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Simulation and optimisation of a manufacturing process

A case study of a high mix and low volume manufacturing process at Atlas Copco

Axel Lund Borg

Högskoleingenjörsprogrammet i maskinteknik

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Abstract

Companies are constantly seeking new ways to increase their efficiency and flexibility to be able to meet the market demand, industry 4.0 has provided companies with new tools that enables them to better track the performance of a process and more easily optimise it. In a high mix and low volume manufacturing process a lot of inefficiencies are prone to occur due to the high variety. A simulation can be a very beneficial tool to use in the optimisation of a manufacturing process. In a simulation a digital twin of the physical process is constructed to replicate the real-world results, the simulation can then be used to test how changes to the process affects the desired performance objectives.

The purpose of this study was to use a simulation to optimise the process by increasing output and reduce lead time as well as increase the visual presentation of the process. The purpose was fulfilled by a review of literature on the subject, interviews, observations and a document study before a simulation model and value stream map was constructed.

The bottleneck analysis and the value stream map highlighted a few inefficiencies in the process that was solved by implementing a few solutions that would improve the balance of the process and increase output and decrease lead time. A visual presentation tool was also developed to calculate the expected lead time for a new order and show how the flow of orders would develop in the near future.

Keyword: Bottleneck analysis, simulation, value stream map, production management.

Teknisk-naturvetenskapliga fakulteten

Uppsala universitet, Utgivningsort Uppsala/Visby

Handledare: Andreas Axelsson   Ämnesgranskare: Morteza Ghobakhloo

Examinator: Lars Degerman

Högskoleingenjörsprogrammet i maskinteknik

Sammanfattning

Organisationer arbetar konstant med att förbättra effektiviteten och flexibiliteten i verksamheten för att kunna möta marknadens krav, industri 4.0 erbjuder företag en rad nya verktyg som gör det lättare att mäta processer mer i detalj och sedan optimera dessa för bästa resultat. I en produktion med en hög mix och låg variation uppstår ofta ineffektiviteter på grund av den höga variationen. En simuleringsmodell över den fysiska processen kan konstrueras att efterlikna produktionen och sedan användas för att se hur förändringar i processen skulle påverka förutbestämda mätparametrar.

Syftet med denna studie var att undersöka hur en simuleringsmodell kunde användas för att öka antalet producerade komponenter minska ledtiden samt ta fram en visuell presentation över processen. Syftet uppfylldes genom en litteraturstudie på ämnet, intervjuer, observationer samt en dokumentstudie innan en simuleringsmodell och värdeflödesanalys upprättades.

Flaskhalsanalysen och värdeflödesanalysen visade på ett antal ineffektiviteter som löstes genom att ta fram lösningar som förbättrar balansen i processen och ökar mängden producerade komponenter samt minskar ledtiderna. Ett visuellt hjälpmedel togs även fram som beräknar ledtiderna för varje ny order och visar hur flödet kommer utvecklas i närtid.

Nyckleord: Flaskhalsanalys, simulering, värdeflödesanalys, produktionsledning

Preface

This project is a bachelor's thesis at Uppsala University and conducted at Atlas Copco in Tierp.

The author would like to thank everyone at the factory for their kind welcoming and especially the supervisor of the project Andreas Axelsson for always having time to answer questions and bounce ideas. I would also like to thank Jonas Pettersson for providing the project with the necessary data and valuable opinions as well as Stefan Thoren who contributed by being interviewed. Last but not least I would also like to thank the subject reviewer Morteza Ghobakhloo for his contribution to the project.

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1 Introduction

Chapter 1 defines the problem and puts it in a wider perspective before presenting the purpose of the study and the questions.

1.1 Background

A company's profitability is in large part due to its ability to produce goods and services in an efficient manner. Efficiency means that an organization is able to use its resources in the most optimal way where manufacturing costs are kept low, the capital required for the process is minimal and the product spends as little time as possible in the process (Kullvén, 2022).

A common problem many companies within the manufacturing space has to deal with is the occurrence of bottlenecks which limits the produced output. A bottleneck is the resource in the system unable to produce goods at the same pace as the rest of the system, the consequences of this is expanding buffers and decreased capacity. An expanding buffer will increase the number of work in process, lead time and the capital requirements for the process. Finding the bottleneck in a process can be complicated as its occurrence may not be obvious to the observer, in a process with a high mix and low volume of components the bottleneck can shift over time, such a system is said to have a shifting bottleneck. One way to find the bottleneck of a system is to study the utilization rate of the given resource, if the utilization is above 90% of the capacity it can be seen as an indication that delays is to be expected since any disturbance can cause the resource to fall behind schedule. To mitigate this risk and reduce the bottleneck, the capacity of the resource can be increased, or the utilization lowered by outsource some work to a third party partner (Olhager, 2023).

A way to visualize the production process and more easily detect the bottleneck is to create a simulation model of the process containing the data for process time, setup time, availability and demand. The result of the simulation is the output the system is able to produce, variations over time, lead time and eventual backlog. With the aid of a simulation it is easier to test how different variables impact the result. Changes can then be made to certain parameters in the model to see how they will impact the overall system without the need to make any costly changes to the physical process. The results will be presented immediately and makes the optimisation of a manufacturing process a lot easier. A simulation model can also be used before designing a new manufacturing process, by using the simulation the capacity can be tailored to meet the requested output and management can avoid spending money on unnecessary equipment (Herps, et al., 2022).

1.2 Problem description

Manufacturing a high mix and low volume of components is challenging for every organisation, the great variety of components and the irregular demand makes the planning of production difficult, and many companies are forced to work reactively instead of proactively (source). The layout is usually constructed where similar operations are placed together and components will travel different routes through the system. Since there is not a clear path through the system it can be difficult to start work orders in an efficient manner, every component will have a unique process time for every operation which makes it difficult to predict buffer levels in the near future. A common problem in a high mix and low volume environment is that orders are usually started without consideration to how they would impact the current manufacturing flow and by introducing a new component to the flow a bottleneck might build up somewhere in the process and increase the lead time for every component. Providing the right amount of capacity for the process can also be challenging, because of the irregular demand the capacity for every operation fluctuates over time creating spare capacity in some areas and a shortage of capacity in others.

Atlas Copco's subdivision industrial technique sells and manufactures industrial power tools. The tools sold are among the highest quality on the market and every component has therefore been tested rigorously and manufactured to a very high standard in order for the tool to meet the requested quality standard. Almost every complex metal component in the tool is produced internally in the Tierp facility while most of the other parts of the tool are being sourced from a third-party vendor.

Given the complexity of a power tool the number of individual components is very high and the product mix produced in the facility is therefore of the high mix low volume characteristic. To work proactively instead of reactively Atlas Copco aims to produce components on a forecast, the forecast is based on the expected yearly demand for every component and used improve the planning of manufacturing and ensure that every component is always in stock. However, as unexpected demand creates shortages some components need to be started earlier than expected. Because of this the expected lead time for a new order is hard to predict once it enters the process and a priority system is used to let the most important components skip the queue.

As the demand has continued to grow, new investments have been made to create cells within the functional layout in a more "line like" manner. The goal of this approach is to shorten the lead times for the specific product family and create a better overview of the situation. The expectation is that if the process is closed off from the rest of the facility buffer levels can be more easily predicted and managed and thus reduce the lead time in the. The cell where this project has been conducted was constructed in 2018 and is called the 562 cell and has had a positive impact on operations with a decrease in lead time. But there's still some uncertainty regarding how much the system is able to produce with the given resources on hand and where the limitations of the system are. The construction of a simulation model and a visual presentation tool is expected to give an increased understanding of the system, increase the visibility of the process and generate improvement suggestions that will increase the number of components produced, reduce lead time and increase the capacity of the bottlenecks.

1.3 Purpose

The purpose of this project is to deliver improvement suggestions that will enhance the visual presentation of the process, reduce the lead time, increase the manufactured output and increase the capacity of the bottleneck.

1.4 Questions

1. Where are the critical bottlenecks within the system for the selected cell of this case study?
2. How can a visual presentation tool be used to increase the efficiency of the manufacturing process?
3. How can the improvements made be measured to have a positive impact on lead time, output and availability of the bottlenecks?

1.5 Delimitations

The project is limited to a certain cell in the workshop responsible for producing the angle changer components. The project is also limited to only evaluating how a simulation model can be used to improve the process and finding a tool that makes the process visually clearer to everyone working in the cell. Any potential improvement regarding process or setup time falls outside the scope of this project and will therefore not be pursued. In reality some of the components processed in the first operation leaves the cell for further processing in other parts of the facility and some operations assist other cells. Since it was regarded as too time consuming to evaluate every components influence on the process a limitation was set to only evaluate the components that goes thru every operation in the cell.

2 Theory

This chapter intends to cover the theory that is at the foundation of the project with the purpose to enhance the knowledge within the subject area and show what has already been done. The areas covered will be the different type of manufacturing systems, simulation modelling, the software Facts Analyzer and data collection.

2.1 Manufacturing layout

There's a number of different layouts a manufacturing company can use. The layout used depends a lot on the number of different components produced and the volumes of those components. The aim of every system is to have a short lead time and a high output of components (Kullvén, 2022).

Historically manufacturing layouts have been categorised into four different categories, fixed position layout, functional layout, cell layout and product line layout. A fixed position layout is beneficial to implement when the objects that's been processed is unable to move, the resources performing the operations will be brought to the object, the approach is generally used in the construction of large objects like a ship or a building (Huang, et al., 2006). In a functional layout every resource performing the same or very similar activity is grouped together, the approach is very beneficial in an environment with a large product variation and low volume. Since the components will take different routes thru the system the layout is very flexible in the way it can handle the variation that the product mix brings (Prince & Kay, 2003). A cell layout is usually used in combination with a functional layout, the cell will contain a few specific operations and is constructed within the functional layout. When the operation on the object is finalised, it will be sent to the next cell for further processing. The advantage of this approach is that the object doesn't have to travel a great distance between the operations and the lead times can therefore be reduced (Morris & Tersine, 1990). The last layout approach is called product line layout, the resources will be placed close together and the goods have to travel a minimal distance between the operations. This approach is commonly used in mass production where the volumes are very high and the product variations low (Slack, et al., 2013).

2.1.1 High mix low volume process

In an environment with a high mix of products and low volumes the flow of material will change a lot over time and thus be hard to predict (Svancara & Kralova, 2012). In such an environment companies can opt for a functional layout design. The shop floor will be divided into sections where one section is devoted to performing a certain activity. The different work orders will be sent to the next activity once they are completed. The uneven flow of workorders thru the workshop can lead to problems like shifting bottlenecks and large buffers unless the production is carefully planned (Zho, et al., 2023).

2.1.2 Bottlenecks

Bottlenecks is the resource in the system that will limit the flow of components, the bottleneck will therefore decide the pace of the whole system. Historically companies have studied the utilization rate, active time, buffer levels and shifting bottleneck analysis to detect bottlenecks and optimise them (Evoma, 2023).

The active time is defined as the time a station is either working, changing tools or is. In the calculation of a shifting bottleneck analysis the operation with the most active time will be the bottleneck, if two operations were to have similar active times they would be regarded as shifting bottlenecks. The availability of a machine can be a large contributing factor as to whether an operation is a bottleneck or not, the availability off an operation is the total time the machine is working and is limited by machine breakdowns and lack of human resources. The availability can be presented as an OEE number, OEE stands for overall equipment effectiveness and is a measurement of availability where the total scheduled manufacturing time is multiplied with the actual machine time and by the percentage of components that had to be discarded. Other important parameters to consider is the process time for every component and the setup time (Kumbhar, et al., 2023).

