that operators only use material from one bin at a time.

7.4 Kitting

When implementing a kitting system there should be a box with compartments that are suitable for the components. Two of these boxes have been created as a proof of concept, but should be more robustly made if used in production permanently. In order to pick the components in the order that they are assembled in, the components in the storage should be rearranged in the same order. An example of what this could look like is shown in Figure 6.2. This will make it easier for the operators to find the correct component faster and using less cognitive capacity. The operators were positive to the concept and used the kitting box. They said it was easier to find the right components and they could find the components without bending their back and neck as much which is preferable since it is a repeated operation.

8

Discussion

In this chapter, a discussion of the method used in the project is presented. The discussion also covers the simulation, data collection and software as well as generally about the project.

8.1 Method

The method that was used in the project was developed based on a combination of methods from the literature study, where VSM and DES were combined, and Banks model. The project plan was followed all the way through and worked well. To implement all proposed changes was not possible in the time of the project, but an implementation guide was developed so that it is possible for the company to implement the changes later. The advantages that were found from using VSM and DES in the same project is that DES can help to answer questions that VSM can not and that VSM can work as a conceptual model and lead the simulation in the right direction. The DES can for instance help to answer questions about capacity more accurately than VSM and it can tell more about the behavior of the system than is possible with the VSM.

One of the most difficult parts of the project was to collect numerical data, due to that production had not fully ramped up when the data collection was performed. The first processes that were timed had longer times than the later ones. Due to limited possibilities to collect data all data that was collected was used in the analysis.

To perform the VSM there was a need to make observations to create a picture of the flow, not base the mapping on the personnel's opinion. However, due to lack of production to observe the current state VSM, there was a need to partly rely on their opinions. To support the observations interviews were performed, these interviews gave a slightly different picture of the production from person to person. When the production was running normally any doubts could be adjusted. The current state VSM could have been performed smoother if the production would have been running in a normal pace. This is because it would have been easier to see the production flow from the beginning and we could have eliminated the part where we relied on the personnel's opinions.

8.2 Simulation

During the project, an idea of advantages and disadvantages associated with using simulation to analyze production was found. Some of the advantages with simulation is that a production can be tested over a long period of time, changes can be tested without any major investments and that it is visual which makes it easier for people that are not involved in interpreting the results. Compared to making manual calculations simulation also provides a time aspect. Negative aspects of simulation is that it is time consuming, the results are never better than the data and therefore there is a high demand for data collection.

There are more advantages with simulation the bigger the system is. For a complex system, it is very difficult or almost impossible to make calculation and estimation of changes in production manually. It is more difficult to determine what effect changes in one part of the process has on other parts of the process in a bigger system. Simulation is a powerful tool that can give any information about a production system as long as it is correctly coded. For a more simple system, the advantages are not as big since it is easier to make calculation manually for a more simple system. For a more complex system, on the other hand, it is more difficult to build the simulation model and especially to verify and validate the model.

In a major system when the production process involves several different departments that do not continuously communicate and understand each others system there is a risk of sub-optimizing the system. This could mean that one department is working to improve their processes, but a department later in the process is the bottleneck and the improvement does hence not give any benefits. By using simulation it is possible to communicate this idea so that resources to improve is spent in the best area.

In some aspects simulation is a tool that definitely should be used, but in some situations, the benefits are not as big as the cost and time required to build and analyze the process. Simulation should be used as a complement to verify changes before they are made. This would reduce the risk when implementing changes.

8.3 Data collection

When analyzing and observing operators there is a risk or chance of seeing the Hawthorne effect. This might lead to that operators are performing their work better and faster when they are being observed. This effect was not clearly seen during the project, but there is a risk that this could have had an effect on the results.

The number of samples for each process in the production differs because there are six processes where the process times were sampled and only two people to perform the sampling. This in combination with the irregular production made if difficult to sample all process equal amount of times. When the data was gathered the production was not running in regular pace and all the opportunities for sampling were used during the data collection phase of the project. The collected and analyzed data had a satisfying confidence interval and was used for the analysis.

