A model to cost effectively improve productivity in an aluminum cutting and drilling station

- A case study

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Datum: VT - 2013
Kurskod: 2SE09E, 15 hp
Abstract

The purpose of this study is to develop a model that aims to cost effectively improve productivity in a manufacturing production process. The study highlights the importance of having knowledge about customer needs and using a holistic process perspective when improving productivity to identify the relations between the process stations and by this find problems that cause waste and losses in productivity. Tools and methods used to make production more efficient such as single minute exchange of die, spaghetti diagram, 5s and master production schedule is presented and applied in the model to see how these effect costs, productivity etc.

Maintenance effects on quality and productivity in a manufacturing company will as well be covered in this thesis. The results and conclusions finally reveals how the process improvement tools, maintenance and production planning for example effects each other and why it is important to establish an attitude in the company where continuous process improvement should be emphasized.
Acknowledgements

For making this thesis possible to write I would like to thank

… Tobias Rudelius and his colleagues at my case company for providing me with valuable information and guidance.

… Mirka Kans for guidance and valuable recommendations for improvements.

… Matias Taye for guidance and valuable recommendations for improvements.

… Basim Al-Najjar for feedback and acceptance of the study.
Abbreviations / Definitions of key terms

**Competitive advantage:** Refers to producing the most value to the lowest cost and to the lowest amount of time (Stalk & Hout, 1990)

**Cost efficiency:** Refers to the relation between production values to the customer with the cost of the production (Ljungberg & Larsson, 2012).

**Cycle time:** Refers to the time a product is being operated in a work station, from start to finish (Ljungberg & Larsson, 2012).

**Lead time:** Refers to the time it takes for a product to move through a process, from its start to goal (Rother & Shook, 2004).

**OEE:** A measurement of how effectively equipment is utilized (Ljungberg, 2000)

**Productivity:** Is defined in the context of the thesis as the output quality and quantity of a process divided with the input quality and quantity. The higher number the better productivity (Saari, S, 2006)

**Production cycle:** The number of cycles a product is produced in an specific time interval (Segerstedt, 2009).

**Pull system:** Refers to when process stations pulls what is necessary up stream in the process creating an system that only produces what the next step in the process needs (Rother & Shook, 2004).

**Push system:** A push system is created when production is ordered separately to each production station without consideration to the next or previous process step

**Sub optimization:** Refers to improving one process station without considering the how this station is connected and effects other process activities (Ljungberg & Larsson, 2012).

**Upstream:** Refers to the path through a production process where finished product is the start and delivery of raw material is the end (Rother & Shook, 2004),
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8
1 Introduction

This chapter will introduce the reader to the thesis and present a background to why this study is conducted. The problem formulation and its purpose are presented and discussed. Lastly the limitations of the research and the thesis are revealed.

1.1 Background

Historically, company’s success has consistently been connected with their approach towards quality. With the increasing globalization of the market, it is becoming more important than ever to meet or even exceed the customers’ demands as more companies compete for the same customers. Improving productivity with consideration to high quality will ensure a path for satisfaction both customers and investors.

The awareness of productivities and qualities importance has led to the creation of production improvement philosophies like Six sigma and Lean production. These are production strategies that make the company aware of waste, value adding as well as non-value adding processes within the production (Petersson et al. 2009). Being aware of this gives the company information about its weaknesses and its strengths, so areas in need of improvement can be identified and the company’s competitive advantage can be highlighted. With better understanding in this area the company can communicate with more knowledge about their potential and limitations to their customers and suppliers to adjust and better satisfy needs and demands (Petersson et al. 2009).

Ljungberg and Larsson (2012) emphasize the importance of identifying processes within the company and using a process approach for improving productivity. Regardless if a company choses to identify and work with processes or use traditional, indirect management approaches, processes will still exist. Without identifying the processes they cannot be measured and areas in need of improvement cannot be found or motivated for development. To view the production as a chain of activities related to each other and actively work with the processes, is to directly attack the problems, search for efficiency and find the value adding steps within the production (Ljungberg & Larsson, 2012).

1.2 Problem discussion

Productivity is discussed by Bergman & Klefsjö (2012) to be an attitude towards progress and constant improvement. It is the desire to improve the current stage of the company, regardless of how well they seem to progress at the moment.

Applying new methods and theories that aids companies to adjust to the constantly changing market and customer needs can help improve the company in several aspects and nevertheless increase productivity (Bergman & Klefsjö, 2012).

Using a process approach towards the production and applying production improvement strategies such as lean is methods that can help companies to explore new opportunities for improvements. Finding for example ways to more efficiently use resources by eliminating waste, shortening led times and increase employee’s commitment, can motivate for changes
towards production improvements and eventually steer the organization to higher productivity (Petersson et al. 2009).

As mentioned in the background, quality is one of the major factors for a company’s success and profitability. Improving productivity and shorten lead times has in several aspects a connection to higher quality. Shorter lead times requires quality related mistakes to be at a minimum and with higher productivity more labor can be put on the quality inspection section. To continuously improve productivity can therefore further be motivated by higher customer satisfaction and keeping customers buying their products (Bergman & Klefsjö, 2012).