2.1.3 Buffer stock

A buffer is used to manage deviations and irregularities in the flow of components. If an operation is unexpectedly offline the following operation can draw work from the buffer and avoid pausing the production altogether. The benefit of a buffer is an increase in output and ability to handle unexpected problems, however with an increase of work in process the lead time for every order entering the system will increase. The buffer has historically been optimised by looking at changes in the buffer levels over time, if the levels are constantly on a high level the buffer is lowered to the point where the following operation will always have a supply of work (Olhager, 2023).

2.1.4 Kanban

The third major difficulty companies with a high mix and low volume manufacturing process faces are how to release work orders in an effective manner, since the order flow is very discontinuous high buffers can build if the planning isn't done carefully. The aim of every manufacturing process is to have a pull system in which the products produced are only the ones who customers are requesting, this is one of the most fundamental principles of LEAN (Kurilova-Palisaitiene & Poksinska, 2017). Traditionally a Kanban system has been used to create a pulling system, a Kanban system uses production cards that are being sent from the assembly line to the components workshop to tell what exactly needs to be manufactured to meet the demand, the system prohibits the release of workorders that isn't needed at the time in a bid to reduce the number of parts in stock (Sugimori, et al., 1977).

2.1.5 Takt time

Takt time stems from the german word "takt" which means beat, it was first introduced as a concept in manufacturing when the Germans started to use it to optimize their manufacturing of airplanes during the war. The idea is that every part of the manufacturing process should produce the same number of parts to meet demand and keep minimum buffer stock (Slomp, et al., 2009). Once the demand is sorted out for the given time period the takt is calculated by dividing the available machine time with the demand, the result is a maximum universal cycle time for the process that every operation must fulfill to meet the demand. The takt time should not be confused with cycle time since the cycle time is the time it takes to produce a part and takt is the maximum time allowed to produce the part. When implementing a takt time in a process one must make sure that the cycle time of every operation is lower than the takt even after adjusting for setup and downtime in order for the takt to work.

Takt time has become a popular tool to use for companies who are operating in a high-volume environment where setup time is usually lower and the demand is easier to predict (Tommelein, 2017).

2.2 Simulation

In a simulation a mathematical model is built up to replicate the reality, the simulation model can then be used to test how changes to the system will impact the end results without the need to try it out on the real process, therefore improvements and optimisation is easier to evaluate. Lead time, produced parts and work in process is some of the parameters that can easily be measured by a simulation model (Qi & Tao, 2018). There are different types of simulation models, the one presented and used in this report is called discrete event simulation (DES). In a discrete event simulation the model will change in discrete time steps, when an object is introduced to the system it will first be affected by the first activity, in the following time step the object will move to the next activity and nothing will happen between the time steps. As the simulation continues a visual is presented to show the observer how the system will change over time and also show how the changes made to the model will impact the different parts of the system. When developing a simulation model one has to first begin the project by defining the problem and present a thesis. The second step is to create a concept of the intended model and gather the relevant data, the quality of the data will be crucial for the accuracy of the model, without accurate data no improvements can be made since it will be impossible to validate the results. The last step is to build the simulation and validate it against the real-world results before the model can be used (Goti, 2010).

2.2.1 Facts Analyzer proffesional

Facts analyzer stand for “factory analyses in conceptual phase using simulation” and is a simulation software developed by Evoma. The software is built on a discrete event simulation approach where the user has to define every parameter that could have an impact on the model. The tool is used in the conceptual phase of factory design and for optimisation of a manufacturing process (Ng, et al., 2011). Some of the features includes bottleneck analysis, multi object optimization which is when the user can see what kind of solutions is required to achieve a certain capacity and cloud-based optimization (Evoma, 2023).

2.3 Value stream mapping

Value stream mapping is a LEAN manufacturing tool first introduced and used in the 1980's, it works like a flowchart where every step of the manufacturing process is documented and presented visually. The symbols used to visualize the process should follow a predefined form, to give the reader an easily understandable chart (Seth & Gupta, 2005).

A value stream map is divided into three parts called information flow, material flow and lead time ladder (Bragila, et al., 2010). The information flow is presented at the top of the chart and provides information regarding customer demand, planning control and supplier information. Customer demand is presented as the number of parts per a given time period, it also shows how often orders are being dispatched from the facility and what kind of forecast the customer use and how often they will place an order. The second part of the information flow section is called production control and is directly connected to the customer tab. The production control tells the reader what kind of system the organization uses to plan production and the forecast it uses to order raw material. The last part of the information flow is focused on the supplier of raw materials or parts depending on the business, the value stream map show the frequency of delivery and the quantity of parts delivered. The second part of the value stream map shows a detailed view of the flow of materials thru the process where painted arrows show the exact path for a given material. Every operation in the process is presented with the details regarding cycle time, uptime, setup time and shift information to give the reader an easy understanding of the capacity for every operation. The last part of a value stream map is called lead time ladder and can be found at the very bottom of the map, the lead time ladder will provide details of how long it takes to process the material in every operation as well as the time the material will spend waiting for the next operation. In the end the process and waiting time is summarised to give the total lead time (Kumar, et al., 2018).

2.4 Key performance indicators

Key performance indicators are used to gauge the performance of a business and should be well aligned with the business strategy and focused on measure the parts of the business that ultimately drive results (Ahmad & Dahfr, 2002). The overall goal is to better serve its market, the first step is to find an alignment between the requested performance and the operational performance of the organisation. Once an acceptable alignment is found key performance indicators can be developed. Every key performance indicator used to gauge the performance of an organisation stems from the five performance measurements, cost, speed, dependability, flexibility and quality that can then be broken down into smaller sub-measures. Cost could be further broken down into cost for raw materials, manufacturing, storage and shipping to easier see which part of the process makes up the bulk of the cost and find ways to optimise that aspect. The number of key performance indicators should be as low as possible but to the point where every part of the process is measured sufficiently (Ahmad & Dahfr, 2002). Introducing more indicators could prove beneficial to evaluate a certain part of the process and find the root cause of a problem. Studies have shown that introducing to many indicators is not time efficient and, in some cases, it could even lead to misperceptions (Sangwa & Sangwan, 2018).

Indicators used to measure a very specific part of the process is more affected by smaller variations and an outlier number would therefore have the potential to interfere with an indicator and cause a misperception of the situation.

3 Method

In this chapter the method for collecting and validating data is presented as well as the design of the study, the various methods for data collection will also be discussed more thoroughly.

3.1 Design of the study

To answer the questions of the study and fulfill the purpose, the approach has been thru a case study, empirical evidence has been collected and analysed to find solutions tailored to needs of the organisation (Säfsten & Gustavsson, 2021). The case study for this report is a high mix and low volume manufacturing process responsible for producing advanced metal components for industrial power tools, the study was carried out at Atlas Copco's Tierp facility and thus making it a case study.

To be able to answer the first questions of the study a deductive approach has been used where a thorough analysis of previous studies on the subject has given inspiration to some of the approaches used in this report. The layout of the project is presented in figure 1.

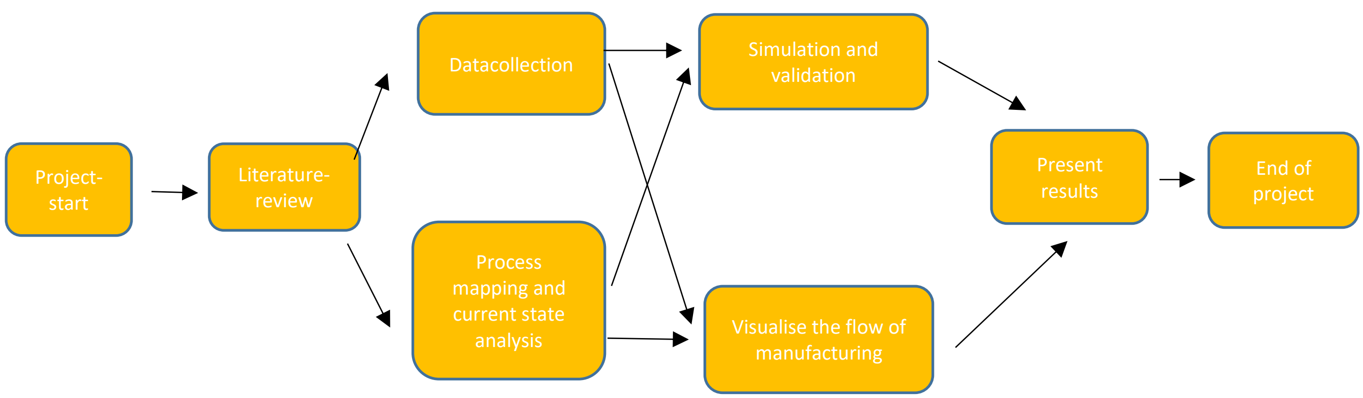

Figure 1: Illustration of the process steps.

The first question of this study is tied to a simulation model, a model was constructed to detect the bottleneck operations, the method was primarily quantitative with a lot of focus put towards finding relevant data regarding process time, setup time, lead time, availability and buffer level limits (Herps, et al., 2022). The relevance of the model is directly dependant on the quality of data used for the simulation, it was therefore extremely important to validate every data set. After validating the data and mapping the process the bottlenecks could be identified and optimised.

To answer the second question a greater focus was put towards finding qualitive methods like interviews and observations to create a current state analysis used to get a better understanding of the situation. By creating a detailed value stream map the result was used to

visualize the flaws in the current workflow and a new one was created to show how an improved version of the process could look like (Bragila, et al., 2010).
For the third and final question the literature review and interviews were used as the primary resource to find suitable key performance indicators. The indicators had to be able to measure the effects on lead time, output and availability for the bottlenecks (Sangwa & Sangwan, 2018).

3.2 Data collection methods

The techniques used to gather data is presented in the following section, a variety of data sources was selected to increase the understanding of the process and ensure a high credibility.

3.2.1 Interview

Interviews are a fundamental part of a current state analysis, by interviewing people from different parts of the organization one's perspective can be enhanced. Finding people with different tasks was crucial to get a nuanced picture of the situation and avoid getting just one perspective and narrative. Interviews is also a good complement to observations since the staff might have some knowledge about details that can be hard to notice. The data from the interviews have been very helpful when answering questions 2 and 3. The interviews were conducted at site and the conversation was recorded and transcribed afterwards. The interviews were structured in a semi structured way where questions were written beforehand and then updated based on the conversation that took place, the interview questions can be found in appendix 1.

3.2.2 Observations

To gain a bird's eye view of the layout of the facility and to answer question 1 and 2 observations was conducted. The data from the observations was validated by the supervisor for the project to secure its relevance.

3.2.3 Documentstudy

The majority of data used in this project is secondary data obtain by the company's OEE software, some of the data analysed was also obtained by staff manually. Every data set was thoroughly dissected before it was put to use. The data used in this project was process times, setup times, lead times, availability and buffer levels.

3.3 Data analysis

Data analysis describes how the collected data was sorted and used to find improvement suggestions for the process, the tools used was value stream mapping, qualitative data analysis and simulation.