8.4 Software

The software AutoMod that was used in the project was chosen because the authors had previously worked with the software. The time for finding another software and learning it was eliminated by using AutoMod. The software is complex which makes it possible to build and visualize any production system but it is also time consuming to implement all details for the system to accurately represent reality. If we would have performed the project again we would have done a research of which software that would be suitable. Perhaps a more simple drag and drop software are preferable for a future project at the company.

8.5 Production

The planning of the production is currently not as accurate as it preferably should be. The orders are finished later than planned many times. To escape this pattern the planning of orders should be evaluated, the orders should be started earlier because the lead time is often longer than expected. In case of an increment of the demand, the production might be able to handle this if the planning is done properly. This is because the orders often have a long time span before they has to be finished but the orders are started too late and are not finished in time. If the production is planned to be leveled the demand could increase without a need of investing in a new bottleneck machine.

The cost reduction for the implementation of the two bin Kanban system was estimated to be 84% for the material handling. The current cost is not completely known but the relation between the current and future could be estimated by computing the number of deliveries now and in the future state. Therefore the cost is not presented in money, but rather as a relation between the current and future state.

8.6 Implementation

During the project we have worked to implement our findings. A prototype of a kitting box has been made and used in the production. The operators were positive to the idea of having a structured kitting box and hopefully a more robust box will be manufactured and used in production. We also got the company to implement the proposed Kanban system in the production of another product. This Kanban system was implemented in the proposed way except for the Kanban box that were proposed to be used as a signal and sent to the warehouse to be refilled. Instead a digital request will be sent to the warehouse for a material transfer when a Kanban box is empty. Further the combination of level A and level B has also been implemented as we suggested.

8.7 Ethics, sustainability and secrecy

Ethics

When doing the quantitative data collection for this thesis a time study was performed. There was a risk that the operators in the production would feel monitored during the study. They might have felt a pressure to perform at their work and that they had to do their work in a strict manner. We have been clear with the purpose of the study which we believe reduced the operators feeling of being monitored. They have for instance informed us about things that they have noticed that can be improved which indicates that they do not mind the study.

Sustainability

The benefits with the improvement potentials that were found were discussed by the authors to find advantages and disadvantages with the different alternatives. To determine which improvements to implement an analysis regarding sustainable aspects were considered. Mainly social and economical aspects were seen to have a correlation with the improvements but also environmental aspect were considered.

Secrecy

Due to the secrecy of the project and the company, it was necessary to only present normalized data. This leads to that the results are at a bit more difficult to interpret.

9
Conclusion

– What is the current capacity of the production?
The capacity of the production is currently 100x when using current number of operators and the work is only performed during regular work hours.

– What can be done to increase the capacity?
With some improvements it is possible to get an output of 129x without any investments and only extending the work hours to cover the weekend. To increase capacity further than this an investment of a new machine has to be made. The capacity can then be increased to 164x, using regular work hours and same number of operators. It can be increased even further if the number of operators is increased. Then it is possible to reach a capacity of 220x.

The different steps in the simulation, Table 6.2, can be used by the company in the future in case of an increased demand. Depending on how big the increment is the company can see how much the production is able to produce. Further, the company can after the implementation analyze the production to find the next constraint if even higher capacity is wanted.

– What are the main benefits of using discrete event simulation when analyzing and improving the company's low volume production?
The main benefit of using discrete event simulation to analyze the company's production is that it is possible to determine the effect of a future investment to a relatively low cost. It is time consuming, but it provides possibilities to implement and test different alternative solutions without making any investments. For a future similar project we would recommend an analysis of what software is suitable for the company.