Stalk and Hout made an investigation (1990) where they compared companies in USA and Europe to Japanese companies. Even though companies in USA and Europe had better conditions for production like standardized processes, shorter distance to customer’s and lower employee costs the Japanese companies still showed higher productivity, better quality and lower storage costs. The key according to the investigation was that the Japanese companies focused more on time management, reducing lead and cycle times in the production. Although the predicted effect of reducing time was that it would have a negative effect on quality and cause higher costs in faulty products, it proved to be the other way around. Shortening lead times simple leaves no time for errors and less time to spend money (Ljungberg & Larsson, 2012).

This motivates why reducing lead time and improving productivity is beneficial but do not discuss why this is a problem, why are companies not as productive as they can be. One reason, according to Imai (1986), is the strategies that companies mainly in Europe and USA use to manage their business. Instead of using a process approach companies are mainly focusing on big leaps with innovation and the result of the production (output). With this approach companies risk missing out on the benefits with a process oriented strategy where focus is put on finding waste and improve the efforts put in the process. With the market being characterized by high competitiveness as it is today, an innovation strategy is also not as suitable as it was several decades ago when the market was characterized by high growth and high margins. The problem can therefore be connected with companies needing to investigate new approaches towards improving production, to improve productivity.

1.3 Problem presentation
It is highly desirable for retailers and customers to buy from suppliers with fast delivery. With fast, flexible production, the customer can more accurately predict their demand and make orders closer to a forecasted sale, which would reduce the risks and need of storage (Stalk and Hout, 1990)

There are several aspects that needs to be considered to achieve high productivity cost efficiently. An effective maintenance plan for example can avoid time and resources spilled to downtime and reduce the need of safety storage due to higher reliability of the machines (Al-Najjar, 2010). Other supporting processes such as a continuous improvement model can help to create routines for management to continuously work with increased productivity (Ljungberg & Larsson, 2012).
By increasing productivity and reducing lead time companies can gain several cost beneficial advantages according to Ljungberg and Larsson (2012). Some of the most important are:

- Competitive advantage – Customers’ demands faster delivery times which require shorter lead times.
- Higher income and lower costs – Customers are in most cases willing to pay more for faster production and as time is money, the company themselves reduces costs.
- Higher quality – Increasing the focus on time means that the production can’t afford errors which increase the overall quality.

Improving productivity is essentially done by working with the processes in the production. It is in the processes the companies mainly improve their production and create their competitive advantage. While products can be studied and analyzed by competitors the processes for producing the products is generally hidden from the outside. If a company is characterized by high flexibility, fast delivery and low prices can this in most of the cases be traced back to the production (Ljungberg & Larsson, 2012).

To be able to offer low prices to the customer, a production process needs to be cost efficient. The customer only wants to pay for what has value to them which makes it vital for companies to reduce none value adding activates as well as improve value adding activities (Petersson et al. 2009). Finding for example an optimal cutting and drilling speed for processing aluminum can balance the production speed with downtime due to tool change, which in this example means as much value adding activities (processing the material) in relation to non-value adding activities (down time) (Publication TN44, 1992). This generally addresses the problems and areas of interest when working with increasing productivity in aluminum cutting and drilling production.

As mentioned before, working with a process oriented approach towards the production can help to find waste and areas in need of improvement. This approach can also help finding constrains and limitations in a process. As a process is not more efficient then its limitations, finding this can help reduce the overall lead time. Cycle time is in these cases an interesting parameter to investigate to increase productivity (Dettmer, 1997).

With the right circumstances, finding solutions to reduce lead time and cycle times in manufacturing companies can be a direct path for increased productivity and higher quality (Stalk and Hout, 1990).

1.4 Problem formulation

How to increase productivity of an aluminum cutting and drilling production station cost effectively?

1.5 Purpose

The purpose of this thesis is to develop a model to increase productivity by suggesting solutions to increase productivity and identify causes behind productivity losses. The model aims to identify waste and non-value- and value adding activities in cutting and drilling production.
stations and find solutions with the use of a holistic process perspective to optimize the value adding activities in a process.

1.6 Relevance
To find if similar studies have previously been conducted, a search through databases with scientific journals was made. The databases Science direct and One Search were used to find relevant articles mainly because they contain a large number of articles in the area of my thesis. Keywords used to find relevant research is listed in the table below:

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<th>Keyword</th>
<th>Database/source</th>
<th>Hits</th>
<th>Relevant hits</th>
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<tr>
<td>Improve productivity cost effectively</td>
<td>One search</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Improve productivity of an aluminium industry</td>
<td>One search</td>
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</tr>
<tr>
<td>Improve productivity by reducing lead time</td>
<td>One search</td>
<td>2</td>
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<tr>
<td>Improve productivity by eliminating waste</td>
<td>One search</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Improve productivity cost effectively</td>
<td>Science direct</td>
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<td>Improve productivity of an aluminium industry</td>
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<td>Improve productivity by eliminating waste</td>
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The database search shows when searching for “Improve productivity by reducing lead time” that there has been some research made about how reducing lead time and cycle time can result in higher productivity (Rho & Yu, 1998) (Kuhlang Edtmayr, Sihn, 2011). This reveals that there is a connection between reducing production cycle time in a process to productivity.