3.3.1 Value stream map

After the data from the interviews and observations had been collected and compiled the material was presented visually in a value stream map to answer the second question for the project. In a value stream map every activity is presented visually and the relations between them is easier to see, it also gives the reader a clear overview of the process and can help spot inefficiencies in the process. (Slack, et al., 2013)

3.3.2 Qualitative dataanalysis

After collecting all the data for the study, a qualitative data analysis was used to structure visualise and finally draw a conclusion (Säfsten & Gustavsson, 2021). The approach requires that the first step data reduction is already present when one plan what kind of data to obtain to help structure the data in the right way from the start. The second step of the analysis is called data display, it means that the data that has been gathered is sorted after area and relevance with the purpose to make it easier to find the right material. To answer question two relevant data was presented in a value stream map. By presenting it visually it was also a lot easier to see if some area needed further data collecting. The last step of the process was to verify the data before making a conclusion and present the improvement suggestions.

3.3.3 Simulation

With the data from the documentation study and observations a simulation model was constructed using Facts Analyzer of the entire process. The model was based on data going back a year and could be verified by comparing the actual results with the results of the simulation. Once the dependability of the model was verified the model was used to find the bottlenecks of the system and later used to find ways to reduce the bottlenecks. The bottlenecks was detected by looking at the buffer levels, utilization rate and active time which is the time that the machine is either working, changing tools or is paused due to a break down (Evoma, 2023). Since multiple bottlenecks can occur in a system it is also of interest to make a shifting bottleneck analysis. The operation with the most active time will be the bottleneck, if more than one operation has periods where it has the most active time the analysis will show that the system has multiple shifting bottlenecks.

3.4 Validity and reliability

Validity for a study aims to ensure that the work that has been carried out have a high accuracy and dependability, this means that correct measures have been used and that the study have explored the topics it was set out to do (Säfsten & Gustavsson, 2021). Validity is usually divided into two different categories, internal and external. Internal validity tells whether the author has investigated what was intendent, in a study with high external validity the results of the study can be generalized and applied at other areas. To test the internal validity of the report the methods used have been discussed with the supervisor of the project to ensure the work is valid and moves the project in the right direction. By applying the triangulation method for data collection every dataset used has been validated by authorised personnel to ensure high validity.

Since this project is a case study where bottlenecks and suggestions of improvements are very specific for a particular manufacturing process the external validity of the project will be low.

A high reliability means that the data collection can be repeated by anyone with the same precision and achieve the same results. The data collection in this project has mainly consisted of interviews, secondary document data and observations. To ensure a high reliability every question can be found under appendix 1 and the answers can be found in chapter 4. The data from documents stems from the automatic system used by the machines to gather data, since it is an automatic system its regarded as very precise and its reliability is considered to be very high.

3.5 Ethics

The purpose of the study was designed and decided together with the supervisor for the project to ensure that every part of the project could be done in an ethical way. Every interview were recorded and transcribed and the respondent had to approve of the transcription before anything was used for the project, in accordance to ethics guidelines from Vetenskapsrådet (Vetenskapsrådet, 2017).

4 Company profile and operations

The following chapter presents the company, the product and the manufacturing process. Furthermore, a current state analysis is presented containing the in-depth explanation of every step of the process and an explanation of how the manufacturing is planned.

4.1 Company profile and market

Atlas Copco was founded in Sweden 1873 and started off by selling railroad equipment to the booming railroad market in Sweden under the name Atlas. As the years progressed the company kept innovating and increased its product offering by selling more advanced tools as well as diesel engines. Over the years the company have continued to grow into new markets and business segments and its products are being sold in 180 countries and employs 49 000 people with a total revenue of over 141 billion SEK. Today the company is divided into four divisions called vacuum technique, compressor technique, power technique and industrial technique.

The Tierp facility is part of the industrial technique division which manufactures power tools for industrial use, the factory is responsible for producing the most complex components of the tool and supplies both the assembly line in Tierp and the one in Hungary.

4.2 Product and processes

This project has been conducted in the components workshop in Tierp on the cell responsible for producing angle changer, the angle changers is divided into two categories called pinions and gears. Within every category there is a range of different components where the differences range from a tolerance measurement to geometrical differences. The number of components is 209 individual parts but some of them have been made for customized orders and are very unlikely to be produced on a regular basis. Some components also leave the cell for further processing elsewhere in the factory after the first operation which leaves 111 individual components in the cell for every operation.

Given that the mix of components is very high and volume low, the philosophy has been to adopt a functional layout for the facility. Within this functional layout separate manufacturing flows have been constructed in a cell like manner to reduce the physical distance a component has to travel in a bid to reduce lead time and create a simpler visual presentation of the manufacturing flow.

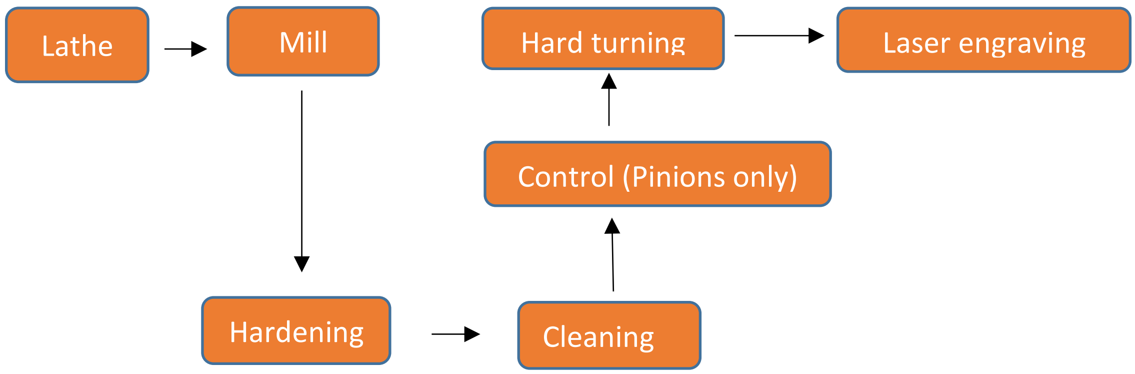

Figure 2: A simplified presentation of the manufacturing process

From figure 2 we can see that the manufacturing process is divided into six major categories, lathe, milling, hardening, cleaning and hard turning as well as a control station for some components.

4.3 Planning and priority system

To be able to meet the demand in a flexible way a safety stock of components is held to give the assembly line the flexibility to assemble every new order as quickly as possible. In periods off normal demand every work order released is based on a forecast to guarantee that the safety stock of components can supply the assembly line with the components required to fill every order. The planning department works with a cover time planning system which breaks down every order into the individual components and raw material needed for the job. Based on the given lead times the system calculates the time it will take to produce the order, the order with the longest cover time is usually the one started first. It is the job of the planning department to evaluate every new order and release it based on the importance of the specific part in terms of the value it will generate and the importance of the client who orders it. A less important part might sometimes be prioritised higher because the customer is regarded as more important and lucrative overall. It is also the task of the planning department to order the raw material and make sure that the inventory cover the needs of production. The forecast produced by the cover time system is shared with suppliers to give them a better understanding of the expected demand. When something is changed in the system it will automatically update every part of the system to keep the suppliers informed of the new situation. Most of the raw material is being stored at the supplier and then shipped to the factory every Monday and Wednesday to meet the demand for the given week.

The prioritisation of components is divided into four different categories, alarm 7,5,3 and components without any alarm. Alarm 7 is the most urgent one and is used when a part is completely out of stock and tied to a customer order, the component will skip the queue at every workstation to ensure that it is ready for assembly as soon as possible. An alarm 5 is used to ensure that the workorder is done by the end of the following week, the safety stock could be very close to running out or the components will be used in a larger upcoming order. Alarm 3 is the least urgent and is used to ensure that the batch is finished by the end of the month. Every time an alarm is used it disrupts the production flow and will have a negative impact on the other components, the alarms is therefore used carefully but in times of high demand they have become a necessity. When demand is higher than forecasted the workshop doesn't have the capacity to produce components on forecast but rather have to release a workorder when the number of components falls below the predetermined safety stock margin. The batch sizes used have been calculated using Wilsons formula (Olhager, 2023):

$$Q = \sqrt{\frac{2 * K * D}{G}}$$

Equation 1: Q = Optimum quantity of every order, K =Cost of each order, D = annual product demand and G =storage cost of each unit.

Every batch size is predetermined and cannot be changed, the decision is founded in the notion that a divided batch size would create more setup time overall to produce the same number of components, since setup time is a non-value added activity, the company aims to keep it at a minimum.

4.4 Process steps

When a work order is put into production it has to be transmitted into the system at least 24 hours before its intended to start, this gives the tools department enough time to prepare the drawings and put forward the right tools needed for the job. The operator then walks over to the tools department to collect a box with the tools and drawings before they walk back and start the set-up process for the machine.

4.4.1 Lathe

The first workstation in the production flow is the Lathe operations, it consists of four individual machines each capable of producing the same parts. The raw material transforms from a raw piece of metal to the general shape, after completion the batch is sent to the gear cutter operations.

4.4.2 Milling and hardening

The buffer capacity for the gear cutter operation is limited to 90 production hours to keep the lead time from escalating, this measurement isn't always obeyed and data from last year showed that the actual level was in the range of 144-48 manufacturing hours. The part will be further processed to get the correct cogs, the process is carried out by two machines that are built to process either the gear or pinion components. After completion the batch will be sent off for hardening and cleaning in another part of the facility. The hardening is usually done within 48 hours, except for a few parts who needs a special type of hardening done in Finland, those usually take two weeks from the time they are shipped to the time they arrive back at the facility. The cleaning operation is on average processed in half a day. Once the hardening and cleaning process is done the parts are being sent back to the 562 cell for the final operations.

4.4.3 Hard turning and laser engraving

The hard turning operation is done on the part to get the precise and exact tolerances required, simultaneously as the operator operate the machine a quality check is conducted on the pinion parts and the laser engraving operation is performed. Two machines are placed here as well, as with the gear cutter machines one machine is designed to manufacture the gear parts and one is designed for the pinions.

4.4.4 Staffing

The shifts are divided into two parts where some work a 3-shift system where the machines are being operated 24 hours a day for five days a week and a 2-shift system where staff is on hand to operate the machines from 05.48 until 23.06 five days a week. No specific breaks exist, and the employees are encouraged to take a lunch break whenever it fits without interrupting the manufacturing. Information regarding shift times can be found in table 1.

Table 1: Shift information

Evening shift		**Dayshift**			**Night shift**
Mon - Thu	Fri - Sun	Mon - Thu	Friday	Sat - Sun	Sun - Thu
14.18 - 23.06	Free	05.48 - 14.30	05.48 - 13.54	Free	22.48 - 06.06

Every machine is operated by one person at the time, some of the staff have the knowledge to operate more than one of the machines which enables more flexibility in case someone is absent. In case staff is missing due to illness or on leave the teamleader for the shift is responsible for the reorganisation of staff, the goal is to give the operations with the largest backlog the best resources for that given day.

5 Result and analysis - Simulation

In this chapter the data used for the project is described in detail and explained, the simulation model is presented together with some suggestions for improvements for the physical process.

5.1 Data analysis

The first part of chapter 5 intends to cover the results of the data collection and explain why certain decisions was made regarding the data points used and how they likely affected the result.

At the beginning of the project the different data sets required for the job was discussed and divided into three categories, manufacturing data, data from planning and production control and additional data like the layout of the facility.