– What are the main benefits of using discrete event simulation in combination with value stream mapping when analyzing and improving the company's low volume production?
The main benefits of using DES in combination with VSM was that the two methods gave different perspectives of the production. The VSM will give a clear picture of the material flow and information flow which is important when constructing the simulation model. Further, the simulation model adds the time aspect into the picture to make it possible to analyze the production over time, not just in the precise moment as the VSM does. The conclusion is that the combination of VSM and DES enhances the analysis by complementing each other.

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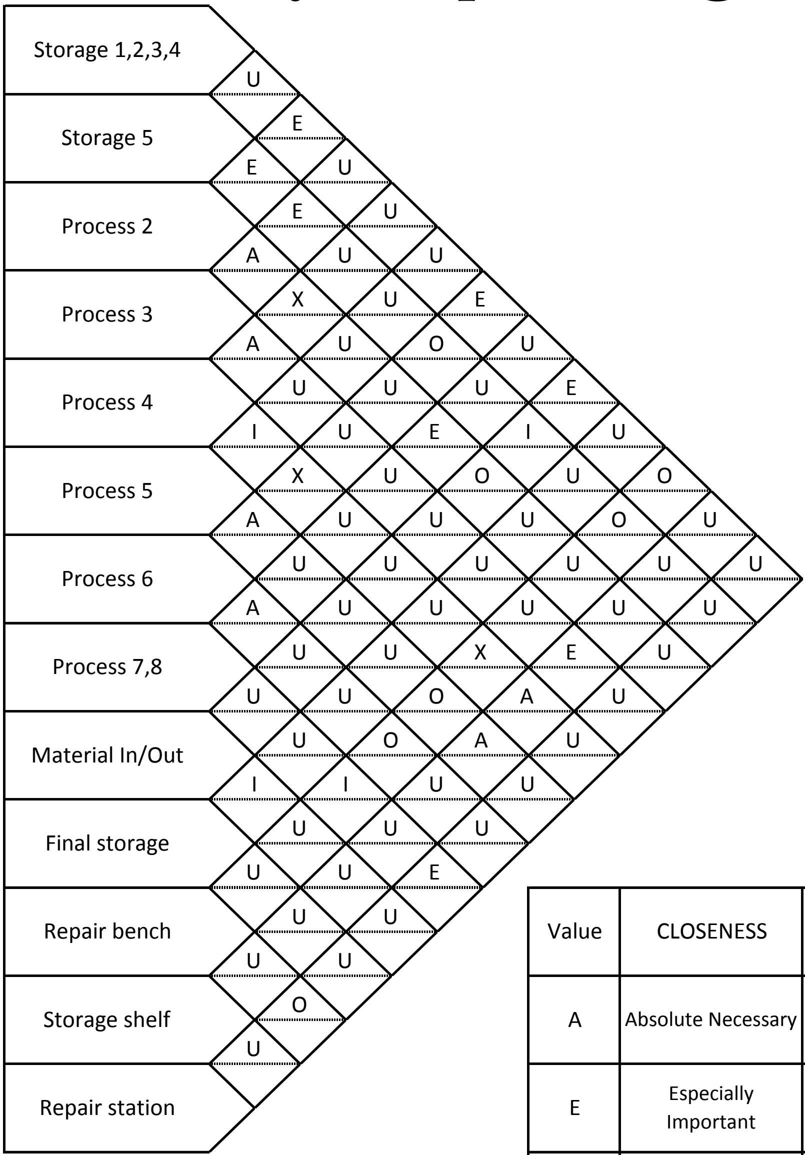
A

Layout planning



Value	CLOSENESS	No. Of Ratings
A	Absolute Necessary	6
E	Especially Important	8
I	Important	4
O	Ordinary Closeness OK	7
U	Unimportant	50
X	Not desirable	3

Figure A.1: Relationship matrix.

Table A.1: Requirement matrix.