The relationship between competitive advantage and high productivity is highlighted in Rho & Yu (1998) and Kuhlang, Edtmayr, Sihn (2011) articles where time management is emphasized to be a major factor to increase productivity. Together with the lead time and cycle times effect on productivity will this thesis cover what in the process that adds value to the product and how these can be optimized to reduce non-value adding activities supporting these. A maintenance and quality aspect will as well be covered to see how they are related to productivity and the production process.
Companies are often aware of their need of improving productivity but knowing where improvements need to be made is not always obvious. By applying a process oriented approach to the production in manufacturing companies, it is possible to easier find the causes in the production for losses in productivity (Ljungberg & Larsson, 2012). Considering this, a company can achieve several benefits in using a model that illustrates and identifies the process for manufacturing their products and reveals where improvements can be made.

1.8 Limitations/delimitations
The model developed in the thesis will only be applied and evaluated on one case company. Lead time will be referred to the time for a product to process from raw material (delivered to the producing company) to finished product. This means that receiving orders and transportation will not be considered due to limitation of the thesis.

Due to time limitations and classified information, some number used to determine set up costs, storage costs etc. are an estimation of the real values. The relation between the factors is however the aspect that is of importance to solve the problem formulation and conclude results in the thesis.
2 Research methodology

This chapter will present a variety of research methodologies and finally present how the research will be conducted for this thesis.

2.1 Qualitative and quantitative research

There are two general approaches to collecting and analyzing data for a research project: Quantitative and qualitative. With a quantitative approach, the research is based on a large collection of data that represents a bigger population. With a qualitative approach, the research is based on less but more profound data, such as qualitative interviews.

The factor that decides which approach is more suitable for a certain project is based on the problem formulation. If the researcher is interested in knowing questions like “where? How? What is the differences? What is the relations?” a quantitative research method is more suitable. If the questions however is in the form of “What is this? What is the underlying pattern” the more suitable approach is qualitative research (Patel and Davidson, 2011).

2.2 Research approach

A researcher’s task is to create theories that should give as precise knowledge about the reality as possible. The foundation of theories is data about the studied reality, called empirical findings. The challenge for the researcher is to connect its theories to the reality, empirical findings. There are generally three approaches to do this: Deductive, inductive and abductive (Patel and Davidson, 2011).

2.2.1 Deductive

The deductive approach uses existing theories to make conclusions about a certain case. Hypothesis is made from theories and tested for the specific reality. For example if motivation in the workplace is to be studied, an existing theory can be used to conduct the study and create hypotheses to test on the workplace. An existing theory is therefore the foundation for how the study is conducted, how the information is analyzed and how the results should be connected to the theory. The results will by this approach not be affected to much by the researchers own opinions and therefore more reliable.

An negative aspect is however that the researcher will be guided by an existing theory which might restrict the opportunity for new theories and science to be discovered (Patel and Davidson, 2011).

2.2.2 Inductive

An inductive approach is when the researcher creates its own theory based on the data, empirical findings, that’s been gathered. To compare with the recent example, a researcher with this approach would first gather empirical data and then based on this information create and theory.

The risk with this approach is that the researcher can’t assure that the theory is generalizable on other cases, as it has only been proved against one specific case. Another risk is that the researcher might have own opinions that might affect the theories outcome.
2.2.3 Abductive
The third approach called abductive is a mix of deductive and inductive. With this approach the researcher will create a theory based on empirical findings and then test this theory on other cases. The researcher will in this case start with an inductive research approach and then use a deductive approach to validate the theory. With this approach the theory created by the researcher can then be developed to be more generalizable.

2.3 Data collection methods
After the problem formulation has been specified its necessary to review how data needed to solve the problem should be gathered. It is important to ask yourself not what method should be used but what information is needed and why do I need this specific information for solving the problem (Bell, 2006).

Gathering data can be performed with several methods. Using a combination of more than one method will give a holistic view of the case which is suggested by Patel and Davidsson (2003).

2.3.1 Interviews
Comparing with a survey, an interviews big advantage is its flexibility. The interviewer has the ability to correspond and elaborate the interviewees answer and can also evaluate the answers from body language, tone of speech etc., which is not possible from a written answer.

There are commonly two types of interviews, structured or unstructured. In a structured interview the questions are prepared and the interviews basically only needs to mark the answer on the prepared sheet of questions. Interviews like this are easy to put together and analyze.

An unstructured interview is more alike a conversation about a specific subject. It can generate lots of interesting information under good circumstances but requires good knowledge and more time for analyzing the answers.

A combination of both can also be used which gives the interviewee space to talk about its areas of concern but still has a structure so the themes and subjects areas the interviewer needs information about is covered (Bell, 2006).

2.3.2 Observations
Observations can be a good complement to interviews as interviews will show peoples perspective of what is happening while an observation can show what is really going on (Bell, 2006). It is necessary to discuss what needs to be observed, what the author is interested in and why the observation should be performed, before conducting an observation. Still with a good motivation for doing observations for a case study, there are some risks involved that can affect the validity of the observations. People can for example interpret situations with different perspective so the author could instead of doing the observation him/herself try to include other or more people for doing the observation (Bell, 2006).

An observation can be unstructured, where the author will create hypothesis and definitions based on what pattern is found during the observation, or structured where the author has chosen what to focus on and created a hypothesis before. Regardless what approach the author’s choses,
one of the most important tasks with an observation is to gather the information in the most objective way possible (Bell, 2009).