5.1.1 Manufacturing data

For the manufacturing data the requested datasets are process time, setup time, availability, mean time to repair, lead time and demand. Every datapoint was obtained from the company's own OEE software where everything is logged automatically, every activity is measured and categorized. The company have another set of documents containing the data for process and setup time that was analysed as well. However, these numbers were obtained when the parts were first introduced, and improvements have since been made making the data inaccurate for the time being. After validating the data with the supervisor for the project the OEE data was considered the optimal one to use and has therefore been the only manufacturing data used in the project. Together with the supervisor for the project an initial decision was made to limit the project and therefore only perform a simulation of a selected set of products, due to the high mix and low volume characteristic of the process a simulation containing every component was regarded as unnecessary. Using the yearly forecast a table was created and ranked based on the volume of every component.

In table 2 the yearly demand for every component in the cell is presented, the top 10% of components (marked in red) constitutes 48% of the total yearly volume, the top 20% of components (marked in black) is responsible for 72% of the volume while the bottom 50% only make up around 8% of the volume produced in a year. To make the model as close to reality as possible the top 20% of components were selected.
Process time and uptime data was easily obtained from the OEE software, the setup time was calculated by dividing the total setup time for the year and divide it by the number of setups. The mean time to repair was calculated in a similar way where the total time the machine was stationary got divided by the number of stops. The mean time to repair was calculated in a similar way where the total time the machine was stationary got divided by the number of stops.

Table 2: the total operations time for the top 20% most produced components

Material number	Operation time (hours)
4220356830	1407,52
4210385815	1324,87
4210249050	1211,37
4220097735	1141,53
4210385938	1055,44
4210385926	999,725
4220356935	996,25
4210067541	951,72
4220350235	872,313
4210246320	842,571
4220087235	762,917
4110092903	729,253
4220110137	693,08
4220362635	626,1
4210067545	603,963
4210067548	596,547
4220337635	592,178
4220110238	591,517
4220319535	536,708
4110145803	497,702
4210385835	444,289
4150179800	435,161
4220083735	376,043

5.1.2 Planning and production control data

To answer the second problem of the project a value stream map was chosen to visualise the process. To conduct a value stream map one needs to have data for every part of the process including information about the system used for planning, forecast from customers and suppliers, shipping schedule and manufacturing data.
The data was gathered from structured interviews with the manager of the planning department.

5.2 The simulation model

The simulation model for the project is presented in figure 3, the model is intended to replicate the actual results from 2022 to simplify the validation and ensure credibility. The hardening and cleaning operation is done outside the 562 cell together with components from other parts of the facility, because of this the actual buffer levels and process data for the operation is outside the scope of this project. The operation is therefore replaced by a buffer that mimics the time it takes before the component is back in the 562 cell.

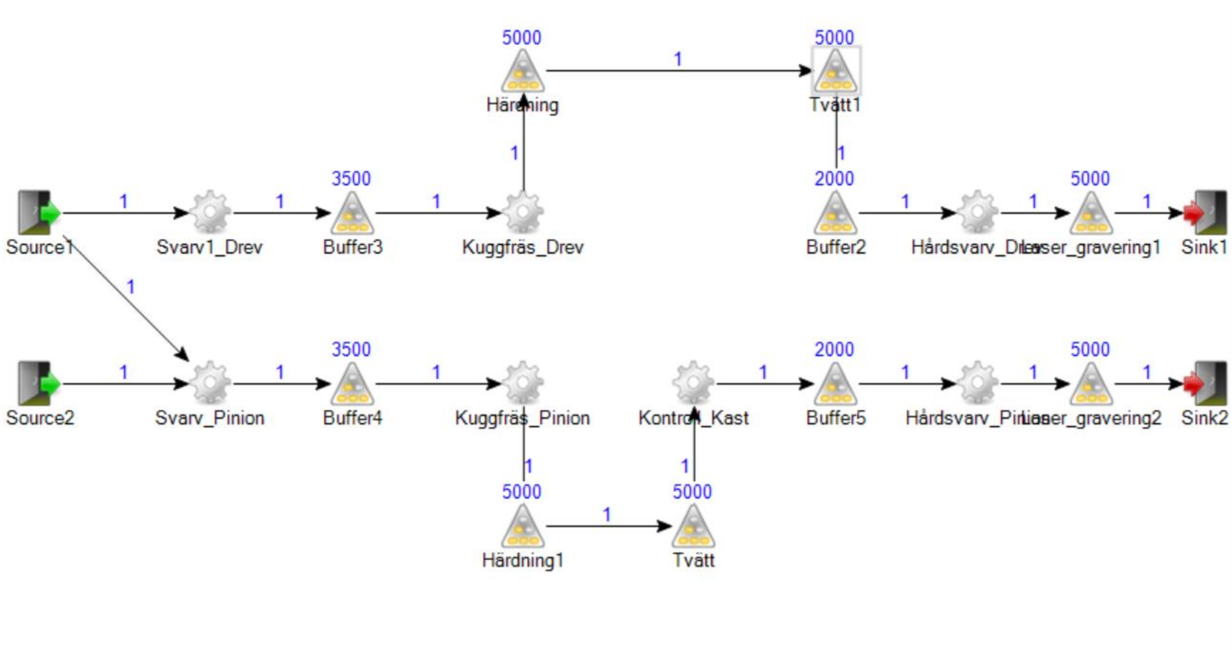

Figure 3: The simulation model of the cell

A comparison between the results of the simulation and the result from last year is made in table 3 and shows that the number of components in the simulation corresponds well with the real-world results. The lead time for the gear components is also within the expected error margin for the model.

Table 3: The simulation results compared to the real-world results for 2022.

	Parts produced	**Lead time**
Gear components	49 185	40.7 days
Pinion component	96 554	6.1 days
Data from last year: Gear	52 029 (+940 discarded)	38 days
Data from last year: Pinion	94 786 (2 477 discarded)	38 days

When comparing the results of the model to the actual results for the process one can see that every measured output variable corresponds well with reality apart from the lead time for the Pinion components. The availability data used for the simulation is an average over the last year, if one were to study the data closer it would become evident that the availability fluctuates a lot over time. The fluctuations cause buffers to build which means that in reality the buffer utilization curve isn’t as smooth as figure 4 and 5 shows, over the year the buffer levels was in the span of 144 to 48 hours in process time for the milling operations and between 190 and 48 hours in process time for the hard turning operation. When the data was averaged it gave the false notion that the system was well balanced, and the buffer utilization were therefore inaccurate.

The hardening and cleaning operations were substituted for a buffer instead of an operation, since those operations were conducted outside of the cell in which this project is carried out, they lacked sufficient data regarding buffer levels and availability. The most realistic approach was therefore to model them as a buffer that released every component after 48 and 12 hours respectively which is the average time it takes for the operations to be completed. For the last operation in the cell, laser engraving, a buffer had to be added that held the components for approximately 48 hours. This was done due to the fact that the real world results showed that components spent an average of 48 hours between completion in the hard turning operation and the laser engraving operation. According to staff at site this number could be misleading due to the fact that some operators might not report it immediately upon completion but rather do it later and therefore create a false lead time. To adjust for this eventuality in the model the median time was selected instead of the average value to cancel out any potential mistakes made by the operator.

Figure 4 and 5 shows how the buffer levels for the mill and hard turning operation developed as time progressed. No figures are provided for the buffer levels over the pinion components, since the lead time for those components were deemed inaccurate any presentation of the buffer levels wouldn't add any value to the report.

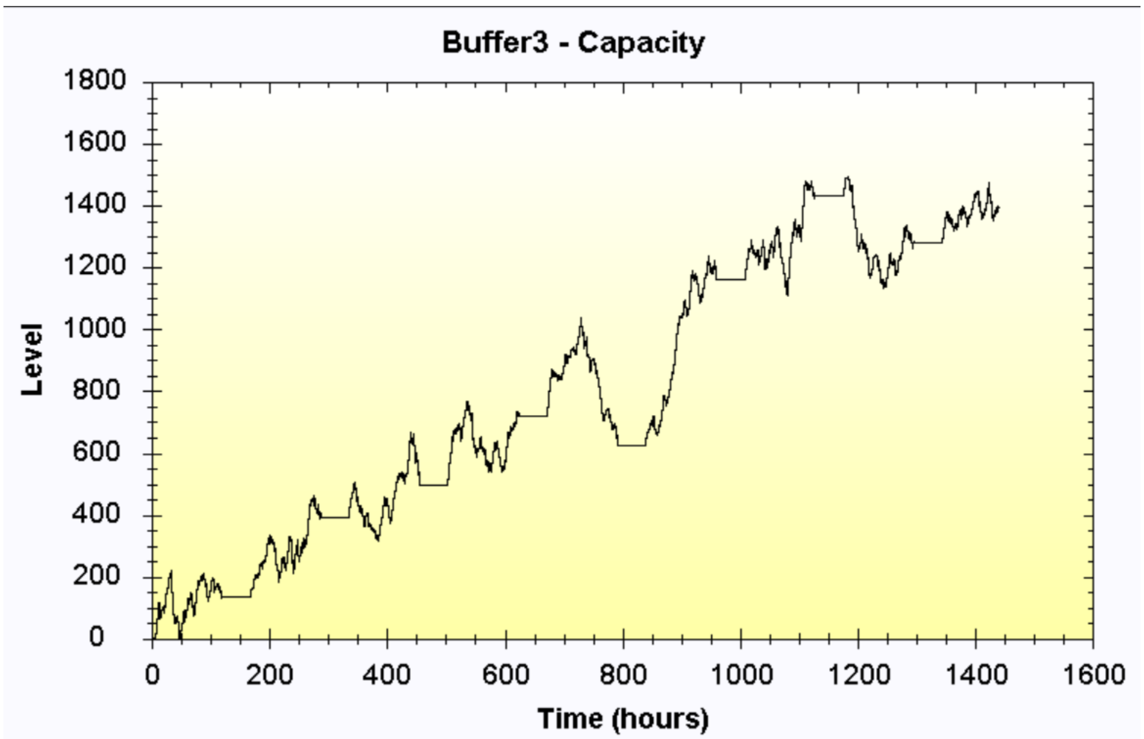

Figure 4: Presentation of the buffer levels before the milling operation for the gear components as time progressed.