Name	Area	Overhead clearance	Max. overhead sup. load	Max. floor loading	Min. column spacing	Water drains	Steam	Compressed air	Foundation or pits	Fire hazard	Special ventilation	Special electrification	Cold air
Storage 1,2,3,4	4	Enough as now	Enough as now	Enough as now	Enough as now		Enough as now		Enough as now				
Storage 5	1									A			
Process 2	2												
Process 3	2							A		A	A		
Process 4	2										A	A	
Process 5	1							A					
Process 6	4							A					
Process 7,8	2					A		A				A	
Material In/Out	3												
Final Storage	2												
Repair bench	2												
Storage shelf	1												
Repair station	2							A					A
Total	28												

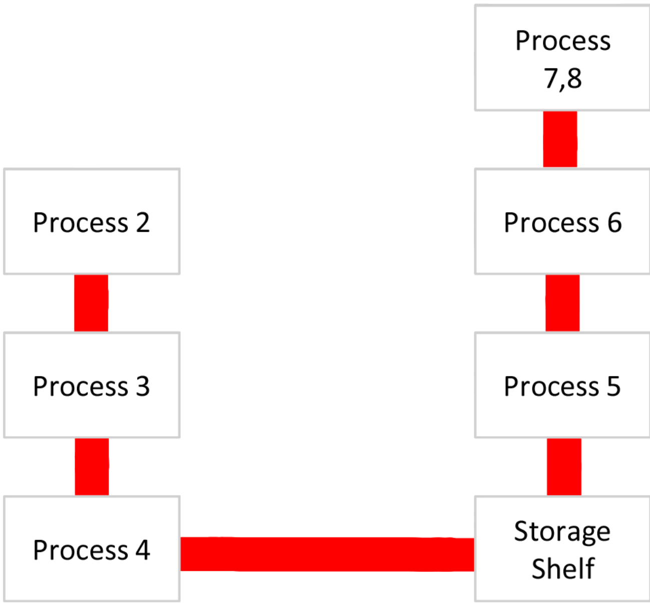


Figure A.2: Relationship diagram with all A connections added.

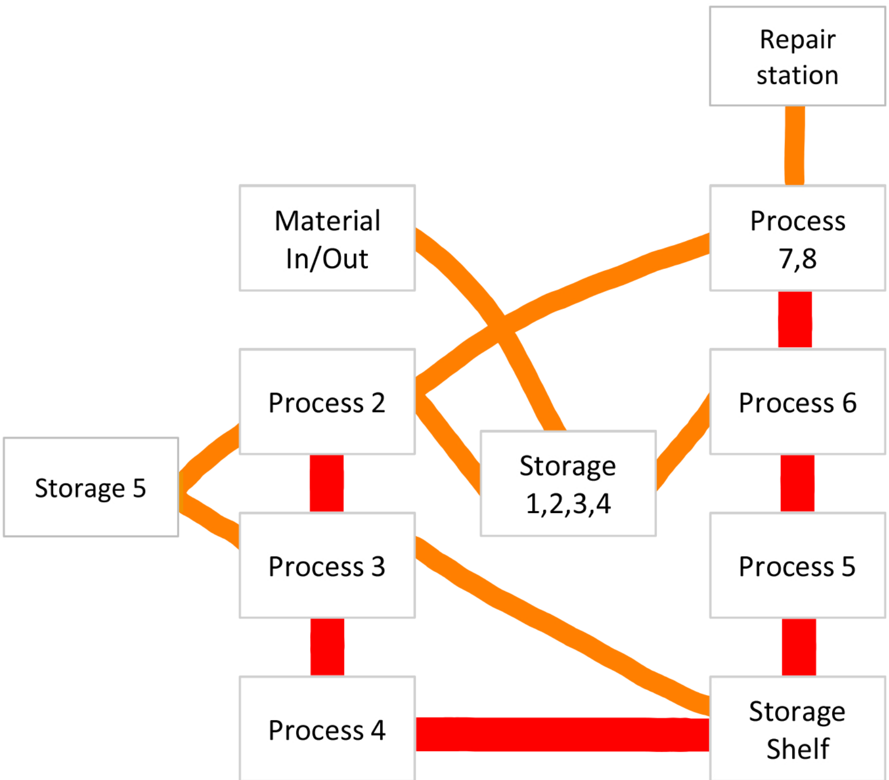


Figure A.3: Relationship diagram with all A and E connections added.