2.3.3 Literature review
A literature review is conducted to gain knowledge about the area of interest and to find if the research and the answer to the problem has not already been found. Finding information about relevant research enables the author to analyse the data collected for its case and make conclusions and answers to the problem (Bryman & Bell, 2011).

The literature review is intended to give the reader a picture of the most important issues within a subject (Bell, 2009). It can also help the author to learn about useful theoretical and methodological approaches within its areas.

2.4 Validity
According to Creswell (2009) validity in the form of qualitative research is based on determining whether the findings are accurate from the researcher’s standpoint or the participant.

Validity deals with questions like how the research matches reality, do the findings capture what is really there, and are investigators observing or measuring what they think they are measuring? Because data doesn’t speak for itself a researchers task is to translate the data where validity of the translation can be measured (Merriam, 1998).

According to Merriam (1998) an investigator can use several basic strategies to enhance validity:

- **Triangulation**: Triangulation means using multiple data sources, investigators or methods to confirm the emerging findings which can add validity to the study.
- **Member checks**: By presenting the data that’s been collected in the research to the involved people from whom the data has been gathered, the results can be checked to assure that they are plausible.
- **Long-term observation**: Gathering data at the research site over a period of time can increase the validity of the findings.
- **Peer examination**: Asking colleagues or mentors to review the findings as the emerge to get external perspective of the findings.

2.5 Reliability
Reliability refers according to Merriam (1998) to how well the researcher’s findings can be repeated if the same research was conducted again. This can for example be problematic in social science where results can vary due to the human’s non-static behaviour.
Just as with validity, reliability can be enhanced by the use of various methods and techniques for gathering data. Furthermore the investigator should explain the assumption and theory behind the study and the social context from which data were collected.

Although there is a connection between reliability and validity, a reliable result does not mean that it is valid (Merriam, 1998). If the boiling temperature is repeatedly measured to 85 degrees, the results are reliable as the temperature is consistent. This doesn’t mean however that the result is valid as errors by the persons measuring, the equipment etc also can occur.

Creswell (2009) suggest that researchers, especially qualitative, should document the procedures of their study and to document as many steps in the process as possible.

2.6 Generalizability
For a study to be valid external, or generalizable, it needs to be able to be applied to situations other than the situations where the study has been conducted. This is important to be able to show that the models and theory developed in the study can be applied for similar cases (Bryman & Bell, 2011).

My research
This section will present the method used to conduct the study for my research.

Research approach
The research for this study will mainly be based on a deductive approach as theory are gathered according to the problem at the case company and from this will a model be developed suitable to the case. As it is only one case that will be studied, my research will use a qualitative approach to gather data and find solutions to the problem.

Data gathering
To get knowledge about the process in my case company some observations will be made as a complement to my interviews and other gathered data. Because the problem area is not specifically known, the observations will be more or less be unstructured so a hypothesis about the problem area will be developed during the data gathering.

I will use a focused non-structural interview approach to gather information for my research. In my own opinion this will be most suited in my situation as the problem is not specified in a certain area (the company needs to improve a process) and a discussion with employees and management within the company can lead to an approach for solving the problem.

Validity, reliability and generalization
Validity and reliability will be enhanced by mainly using multiple data sources for the theory and developing the model. Furthermore will validity of this study will be assured by using external auditors to review the thesis during the progress (peer examination). This will mainly consist of tutoring sessions with employees at the case company and the examiner and tutors at the university.
The result of the observation will be conducted several times at different occasions to increase reliability of the findings. Notes of how data has been gathered will also be noted to emphasize validity.

Lastly, generalization will be ensured by using the model in the thesis to solve the problem that is developed for general cases similar to this case.
3 Theory

This chapter will present theory necessary to solve the problem formulation and to create a model to cost effectively improve productivity in a cutting and drilling station. The first part presents tools used to create a holistic perspective of a business process while the second part present tools used to make production more efficient. The last part presents a production approach which is used to establish a continuous attitude towards process improvement in an organization.

3.1-3.2 Process and problem identification tools

3.1 Value stream mapping

A value stream is all activities included in the creation of a product. It is everything between raw material and final product, including information flow and product design (Even customers and suppliers processes depending on the needed scope of the value stream).

The benefits that can be gained from mapping the value stream according to Rother and Shook (2004) are:

- It helps you identify waste and the root causes for it.
- It creates an understanding and a link between departments and employees within the company.
- It supports decisions and suggestions for improvements.
- It shows what impact changes and decisions have on the process and gives the opportunity to discuss and avoid unwanted consequences.
- It creates a common vision and a layout for how to improve the production flow.
- It shows the connection between the information flow and the material flow in the process.

Mapping the process itself will not improve it in any aspect. To make improvements a vision of how the organization wants the process to look like according to its goals and customers’ demands also needs to be made.

Mapping the current process and how the process looks ideally is work best done at the same time. Ideas about improvements may appear when mapping the process and new facts about the current process may also be needed when developing the optimized process (Rother and Shook, 2004).

Improving processes with process mapping is not suggested to be a detailed project taking too much time from workers. Rother and Shook (2004) suggest that it is better to take small steps moving towards an ideal situation and continuously working with details to improve the process according to the company’s vision.