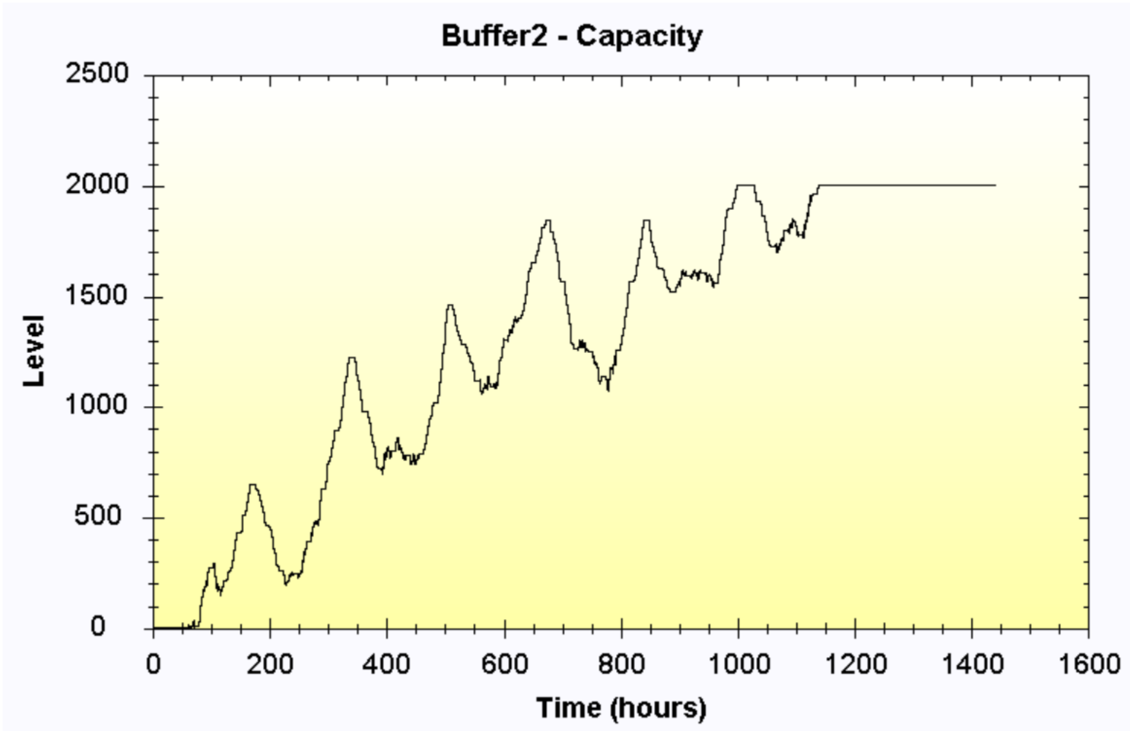

Figure 5: Presentation of the buffer levels before the hard turning operation for the gear components as time progressed

Initial tests of the model showed that the buffer levels kept rising as time passed for the gear components. Since the simulation was more prone to operate at or close to a full buffer level utilization the buffer limits in the simulation were based on the average levels to get the most accurate description of the process. Finally, a shift table was inserted into the model containing the shift times available in the company's database.

5.2.1 Validation

The most important thing when conducting a simulation is to ensure its credibility before it can be used to find improvements. Once the model was operational the first validation method was to compare the output and lead time of the model to the actual results from last year, when the results came close enough staff was asked whether the bottlenecks in the model were realistic. The final step of the validation process was to compare the active time of every operation to the active time obtained from the OEE data.

5.2.2 Bottlenecks

In figure 6 and 7 the primary bottleneck of the system is the Lathe operations for both the pinion and gear components. For the gear components the hard turning operations is a major bottleneck as well and the milling operation is a shifting bottleneck. For the pinon process the lathe operation is the bottleneck almost 70% of the time and the milling operation is an shifting bottleneck 20% of the time. This corresponds well with the staffs view of the bottlenecks in the actual process.

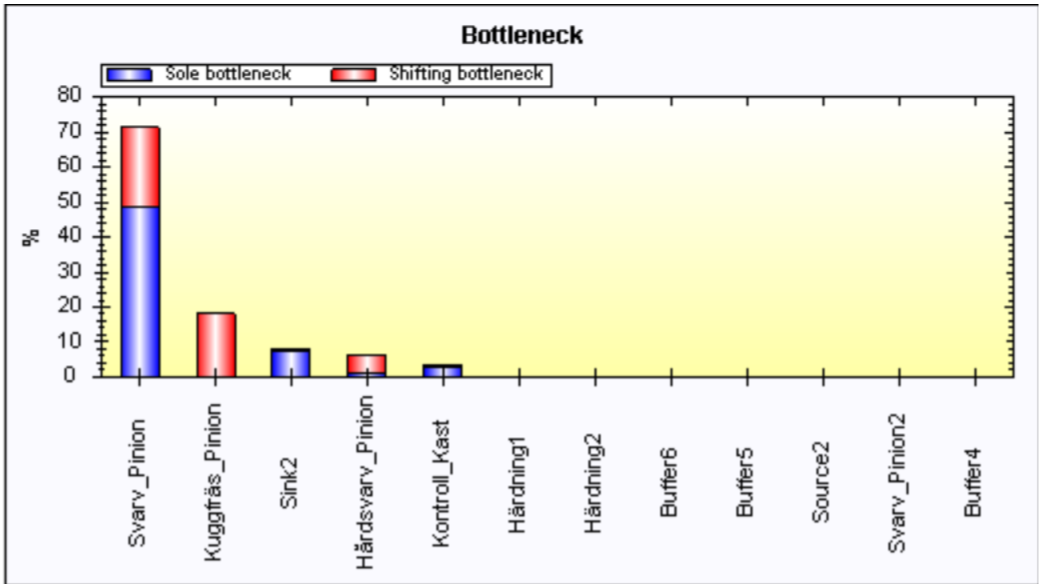

Figure 6: The shifting bottleneck analysis for the pinion components

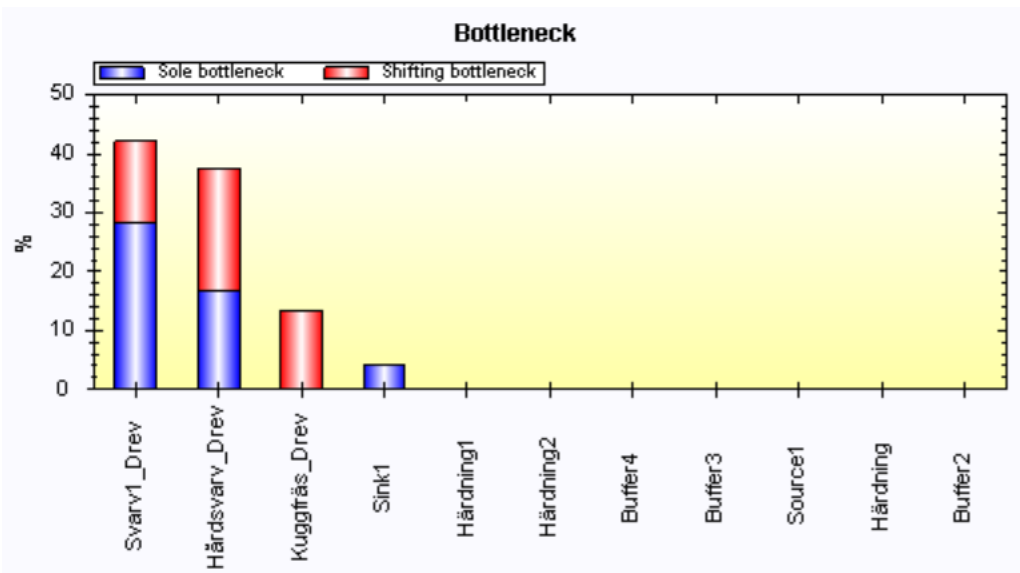

Figure 7: The shifting bottleneck analysis of the gear components

5.2.3 Improvement experiments

Experiments were performed with the model to generate improvement suggestions, the result was six potential improvements that would either generate an increased amount of components produced or a decrease in lead time for the system.

5.2.4 Improvement 1

The OEE software provides a good explanation as to why the machine has been stationary and for how long, the various reasons are presented in a list and a figure to show how much of the down time the various reasons make up. One of main reasons for stationary machinery is the lack of staff due to sickness or leave, when a shift is short of staff the idea is to relocate the human resources based on which operation has the biggest backlog. However, some staff doesn't have the knowledge to operate more than one of the machines, the production process will therefore be out of balance and buffers will expand. The simulation shows that by educating more operators how to operate more of the equipment in the cell, output could be increased, and lead times would decrease. In an optimal situation the right allocation of staff could increase the number of gears produced by 10% while the lead times would be cut in half, the same approach would also increase the number of Pinions produced by around 5%.

5.2.5 Improvement 2

On a yearly basis the 562 cell loses almost 3000 hours due to absent personal, this loss accounts for roughly what two employee's contribution are over a year and thus make it profitable to hire at least two new employees. In reality the sick leave would not be spread out evenly throughout the year, on occasion more than two could be away on the same day and everybody can be present at the same time. On days with an overcapacity of staff other tasked could be performed like preventative maintenance.

5.2.6 Improvement 3

Figure 4 and 5 showed how the buffer levels developed over time, the simulation software was used to optimise those levels based on two parameters, maximise output and minimise buffer levels. Experiments were conducted were the availability levels changed between the simulations to better mimic the actual process.

Table 4 shows the optimal number of components for every buffer. When translating the new buffer levels to lead time the simulation shows that the lead time could potentially be as low as 25 calendar days and still be able to produce the same output as it does now. In reality however such a small buffer for the milling operation wouldn't be possible since some batch sizes are larger than 500 pieces, allowing just one or a few smaller batches in the buffer would also make the process vulnerable to disturbances in the lathe operation. If the lathe operation is forced to stop due to an unforeseen reason the milling operation would very soon run out of work and be unable to supply the hard turning operation and thus lower produced output. It would be more beneficial to put the focus on optimising the hard turning buffer since its almost a big of a bottleneck as the lathe operation.

Table 4: the optimal buffer levels obtained by the simulation software.

	Milling buffer	**Hard turning buffer**
Standard setting	510 pieces/13 hours of process time	1850 pieces/70 hours of process time
Increased Lathe availability	500 pieces/13 hours of process time	2075 pieces/74 hours of process time
Increased mill availability	340 pieces/8,5 hours of process time	2620 pieces/93 hours of process time
Increased hard turning availability	270 pieces/7 hours of process time	930 pieces/33 hours of process time

5.2.7 Improvement 4

In figure 8 and 9 we can see the capacity utilization for every operation, the green area of the bar represents the time the machine is working, red bar is the stationary time and the yellow section is the time were the machine is prevented from operating due to a full buffer ahead. The blue bar named “unplanned” represents the time a machine isn’t working due to a weekend or the absence of a third shift. In times where the operation is prohibited from producing the spare capacity could be used to manufacture other components in the workshop. The first lathe operation in the process is very flexible in the way it can produce a lot of various components for other cells within the facility. Sharing some of the capacity would be very beneficial for other parts of the facility and doing so wouldn’t have a negative impact on the total output for the 562 cell.