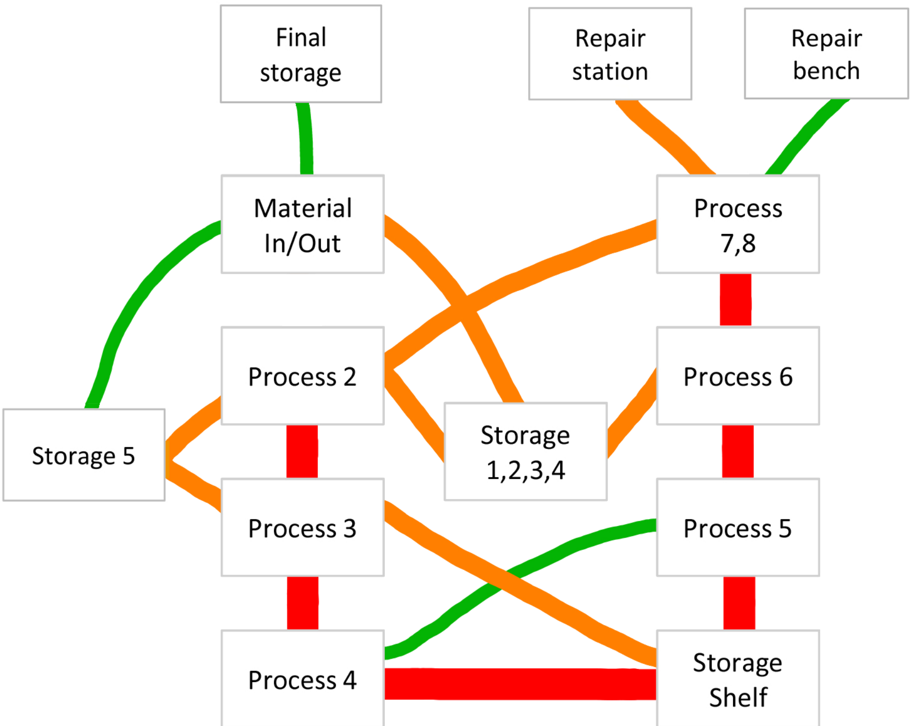


Figure A.4: Relationship diagram with all A, E and I connections added.