3.1.1 Mapping the process

Mapping a process is usually done with targeting a single product or product group. To not make it to comprehensive it should include one process flow which for example could be from door to door in a factory (receiving raw material to shipping finished product) (Petersson et al. 2009). Before starting to map the process, information about the company, the process and the
customer needs to be gathered. A specification of what value the product has according to the customers’ needs should be included. This is to make sure that changes and improvements of the process will be at the purpose of increasing the product value to the customer. Information necessary about the customer and the company could typically include (Petersson et al. 2009):

- **Customer demands**
  
  - How many products are demanded each month/week of each article
  - Quality standards
  - When deliveries are required after order

- **Process:**
  
  - Which activities that is included in the process
  - Info about the product group (how many different articles etc.),
  - Set up times
  - Frequency of raw material delivery.

After collecting relevant information, the process purpose should be defined and a starting point and an ending should be set. A clear definition of the purpose of the process will make the improvements easier to make and the scope easier to define (Ljungberg & Larsson, 2012).

A practical method when mapping the process is by brainstorming write all processes on post-it notes and arranges them in order. It is convenient to walk thought the process downstream and take note of each process (Petersson et al. 2009). Processes that are similar to each other and describe almost the same activities can be put together and gaps should be identified and filled (Ljungberg & Larsson, 2012).

The next step it to write the input and output of each process. This makes it easier to see what happens in each process and makes sure that the map does not miss any step, as each output of an activity should be the next activities input. The activities described in the process map should also be at the same detailed level, one should not be described in more detailed than the other. If these points aren’t logical something is missing or arrangements need to be made in process. It is also necessary to be able to make measurements of process performance parameters (Ljungberg & Larsson, 2012).

Describing what is happening in each activity makes it possible to get a good picture of why each activity is included. This should be considered when naming the processes as well. The name should reflect why a process exists, more than how a process is performed. A process activity that is named for example “driving a car to Stockholm” is better named “transfer to Stockholm”, which makes it easier to find alternatives for improvement. This lays the ground work for creating the future state of the map (Ljungberg & Larsson, 2012).

**3.1.2 Developing a future state of a process map**

With knowledge about the customer’s needs a process can be adjusted to become a standardized path to satisfying the customer needs. The challenge lies in translating the customer needs into product needs and process needs. A customer can for example want a tasty cup of coffee which can of course be depended on a number of variables like temperature, input of beans, with our without sugar/milk etc. Knowledge about the customer needs together with genuine
understanding of the process and the product is important to translate the customer demands to product specification and process demands. In the example with the coffee, the need from the customer could with knowledge about the customer be translated to correct temperature which can further be translated into securing the brewing temperature, the process demands (Ljungberg & Larsson, 2012). Furthermore should the demands from the customer decide which parameters that should be measured in the process.

To be able to identify the process demands from the customer demands it is necessary to translate direct customer demands to indirect customer demands on the process. If for example a customer wants hot coffee served will this need indirectly require that the coffee is served right after its brewed. This creates a better balance on the demands of a process as they will be more divided in the process activities and not only on the last step of the process output (Ljungberg & Larsson, 2012).

Some principles when redesigning a process according to Ljungberg & Larsson (2012) is to start with the value adding activities and build with other needed activities gradually. The process should be as simple as possible with only necessary non-value adding activities and few transfers between different participants. The non-value adding activities should be parallel with the value adding activities if this is possible to not affect the ground structure with value adding activates.

**Supermarket storage**

There are often parts of a production process where creating a continuous flow is not possible. Intermediate storage is in these parts necessary and some of the reasons for this can be (Rother & Shook, 2004):

- The process is intended for several different articles
- Some process steps is located at suppliers far from the main production and
- Processes have very long lead times which make it inefficient to connect them to the rest of the production.

To avoid planning production individually in these processes, supermarket storage can be implemented after the process where the next depended process steps gathers the needed articles from the supermarket which indicates what needs to be produced upstream. This makes a continuous flow possible after the supermarket storage but may require larger batches being produced from the other processes where continuous production is not possible.

The main purpose of an supermarket storage is to simplify the production planning by using the storage levels as an indicator of what needs to be produced and how much that needs to be produced (Rother & Shook, 2004). This system therefore does not require any specific material planning for each production process (Material planning can be focused on production steps close to the customer).

**3.2 Waste and value analysis**

All activities included in a process can be divided in to three categories:
Value adding: Activities in the process that leads to directly satisfying the customer needs are adding value to the product. Simply put, value adding activities are labor or service that the customer is willing to pay for. All value adding activities do not need to directly have an relation to what the customer are buying but as long as the activity is adding an value to the product or service that satisfies the customer needs, it is viewed as an value adding activity.

Non-value adding activities: All activities that do not create a value to the customer but are necessary for a certain process to operate fall into this category. This means that there could be an internal customer or a stakeholder which need is fulfilled with this activity, and not the customer buying the product. It is safe to say that more steps in a process create more internal customers which has demands to each other that creates the non-value adding activities.

Waste: Are activities that do not create a value to the customer, an internal customer or any other involved party. Waste can for example consist of work being done twice and adjustments due to errors (Ljungerberg & Larsson, 2012).