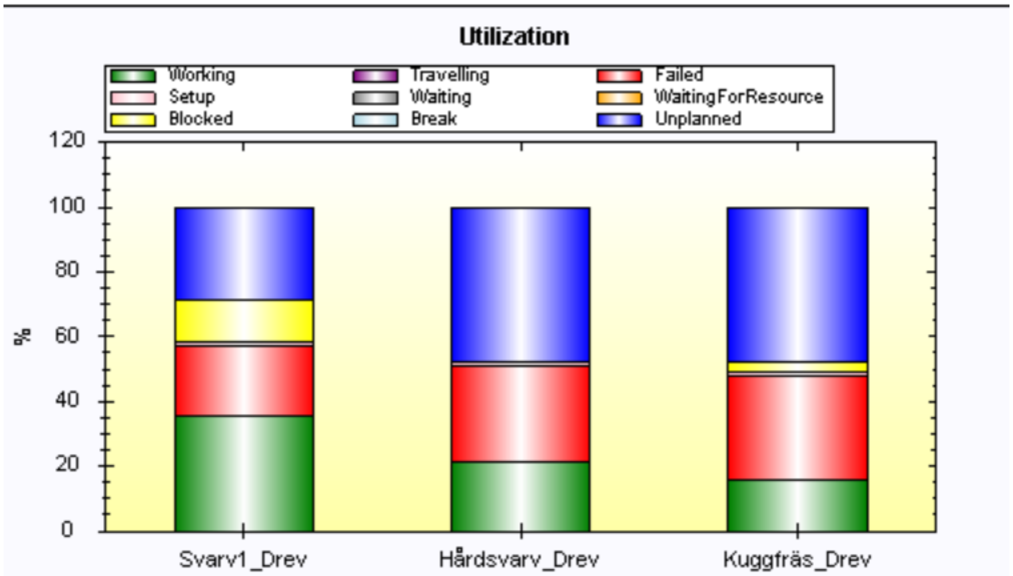

Figure 8: Utilisation for every operation in the gear process

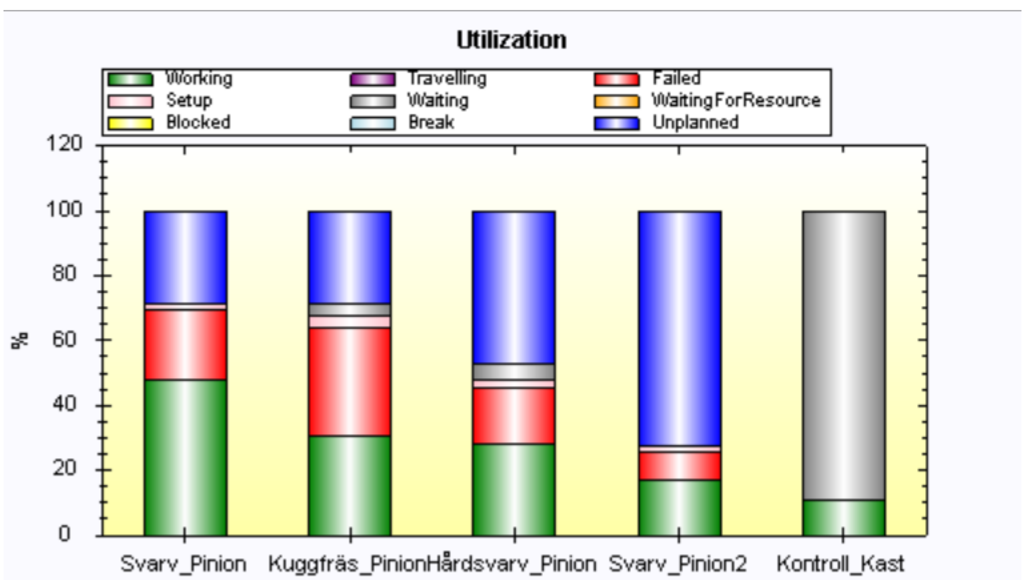

Figure 9: Utilisation for every operation in the pinon process

5.2.8 Improvement 5

Furthermore, the simulation model was used to see how an increase in capacity would impact the process. It showed that an extra shift on the hard turning operation for the gear components would have yielded an increase of 26% of produced parts and reduced the lead time with 40%. While the numbers look very promising one of the main obstacles would be to find competent staff willing to work the extra shift. The subject was brought up in interviews with the supervisor who stressed how hard it is to find suitable staff at the moment, however an extra shift would be possible for a limited amount of time with the manpower they have now. An extra shift for a period of time when demand is increasing could still be very profitable and easier to implement rather than adding a full extra shift. Given that the lathe operation was the clear bottleneck for the pinion components an increase in machine time would increase the output for the process. Without increasing the availability or machine time for the other operations a further 1 000 lathe hours would improve output by 19%. 1 000 hours wouldn't justify a new investment however, as seen above in figure 9 the previous suggestion there's some overcapacity from time to time within the cell that could be used. There's also a strong possibility that other cells might have a similar situation, capacity could therefore be sourced from other parts of the facility to increase output without the need for further investment.

5.2.9 Improvement 6

When a workorder is put into production the batch size is predetermined using Wilson's formula, the formula aims to provide the most economically beneficial batch size. The system is very useful when manufacturing is based on a forecast since there is no risk that the safety stock will run out. However, the strategy becomes less efficient in periods of high demand were the safety stock of some components run out before the planning department has time to start the workorder. A reduced batch size would enable a higher flow of components to be manufactured and therefore make it easier to produce a higher variety of components within the given timeframe. The simulation model was used to see whether the batches could be made smaller without losing any output. The results showed that batches for gear components could be decreased by 20% and still be able to produce the same number of components, for the pinion parts a 10% reduction would still produce the same amount of components and a 20% decrease would lead to a decrease in output by 1.5%, any increase in batch size gave no increase in output. The result was a bit of a surprise since any reduction in batch size would lead to extra setup time that would limit the process time and thus produce fewer components. A further analysis of the formula was conducted which showed that the setup time used for the calculation were most likely based on inaccurate data. The simulation was created on the data obtained from the OEE software compared to the manually measured data compiled in a separate document and used for the calculation.

6 Result and analysis – Visual presentation tool and key performance indicators

In this chapter a current and future state value stream map is presented containing improvement suggestions for the manufacturing process, a visual presentation tool purposely designed for the organisation is also presented. At the end of the chapter a new set of performance key indicators is put forward to ensure that the prospected improvements generate actual value for Atlas Copco.

6.1 Current state value stream map

Figure 10 presents a simplified value stream map of the current state. The value stream map was performed on the component with the highest yearly volume to show how the process is most likely to look at any given time. The lead time ladder at the bottom of the figure calculates the time every individual component is being processed and the total lead time is the number of days manufactured and shouldn't be confused with the number of calendar days since weekends are not included. The value stream map shows that components spend on average a lot of time in the milling and hard turning buffers, the simulation showed a similar pattern and buffer levels were therefore investigated further in a bid to reduce the total lead time of the process. The laser engraving operation were also highlighted as a potential area of improvement, in theory the hard turning operator should be able to perform both operations simultaneously and therefore reduce the lead time to just a few hours.

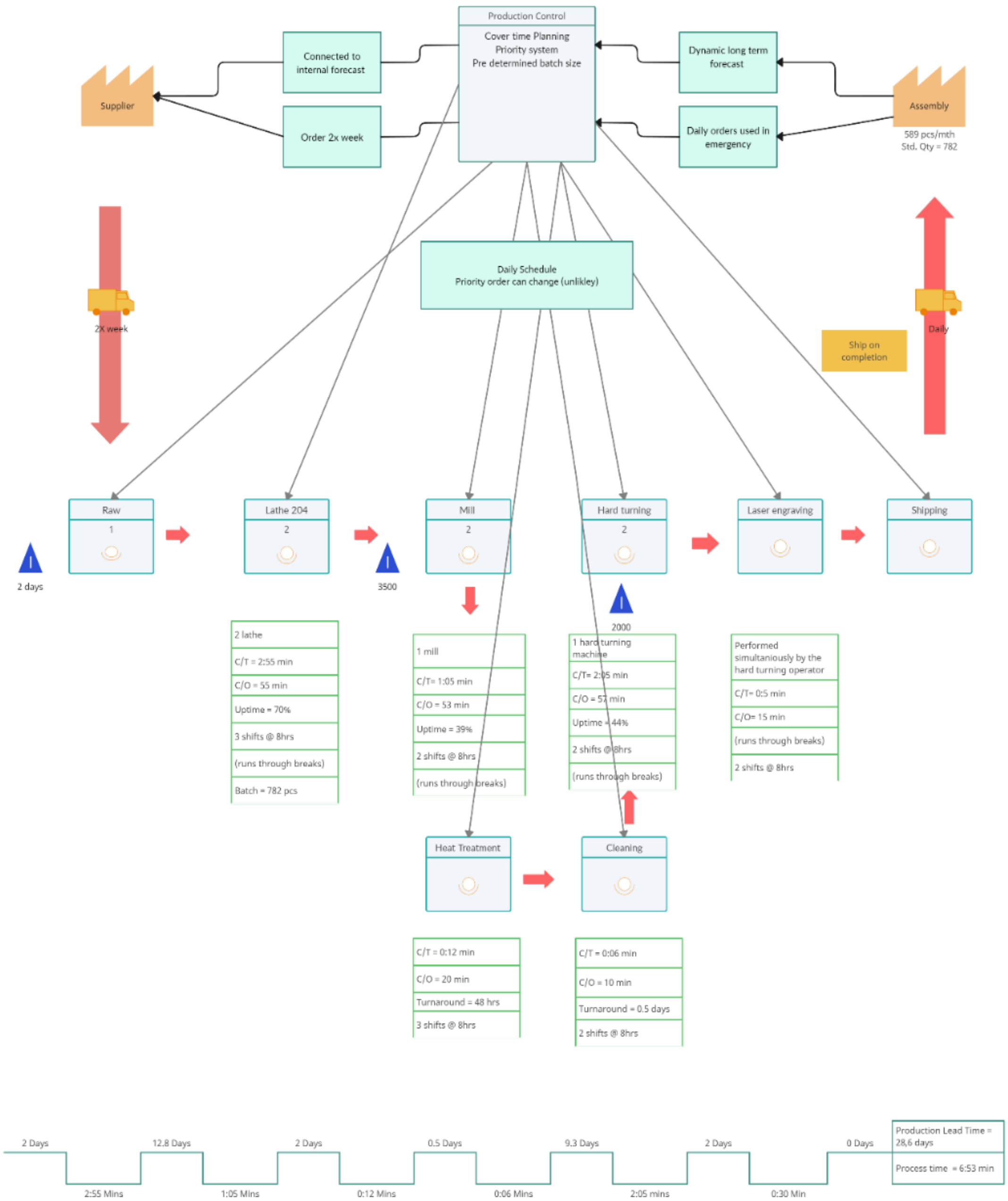

Figure 10: Current state value stream map

6.2 Future state value stream map

In figure 11 a future state value stream map is presented containing all of the improvement suggestions previously presented in this report