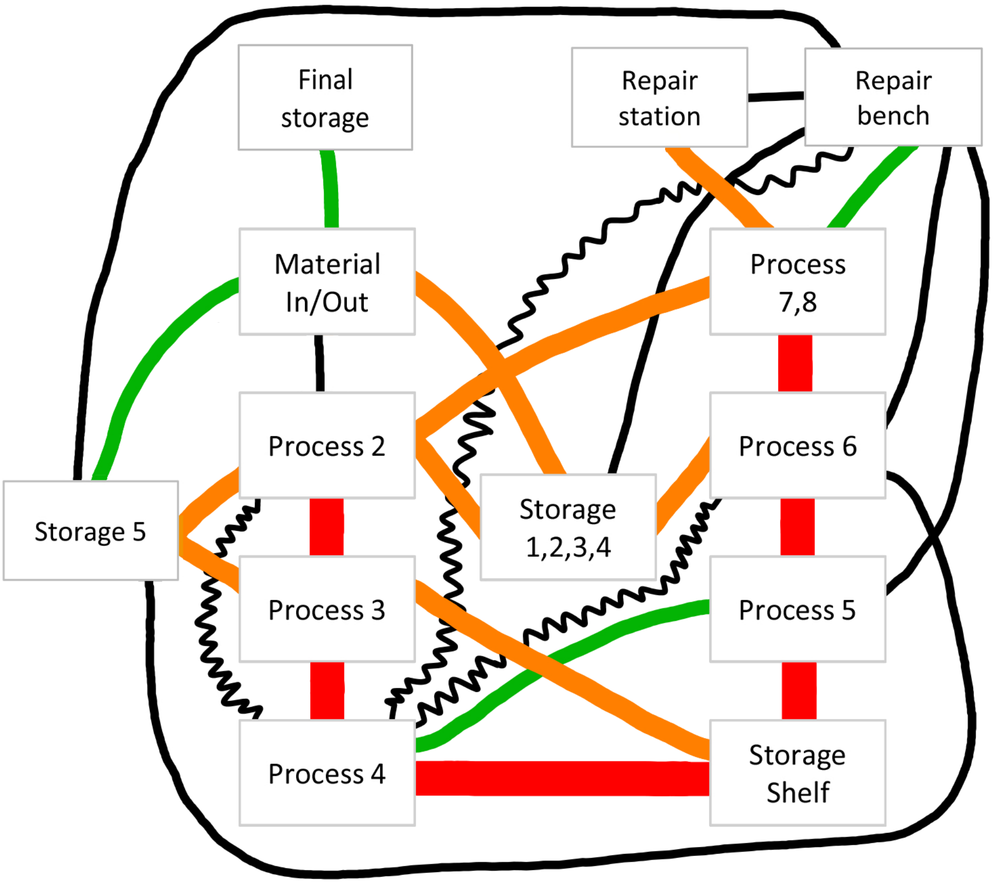


Figure A.5: Relationship diagram with all connections added, O=black straight line and X=black zig-zag line.

B

Layouts

In this appendix the produced layouts are shown. In the layouts the travelling way for material is represented with the lines and arrows.

Figure B.1: Current layout.

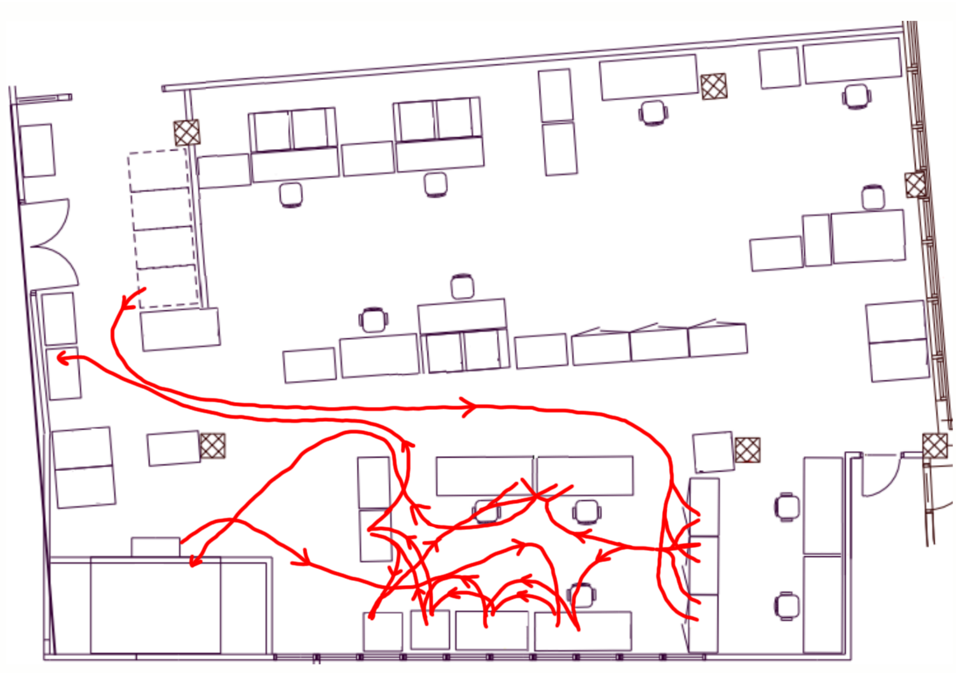


Figure B.2: First layout proposal developed by previous to the time of study, proposal A.