As a part of the lean strategy, it is important to identify these and eliminate or reduce the two last mentioned (Liker, 2009). When starting to evaluate what adds value in the process, the customers’ demands from the service or the product needs to be identified (this includes both the external customer and the internal). When categorizing waste in a process, there are generally seven types of waste one can find:

<table>
<thead>
<tr>
<th>Waste</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>Products are produced which no one has ordered which creates waste through for example storage costs.</td>
</tr>
<tr>
<td>Waiting</td>
<td>Operators are monitoring an automated machine or waiting for the next step of the process.</td>
</tr>
<tr>
<td>Transportation</td>
<td>Materials having to move unnecessary long ways while in the production or transportations in and out of storage.</td>
</tr>
<tr>
<td>Over processing</td>
<td>Products and components that need extra processing due to poor tools or product design.</td>
</tr>
<tr>
<td>Inventory</td>
<td>All inventory including work in progress or finished products that creates unnecessary transportation and damages due to storing. Storage can also hide problems related to long set up times, poor production planning and late deliveries from suppliers.</td>
</tr>
</tbody>
</table>
Unnecessary motion  All motions that is not a part of the value adding activities such as finding tools and needing to walk distances to get equipment are activities that are a form of waste.

Defects  Costs and time wasted to faulty products are all waste.

*Table 3.7 the seven most common types of waste. Source: Liker, 2009.*

Liker (2009) believes that the most serious form of waste was overproduction. Producing more than is necessary indirectly creates more waste in the other categorizes and can also lower the motivation of improving the processes overall. Why should a company with a large inventory care about faulty products, time wasted due to waiting, unnecessary movement when enough components always are available? To identify and avoid hiding problems, companies should work with identifying waste, especially waste due to overproduction.

### 3.3-3.6 Production and process improvement tools

*This part will present tools and methods that aims to increase productivity by planning production cost effectively and reduce unnecessary production time spent on non-value adding activites*

#### 3.3 Master production schedule

Master production scheduling (MPS) is a model for manufacturing planning with the objective to optimize manufacturing resources. It is used as a link between sales and actual production where sales states what manufacturing output that is required and MPS translates these requirements to the specific products that needs to be produced to make up that output (Vollmann et al, 2005). By linking production to sales, MPS can provide information about when products will be available in the future for sales to be able to negotiate and make promises to customers about delivery.

For planning production, MPS takes several factors into consideration. These include capacity limitations, the cost of production, other resource consideration, and the sales and operation plan. A consequence of this might be that the MPS system wants to produce a large batch of a product even though demand is low or no products even though demanded. This is to effectively utilize production capacity, reducing time waste etc. (Vollmann et al, 2005).

#### 3.3.1 Planning order quantities

If a several products are produced with the same machine, production order quantities can have a large impact on the storage and set up costs (costs related to waste according to the lean philosophy). Segerstedt (2009) presents a model where machine capacity, product demand, set up time, set up costs, storage costs etc. are taken into account to calculate an order quantity that balance set up costs with storage costs to find the most cost efficient production plan.
The first step is to make sure that the products demanded can be produced with the current machine capacity. It is no point on continuing with the calculations if this is not possible. The least amount of production days that is needed to produce each product demand is calculated with the following formula:

\[ T_{\text{min}} = \frac{\sum S_i}{1 - \sum \text{Demand} \times p. \text{capacity}} \]  

(Formula 3.14)

The number \( T_{\text{min}} \) indicates how many production days that are needed to produce each product according to the demand. The summary of the demand multiplied with production capacity cannot be more than one for the current production demand to be possible. This would indicate that more products are demanded then it is possible to produce. \( S_i \) in formula 3.14 is the summary of set up times and a higher number of \( S_i \) will increase the number of production days that are required to produce the products demanded (Segerstedt, 2009).

The next step after making sure that production is possible is to find the optimal order quantity. Increasing the order quantity for example would result in higher storage costs but would also require less set ups, lowering set up costs. To be able to calculate the order quantity that optimizes storage and set up costs, different order quantities is used where storage and set up costs are added to find the lowest amount of costs. An example is illustrated in the table below:

![Chart 3.1](chart.png)

Chart 3.1 an chart illustrating how order quantities effects storage and set up costs each production day (P.day).

This chart shows how the cost due to storage and set ups is affected by number of products being ordered each production cycle.

**3.3.2 Calculating safety storage**

As the forecast used to estimate the production quantities and production order is usually not fixed, variation in the customer demand might occur. This should also be accounted for when ordering production to avoid unexpected changes that could risk storage not carrying enough products to cover demand. It is necessary to estimate the accuracy of the forecasts to determine
how large the safety storage needs to be. According to Segerstedt (2009) this can be calculated by a mean absolute deviation (MAD) which is the mean value of each deviation from the forecast and the actual value (actual order). The formula used to update and determine MAD is:

$$MAD_t = MAD_{t-1} + \beta(|X_{t-1} - P_{t-1}| - MAD_{t-1}) \quad \text{Formula 3.2}$$

MAD\(_t\) is the current mean deviation while MAD\(_{t-1}\) is the previous. Beta’s value is usually set to 0,1 (Segerstedt, 2009) which means that variation will not have a significant impact on the mean deviation. This is also more suitable when some days might not have any production at all (Forecast is set to zero). A higher beta number would mean that the mean deviation would have a larger effect by this. X\(_{t-1}\) will be actual order for a product group while P\(_{t-1}\) will be the previous forecast. A higher difference between X\(_{t-1}\) and P\(_{t-1}\) would mean a higher MAD number as this would indicate that the forecast and the demand is not very accurate.