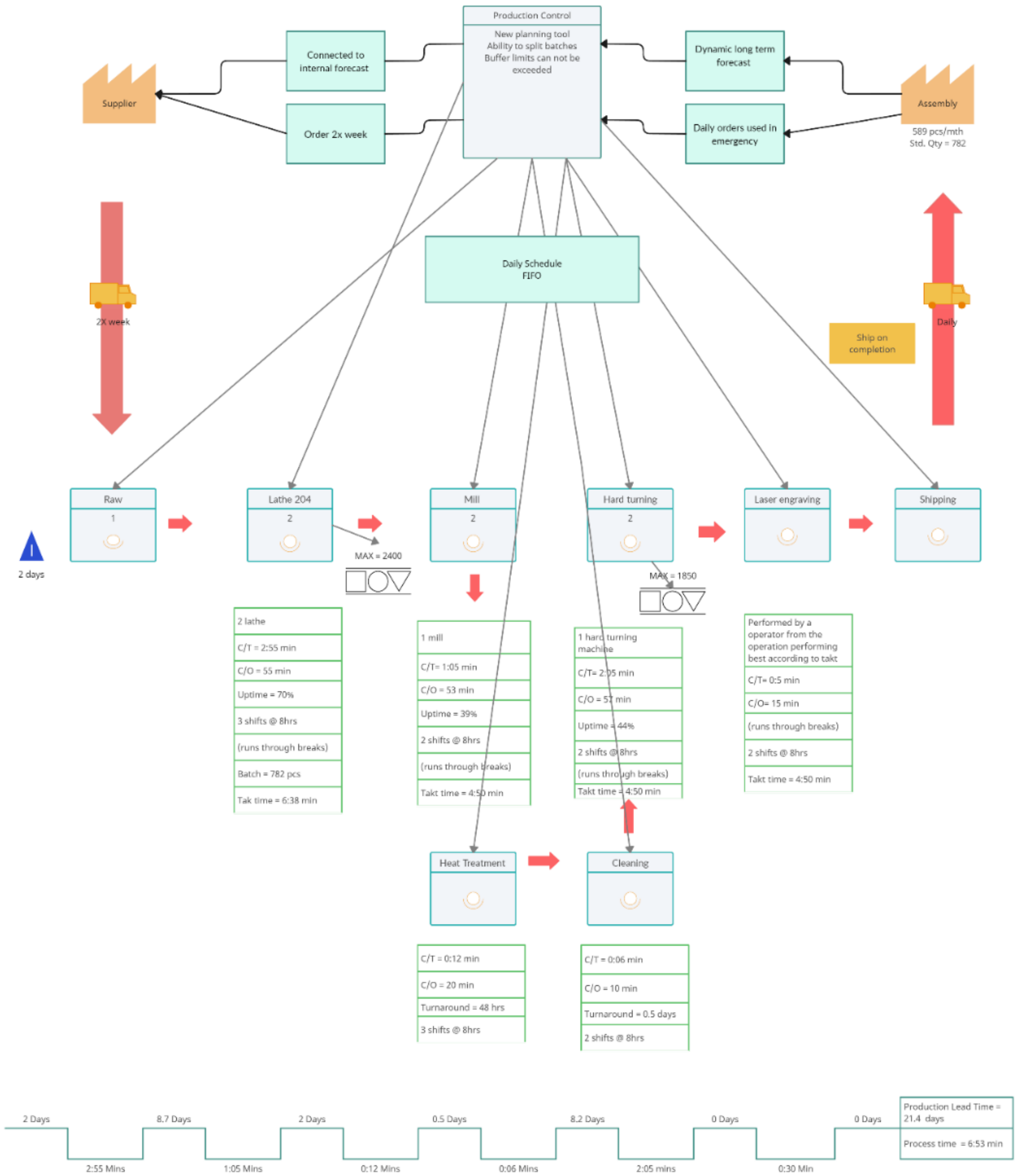

Figure 11: The future state value stream map.

6.2.1 The physical changes

Figure 11 show the future state value stream map, a few changes were made to the physical layout of the cell, the most obvious is the introduction of a conveyor belt instead of a pallet rack for the milling and hard turning operation. The conveyor belt is used to limit the buffers physically and also show it visually, when a batch is processed it is put on the conveyor belt, the buffer limit is reached when the conveyor belt is full. This clearly shows the previous operation that no further work can be processed until the buffer is decreased. The previous operation can then process a work order from another part of the facility or perform preventative maintenance work. By using a conveyor belt rather than a pallet rack the expectation is that lead times will be more predictable and the "first in first out" strategy would be used even further since no changes to the order can be made once the batch is placed on the belt. The buffer limit for the hard turning operation is set to 1 850 components, it was based on the simulation's calculations regarding the optimal buffer level. The simulation suggested a buffer limit for the milling operation that was impossible to implement in real life. To find the optimal buffer level data was researched and showed that the buffer level moved in a span of 2400 components last year. 2 400 components were then selected as the limit that would be able to supply the hard turning operation with a constant flow of orders without inflating lead times to much.

A large screen displaying the current takt in the system is also introduced in three places to give the operators a better understanding of how well the various operations perform compared to each other. The target is set by the production control who breaks down the demand into monthly, weekly, daily and shift targets.

The last physical alternation to the system is the allocation of staff for the laser engraving operation. In the current setup the operation is performed by the staff on the hard turning operation and intended to be done simultaneously with the hard turning operation, a batch takes on average two days to be completed here. With the introduction of a takt system the operation who currently is ahead has to send staff down to perform the job, this will help the final operation focus solely on operating as efficiently as possible without any interruptions.

6.2.2 The planning tool

A new planning tool was developed to calculate lead times for new workorders and give the production control and planning department an enhanced overview of the situation. The tool was created in Microsoft excel and is split up into three different windows, one intended for the planning department, one for the operators and the last one for the production control. Figure 12 presents the first window of the production control tool intended to be used by the operator. Every individual workcenter is presented on the X-axis, and the work orders are shown on the Y-axis.

Materialnummer	56235204	56235201	56284261	56244156	56244157	55764290	51201000	56235155	56235163
4150234700	10,3125			15,85				9,17	
4220319535	6,458333			3,88				1,81	
4210067541	39,11111			24,00				24,89	
4220097735	42,58333							12,17	
4150232300				1,48				1,27	
4150233800				13,30				11,40	
4150233300				21,58				17,27	
4150232300				19,41				16,63	
4220356830				14,02				23,37	
4210385815				20,48				27,30	
4150233800				13,30				11,40	
4220362535		40			40			6,46	40
Summa	**118,8253**	**40,92**	**0**	**155,4046**	**41,085**	**0**	**0**	**177,9646111**	**40,7311**
Antal dagar	**3,536467**	**2,435714**		**20,04574**	**3,515144**			**22,29294891**	**2,791331**

Takt	56235204	56235201	56284261	56244156	56244157	55764290		56235155	56235163
Dag	70	100		90	120			100	50,00
Kväll	70	50		60	90			110	150,00
Natt	70	90		150	75			230	90,00
Totalt	210	240	0	300	285	0	0	440	290

Figure 12: The operators view in the new planning tool

Once a new workorder enters the system the total process time and setup time in hours for each station is put into the document, as the operators finishes a batch the time for that specific operation is erased in the document and give everyone a clear understanding of the current backlog for every operation. At the end of every shift the number of components produced will be reported in the shift bar to give an accurate understanding of how well every operation is performing that day. The document will give both the operators and the production control a better view regarding which workorders will arrive and when. The second window is presented in figure 13 and is intended to be used by the production control, the OEE data is updated regularly to give an accurate number for the average expected capacity that is used to calculate expected lead times.

Materialnummer	56235204	56235201	56244156	56244157	56235155	56235163
4220356830	0,0486	0	0,018056	0	0,03472	0
4220097735	23,32			0,01833		0,02361
111	0	0	0	0	0	0

Partistorlek
400

Daglig kapacitet		
56235204	33,6	
56235201	16,8	
56284261		
56244156	7,7525	*
56244157	11,688	*
55764290		
51201000		
56235155	7,983	
56235163	14,592	
Totalt	92,4155	

Figure 13: The production control view in the new planning tool.

If a shift were to be added the production control can add the extra capacity to the document to see how it will affect lead times for the process.

The lead time calculation is based on the premise that every new order who enters the system will be processed last and that the first in first out principle will be used in every operation apart from the hardening and cleaning where the average time for completion is used. The calculation is performed by dividing the total amount of work for the first operation by the expected capacity to get the lead time for the first operation. During the time it took the order to pass thru the first operation the second operation would have processed some or all of the orders in front. Before the lead time for the second operation can be calculated a calculation of the new backlog for the second operation has to be performed. The new backlog is calculated by taking the total amount of process time for the second operation at the start and subtract it with the time processed during the time it took for the order to pass thru the first operation. Two and a half days is then added to the lead time to account for the hardening and cleaning operation. The lead time for the third operation is calculated in the same way as the second one, for the laser engraving operation 2 days is added to obtain an accurate lead time. The lead time calculations were validated by calculating the expected lead time for two components that was put into production at the beginning April. The gear component was completed in 23 days compared to the calculated 26 days, the pinon component was completed in 25 days compared to the calculated time of 22 days. The last window is called planning control and presented in figure 14, this window is intended to be used by the planning department.

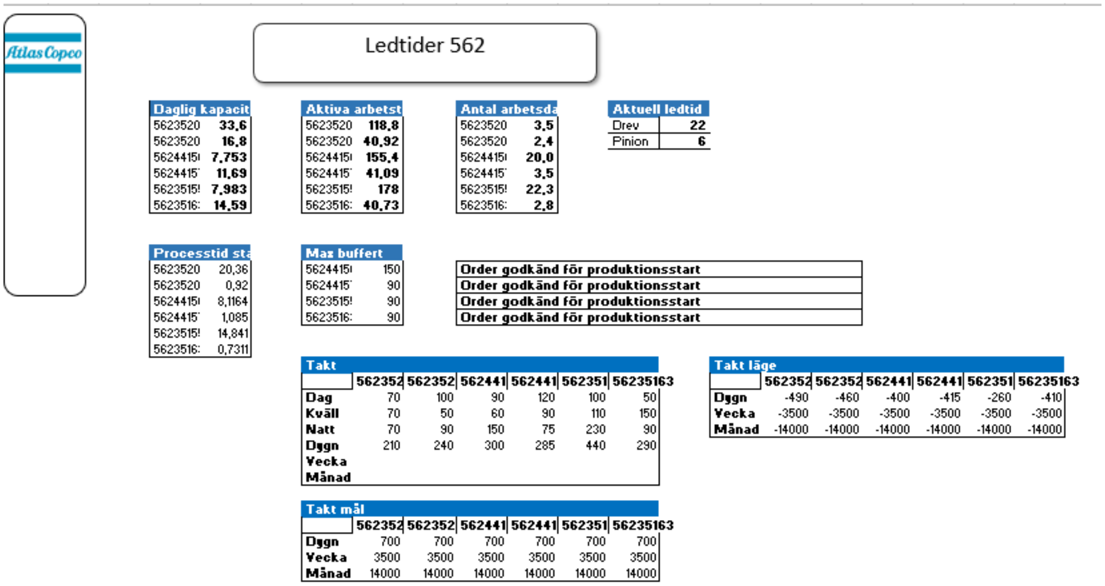

Figure 14: The planning departments view in the new planning tool.

Before the start of a new workorder the person responsible for the release of the order can insert the new order to the system to see whether the work would breach any pre-determined buffer levels and the expected lead time for the new component will be displayed. If the new work order would breach the buffer limits another component could be started to keep the buffers at an acceptable limit.

6.2.3 Ability to split a batch

In the future state value stream map batch sizes will be reduced by 20% for drive components and 10% for pinion components, the planning department will also be able to reduce batch sizes to better meet demand in periods of increased demand. Due to the high mix and low volume some components are produced every month, and some are produced just a couple of times a year. The low volume components will then be placed in safety stock for a long period of time. In periods of increased demand it would be beneficial to decrease the batch sizes of low volume components to meet the safety stock requirements rather than producing the most economical beneficial size. By decreasing the batch size, a higher variety of components can be manufactured in a given timeframe, enabling the assembly line to function without disturbances and increase the capital turnover.

6.2.4 Takt

The future state value stream map also introduces a *takt* to the system, The benefits of a *takt* are that it can reduce buffers and increase output of products, however it can also be used to make sure that every operation is on schedule, if one operation falls behind the takt board will clearly show it and resources can be deployed to assist that operation. The takt presented for this project aims to provide the production control an enhanced knowledge regarding which operation is the current bottleneck of the system. The takt is based on the monthly demand and split up into weekly, daily and shift demand, at the end of a shift the number of components produced is reported and the takt board is updated. If one of the operations falls behind schedule production control can relocate staff to that specific operation in a bid to try and rebalance the process so that output can be kept high, and no extra buffers will build. Table 5 lists the number of components every workcenter has produced between April 1 and May 6. From studying table 4, it becomes evident that the milling operation have produced more gear components than the hard turning operation has been able to, as a consequence buffer level will increase for the hard turning operation.

Table 5: Displays the components produced in the last month.