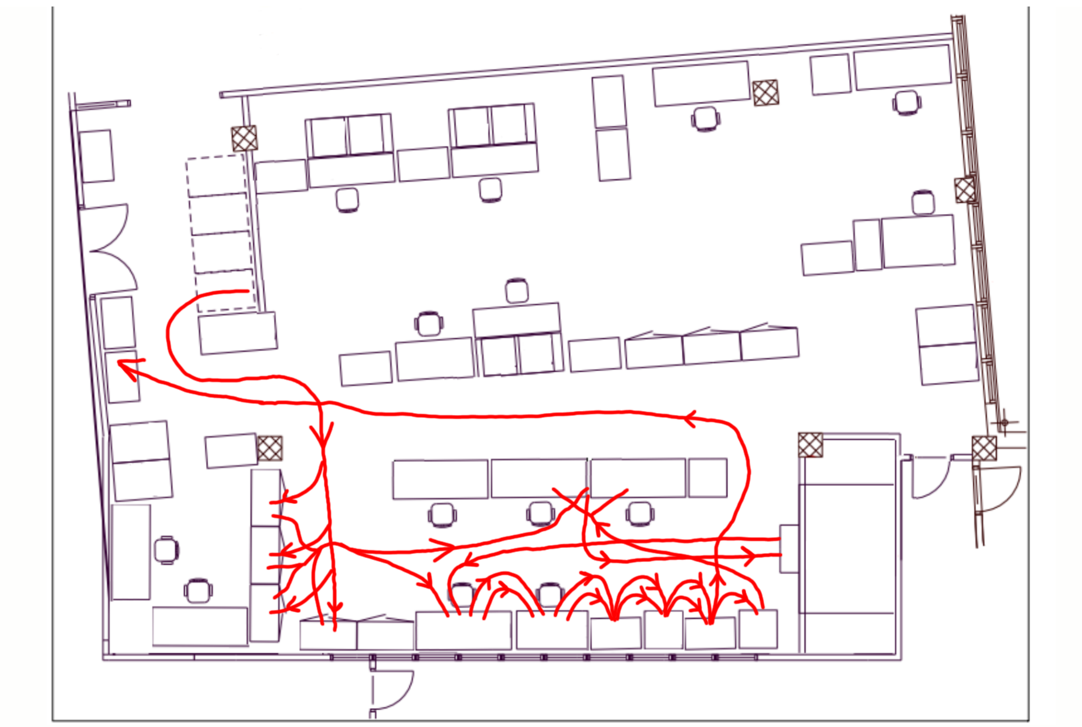


Figure B.3: Layout proposal B.

Figure B.4: Layout proposal C.