MAD is used to determine the safety storage. To be able to accurately create safety storage, knowledge about how the deviation between the forecast and actual orders needs to be estimated through calculating MAD.

Before calculating MAD, the forecast (P) needs to be determined. According to Segerstedt (2009) the current forecast can be calculated and updated with the following formula;

$$P_t = P_{t-1} + \alpha (X_{t-1} - P_{t-1}) \quad \text{Formula 3.3}$$

which uses the previous forecast and subtracts or adds the difference between the actual order and the forecast. The difference between X\(_{t-1}\) and P\(_{t-1}\) is multiplied with a constant which value determines how much impact forecast errors should have on the current forecast. This number is usually set between 0,1 and 0,25 (Segerstedt, 2009).

It is also necessary to know how long the lead time will be from ordering production to the product is processed. This is to make sure that products can be produced and finished in time if the storage amount would drop below the safety storage. This is calculated by the following formula;

$$MAD_t = MAD \frac{t_l}{\sqrt{t_p}} \quad \text{Formula 3.4}$$

where tl is the lead time from order to finished product and tp the forecast time interval.

The safety storage can now be calculated for different probabilities that the safety storage will be enough to cover the demand.

The mean absolute deviation is converted to the standard deviation, which is $\sigma = \sqrt{\frac{\pi}{2} \cdot MAD}$ (Segerstedt, 2009), and multiplied with a constant found in appendix 1. The constant will be higher for a more accurate result, meaning more products in the safety storage.
3.4 Single minute exchange (SMED)
For producing companies with diversified, low volume production, tool changes and set up time is commonly one of the main challenges when aiming for improved productivity. Large dies and tools can take several hours, even days, to change and with several changes per week, a large amount of non-value adding time is split for this work (Shingo, 1985).

The SMED system is a set of theory and techniques that aim to reduce set up time to under 10 minutes, regardless of the current set up time. Although in practice, this is of course not possible in every case, it is the main goal and ambition with the SMED system and can be met in surprisingly high percentage of cases (Shingo, 1985).

According to the SMED system set up operations can be divided into two categories, internal and external. Internal operations are operations that can only be done when the machine is stopped and external operations are operations that can be done while the machine is running. A die for a machine can only be attached when the machine is stopped (internal operation) while for example bolts to attach the die can be assembled and sorted while the machine is running. These findings were what first inspired the creation of SMED system and the idea to convert internal operations to external becomes the foundation of the system (Shingo, 1985).

Traditionally, to reduce the impact of set up time companies have had to increase lot sizes to lower the amount of time loss of each product. This will lower the set up negative impact on productivity but carries some disadvantages, which according Shingo (1985) are the following:

- Requires the customer to make larger orders to avoid high prices
- Larger costs related to inventory
- Larger quality problems, as this method requires mass production techniques
- More labor related to inventory and large batches

The SMED system can according to Shingo (1985) benefit an organization compared with the traditional techniques both indirectly and directly. Directly, applying the SMED system reduces errors and safety during changeovers, increase product quality and reduces time spent with fine tuning the machines, this mainly due to standardizations of the changeovers. Indirectly SMED will reduce inventory, increase product flexibility and the rationalization of tools.

3.5 5S
5S is a system of steps used by organizations to arrange work areas for improved performance, comfort, safety and cleanliness. Overall it can improve efficiencies in the work space and improve productivity (Peterson, Smith, 1998). Besides improving productivity, 5S has a synergic or cooperative effect that emphasizes organizational efficacy. This means that the “team” effort will far more exceed a single person’s effort. A cleaner work environment also creates a “transparency” where dirt and unnecessary items are exposed and can be cleaned or removed. This will not only create a safer more productive environment but can also give customers visiting the work area a better impression of the company (Kobayashi, 2008).
The 5s stands for Sorting, Simplifying Access, Sweeping, Standardization and Sled-Discipline, which can be summarized by (Peterson, Smith, 1998):

- **Sorting:**
  - Determine the frequency of usage for every item in the workplace
  - Mark the items that are not used and recycle, donate or auction these
  - Eliminate sources of clutter

- **Simplifying access to needed items:** This step involves arranging the items according to frequency of usage

- **Sweeping:** This activity primarily includes visually and physically sweeping the work area to find missing and misplaced objects, find repeated violations and identify housekeeping problems.

- **Standardizing:** If locations for tools and other needed items are standardized, it is easier for everyone in the workplace to locate needed objects quickly and sweep the area for higher cleanliness.

- **Self-discipline:** The last steps are intended to maintain the 5s procedure by making sure that all associates are doing their part to follow through the 5s actions agreed upon.

According to an article in “International Journal of Production Research” (Ablanedo-Rosasa, Alidaee, 2010) the most important factors for implementing 5s is investment in training for management and employees about 5s, it is continuously followed up and improved and is used beside and to support other quality improvement tools.

### 3.6 Spaghetti diagram

A spaghetti diagram is a part of the lean manufacturing strategy and is used as a tool to shows how material and workers move in a workstation when operating or performing its task (Theodore T, 2010). By mapping the physical movement of for example an operator it is possible to plan for reducing waste associated with unnecessary movement and transportation. Spaghetti diagram requires an identification of the process flow in the facility and a brief description of what is being done in the particular area. When analyzing the diagram, the variable TTD (total travel distance) is commonly used to see the total distance the operator or the part is traveling through the facility. According to Theodore T (2010), creating a spaghetti diagram can be summarized by the following steps:

1. Obtain an facility layout drawing and an existing rout sheet of a product of existing (if not it is necessary to create one yourself)
2. Draw a continuous curve starting at the first location at the routing sheet and continue with the remaining locations and calculate the TTD.
3. Estimate the travel time by using a 1.34 m/s walking pace or the speed of the device that is being mapped.
4. Move the process closer together or rearrange to reduce TTD.