	Lathe Gear	**Lathe Pinion**	**Mill Gear**	**Mill Pinion**	**Hard turning Gear**	**Hard turning Pinion**
Number of components	5 200	9 750	9 200	10 600	5 300	11 650

With a takt in the system some resources could have been redistributed from the milling operation to the hard turning operation and the output of the system could therefore have been increased

6.3 Core performance indicators

During interviews with production control and the planning department the role of the workshop in the overall organization was discussed. The results of those discussions were the conclusion that the workshop is a support function to the final assembly with the main goal of suppling components on time and at a competitive price. The main key performance indicator is therefore to measure the number of alarms used and occasions where the assembly must stop a new order due to a component shortage. The second performance indicator is lead time, the lead time should be kept as low as possible to increase the capital turnover and flexibility of the system. The third indicator is an evaluation of the takt, the takt should be evaluated everyday for every operation, the overall goal is to reach the takt target everyday and operations will be evaluated based on the percentage of days they manage to reach the takt targets. The fourth goal is the cost to produce every component, the cost is calculated for every component by multiplying the total operating time with the internal cost per machine hour(confidential). The fifth performance indicator is the cost of cassation, by tracking cassations the company can work towards reducing waste to a minimum. The final performance indicator is the overall equipment effectiveness also called OEE, the score measures the percentage of time an operation performs a value-added activity like process time. The intention of the OEE score is to make sure that the equipment is used as efficiently as possible.

7 Discussion

In this chapter the results and analysis of the study is discussed, the degree to which the initial problems of the study have been answered is discussed as does some of the obstacles that occurred during the project, finally the methods used for the project is discussed and evaluated.

7.1 Were the questions and purpose of the study met?

The first part of chapter 7 discusses the degree to which the questions of the study was answered and how the results of the study can improve the manufacturing process.

7.1.1 Question 1

The first question of the project was "Where are the critical bottlenecks within the system for the selected cell of this case study?" the question was answered by constructing a simulation model of the manufacturing process and conduct a simulation. The results are presented in figure 6 and 7 and shows that the lathe operation was the sole bottleneck most of the time last year and the hard turning operation was a shifting bottleneck for the gear components, the results corresponded well with company's own perception of the bottlenecks. One of the main flaws of the simulation model was the average availability data used in the study, the simulation showed that pinion components would have had very low buffer levels last year. This was inaccurate since data from last year showed that the reported average lead time was 38 days. The reason for the big discrepancy in lead time and buffer levels are believed to steam from the fact that over the last year the availability of every operation fluctuated a lot from month to month. The fluctuations put the process out of balance and some operations produced more components than others and thus increased the buffer levels. The simulation model was still able to produce an output close to the actual process and could therefore be used to find improvements in the process.

The main discovery made by the simulation was the fact that resources could be utilised in a more efficient way. Experiments showed that by reallocating staff output could be increased and lead times would decrease and thus fulfilling two of the main objectives of this study without the need for a capital investment. The experiments also concluded that a reduction of buffer limits would enable spare capacity to be used elsewhere in the factory and assist other operations to increase their output without decreasing the output of the cell.

Since the model is not an exact replica of the process, the improvement suggestions will not translate 100% between the model and reality and should therefore be seen as what could be achieved in an optimal state. To get a more accurate simulation the model must be able to cope with variations in availability and buffer levels for the hardening and cleaning operation has to be taken into consideration. The simulation coincides well with other academic work on the subject who have also found that a simulation model of a process can highlight area of improvement. The improvement suggestions generated for the process was all based on previous theories on how to improve productivity in a manufacturing process where bottleneck detection and optimisation as well as takt was used. The overarching methodology used to optimise the system was founded in the principle of minimising waste in the process and utilise resources in a way that would optimise the total output of the system. Every improvement suggestion generated was evaluated on the basis of how it impacted the end result and improvements that did not were disregarded.

7.1.2 Question 2

The second question of the project was “How can the manufacturing process be more easily visualised?” This question was a lot more open ended than the first one and can be interpreted in many ways. The focus was early on directed towards finding a tool that would give everyone working within the cell an increased understanding how many orders are being processed at the time and how the flow of orders would develop in the near future. The planning tool presented in this report should in theory be able to present the process visually to everyone. It is dependent on everyone to use it properly and any misuse of it can create false information. The lead time calculation function was impossible to back test since the data required to perform the back test was not available. To see whether the function was useful the first calculation was done in April and put on hold until the part was finished. This approach meant that just a few calculations were validated during this project, for the formula to be used on a daily basis further experiment would have to be performed. The second question was answered both practically and theoretically, the value stream map tool is a proven method to use in academia to visualise a process, the takt used to balance the system is also a tool based on previous academic work. Some of the improvement areas highlighted by the value stream map was then solved practically where a solution was made to fit the needs of the organisation. As with the simulation an approach were used to generate improvements that would optimise the utilisation of resources and minimise waste. The planning tool and takt aims to give the production control and planning department a greater understanding of the process to better allocate resources at the moment. The expectation of the planning tool is also that it will give everyone an increased understanding of the process that could yield smaller incremental gains as employees use their newfound knowledge to optimise the process.

7.1.3 Question 3

The third and final question of this study was “How can the improvements made be measured to have a positive impact on lead time, output and availability of the bottlenecks.” To assess whether the changes to the process yield any improvements a new set of key performance indicators were suggested. The indicators will measure parameters in the process that should be affected by the improvements made, a baseline has to be set before the changes is made to see their impact on the process. The literature review showed that a lot of key indicators could be used to gauge the performance of a manufacturing process, some of the common ones were disregarded for this study since they measured similar things as the ones selected. The literature review also showed that the number of key performance indicators should be kept as low as possible and ideally focus more on broader measures since they are less prone to random fluctuations. The indicators used should be based in theory but then selected practically depending on where in the organisation the manufacturing process fits in. In this case the manufacturing process is a support function to the assembly line, since the price of the final product is a lot higher than the price for the components produced it made sense to prioritise an indicator that evaluated whether demand could be supplied. Since the cost of delivering a product late is deemed higher than to pay an extra price for an individual component the prioritisation made sense. Every indicator was validated by staff to ensure that they were relevant to the process and could be measured easily. It has to be mentioned that ranking the indicators based on their importance isn't easy and their importance can vary from time to time. A strong OEE score for the milling operations would not be as important as a good score for the lathe operation since the milling operations isn't a bottleneck in the system. A lowered OEE score for the milling operation would not therefore affect the system in the same way a lowered OEE score for the lathe operation would. When evaluating an operation based on the performance key indicators the importance of the indicators should not be set in stone but rather be evaluated based on current conditions. However, in general the indicators should be prioritised in the order they are presented to ensure optimal results for the process.

7.2 Method discussion

The methods used in this project was in large part chosen to fit the needs of the simulation model and be able to do during the limited time of the project. The simulation model relied heavily on secondary data obtained by the OEE software, since time was limited no primary data except from layout information was collected and used. To increase the validity of the project primary data would have to be collected and compared to the secondary data, however the secondary data was regarded as very reliable by staff and was therefore used. For the simulation only 20% of the components in the cell was selected since they represented most of the volume, if the project had been conducted over a larger period of time more components could have been added to the simulation to increase the validity and reliability even further. Some of the components processed in the first operation leaves the cell for further processing in other parts of the facility, those components were also disregarded. A more in-depth simulation could have looked how variations in availability affected buffers and how spare capacity from other parts of the facility could be used to increase efficiency.

As part of the task to visualise the process a value stream map was selected, the decision was made with the intention to give the reader of the report a better presentation of the process and highlight areas of improvement. The value stream map presented in this report is therefore a simplified version of a full value stream map, a complete version would have been outside the scope of this report and taken up too much time. A more thorough value stream map could potentially have steered the project in a different direction where other inefficiencies would have been explored. Focus was instead shifted towards finding a way to visualise the process on a day-to-day basis to give the company a useful tool in daily activities to comply with the purpose of the study.

8 Conclusion

In this chapter conclusions regarding the choice of methods and the results of the study is discussed as well as to what extent the purpose and questions of the project was achieved.

8.1 Conclusions

The purpose of this project was to deliver improvement suggestions that would reduce the lead time, increase the output and increase the capacity of the bottleneck. The purpose was in part fulfilled by constructing a simulation model where the bottlenecks of the process was found using a shifting bottleneck analysis. The simulation model was also used to answer the first question of the study. Experiments were then performed on the model to see how the process could be improved. The results showed that the lead time could be reduced by implementing limitations on buffer levels, the limitations would also prohibit the first operation from working during certain periods and therefore create spare capacity that could be used to assist other parts of the facility. Furthermore, experiments showed that if reallocation of staff were done in a more efficient manner output would increase and lead times decrease. The last experiment was done to find the optimal batch sizes, experiments showed that batch sizes could be decreased by 20% for drive components and 10% for pinion components and still be able to deliver the same output. The model was validated by comparing the results of the model to the actual results of the process and experiments highlighted a few areas of improvements and gave a few actionable steps as to how they could be implemented. With more time and information regarding the hardening and cleaning operation a model could be constructed to give more accurate results. However, the results obtained by this model was still deemed to be sufficient enough to deliver improvement suggestions.

The second part of the project was mainly focused on the second question of the study to find a tool that could present the process visually to everyone working within the cell, a tool was designed to fit the needs of the organisation and a takt was also introduced. The tool was designed purposefully for the organisation and hasn't been tested in daily activities yet, some modification are therefore to be expected ones its implemented and should therefore be regarded as a first draft rather than a final product. The introduction of a takt to the system was done to further visualise the process and help production control allocate human resources in the most efficient way possible.

To answer the third and final question of the study a great focus was directed towards the literature review and interviews to better understand the role of the process in the overall organisation. Once the role was established suitable key performance indicators were chosen based on the literature review to ensure that measured performance would be the most beneficial one for the overall organisation.

8.2 Practical implications

The following list represents the actionable steps the company can take to implement the improvements suggested in this report. The list can be seen as a step by step guide where the first steps are seen as the easiest in terms of the effort required versus the potential outcome. An in depth explanation as to why every step would be beneficial to implement and how it would be done can be found in chapter 5 and 6.

1. Ability to modify batch sizes.
2. Introduce a takt.
3. Implement the new planning tool.
4. Retrain staff to operate more of the machines.
5. Hire two extra employees.

8.3 Further studies

To improve the model and obtain an even more accurate results a new and more advanced simulation model can be constructed where an increased amount of components are taken into consideration and where the availability is allowed to shift during the simulation. During the course of the project focus was put towards finding ways to utilise the existing resources in the most optimal way. This project was focused on finding a top down approach to utilise the resources efficiently. A study focused on optimising the workspace and tasks of the operator could prove beneficial to find smaller incremental efficiencies and reduce the bottlenecks even further. The buffer levels before the milling operations are a large contributing factor to the total lead time, the process time is however the lowest among the main operation and the operation should in theory have small to no buffers at al. A further deep dive into the buffer levels of the milling operation would be interesting to find out why the buffers levels have been so high.

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Appendix

In the appendix extra information is supplied that didn't fit into the report, the interview questions is presented in appendix 1.

Appendix 1: Interview questions

Appendix 1: interview questions

Questions for production management

- When was the current cell constructed?
- What did the process look like before the rebuild?
- Which targets were set for the new cell?
- How was the capacity decided?
- How were the lead times affected by the new setup?
- What has worked well?
- What hasn’t worked well?
- Would extra machinery be necessary, or could the current setup meet future demand?
- What is the lead time target?
- How would the optimal setup look like?

Questions for the planning department

- What are the tasks of the planning department?
- What defines good planning?
- How decides which workorders are being started and why?
- How is the relationship between the departments?