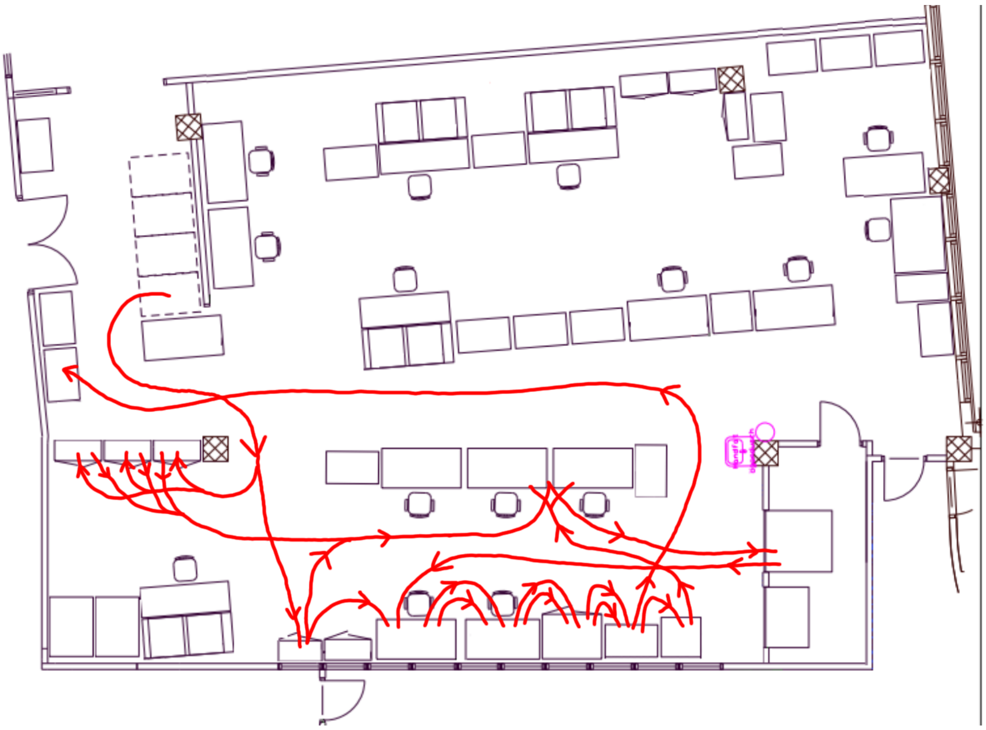


Figure B.5: Layout proposal D.

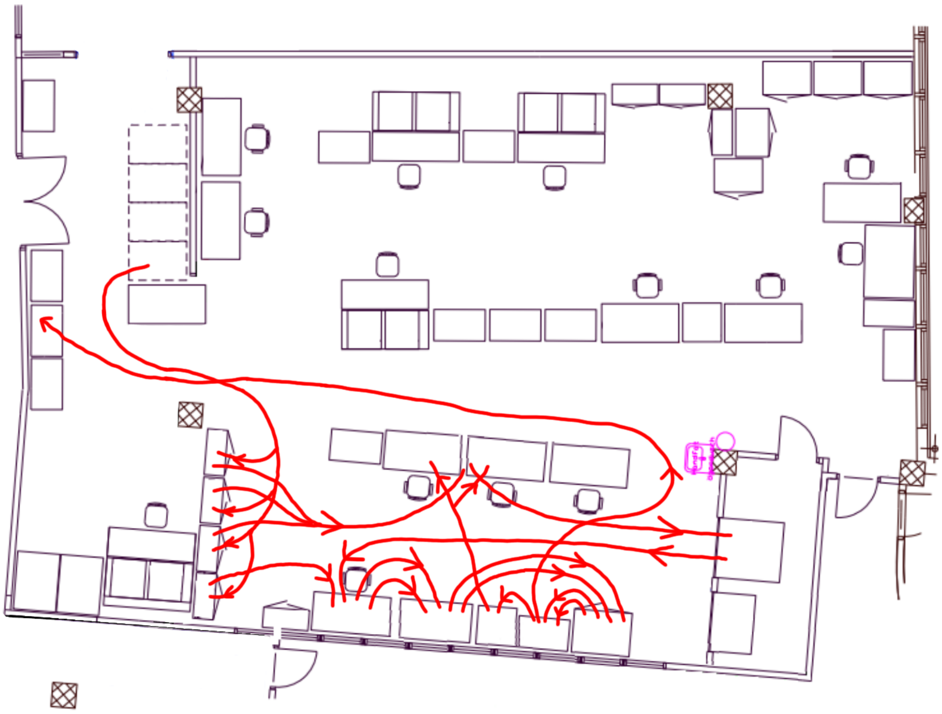


Figure B.6: Final proposal.