A rough illustration of how a spaghetti diagram can look before and after improvements have been made are illustrated in the figures 3.9.1 and 3.9.2. This shows how rearranging workstations and tools can significantly reduce TTD.
3.7-3.8 Production attitudes and approaches

The last part of the theory chapter presents important areas and production attitudes that is necessary to consider for improving productivity in manufacturing companies.

3.7 Maintenance

Using highly complex, often automated, production machinery in manufacturing industries has required companies to improve and consider maintenance planning and develop maintenance concepts. Concepts such as preventive, condition-based and total productive maintenance are used and implemented in many industries, especially where production methodologies like JIT
(Just in time) are used, where down time of machinery needs to be minimized. It is certain that maintenance has an impact on several activities in an industry such as quality, production, work environment and safety, which makes it important to consider for sustaining an effective production (Al-Najjar, 2001).

### 3.7.1 Maintenance impact on production
Considering maintenance and establishing an effective maintenance plan generally aims to reduce the number of production stoppages and production time lost to down time of machines. It is known that fast delivery of products is highly desired for customers, which make down times a great risk for failing in delivering products in time. To avoid this risk companies needs instead to build a safety storage which creates costs as well.

Integrating maintenance into the production can be effective to avoid down time and optimize capacity of production stations (Al-Najjar, 2001).

### 3.7.2 Maintenance impact on quality
Maintenance can according to Al-Najjar (2001) have a large impact on variations in the production. Poor tool conditions in production machinery are closely related to poor quality output from the machine. If not enough time needed to maintain machinery in good condition is prioritized, scrap and rework will increase creating higher production costs and increase the capacity requirement of the machinery. This can lead to a vicious cycle where less production time available due to increased capacity requirements in an machine lead to even less time for maintenance, creating even more scrap etcetera. The vicious cycle poor maintenance might lead to is illustrated in fig 3.13.

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*Fig 3.13 an illustration of how poor maintenance might create an vicious cycle leading to poor quality. Source: Al-najjar, 2001.*
3.7.3 TPM – Total productive maintenance

Total productive maintenance is a maintenance concept that aims to increase the equipment efficiency and improve company’s processes. It requires operators involved in the process to be included in the maintenance tasks to establish continuous equipment maintenance, which aims to avoid losses in productivity (Ljungberg, 2000) (Al-Najjar, 2001). A commonly used tool to measure equipment efficiency in TPM is OEE, which stands for Overall equipment efficiency. This measurement shows how well a machines capacity is utilized by comparing its available production time minus stoppages, operator’s efficiency (the theoretical cycle time compared with the real cycle time) and number of defective products. An 100 % effective machine has no stoppages due to for example errors and set ups, no idle time where operators are not working during available time and scrap due to quality errors (Ljungberg, 2000).

Losses in equipment’s efficiency are according to Ljungberg (2000) caused by six main reasons categorized by the following titles:

**Stoppages and equipment errors** – Causing losses in production time by either unexpected machine errors or more frequently smaller stoppages generally only requiring small adjustments.

**Set ups and adjustments** – Caused by changing fixtures and adjusting the machine to new set ups.

**Idle production time** – Small stoppages caused by for example products getting stuck in the machine causes idle time that results in losses in productivity. Time wasted due to waiting is also put in this category.

**Reduced production speed** – Machine is not running at its optimal speed.

**Product defects** – Caused by quality errors in the products produced resulting in scrap or rework.

**Machine start-up losses** – Most machines are more or less unstable after a set up or when it haven’t been used for a period of time. This mainly causes rework in the process.

By reducing these efficiency losses, a machines capacity can significantly be increased. TPM aims to avoid these productivity losses by partially including operators in machine maintenance to establish continuous equipment service (Ljungberg, 2000).

3.8 Kaizen

Kaizen, which is originally created through the lean manufacturing system, stands for continuous improvement by constant small steps. It is a management strategy originally developed in Japan that in general terms aims for continuous improvement by involving all employees, from management to operators, in the improvement work (Imai, 1996).

Compared with the European and American result and innovation approach to management, kaizen focuses on process oriented management and decisions. The differences are illustrated in figure 3.5 which shows how a result oriented approach motivates and values for example its
employees and production by evaluating the results, while the process oriented approach motivates and improves the process and employees efforts to gain the results. The last mentioned approach is more a long-term way of management, as it is focused on employee’s efforts and generally requires changes in behavior. Result oriented approach on the other hand is more direct and short-term (Imai, 1996).

Figure 3.5 Process oriented values compared with result oriented values. Source: Imai, 1986.

The innovative and result oriented management has previously been proven effective during two decades before the collapse of the oil industry, when the market looked significantly different from today. The market then was characterized by:

- Fast growing markets
- Customer preferring large quantities before quality
- Low raw material prices
- Management that is more urgent to increase sales then lowering costs

Today the market is different. Because of the oil industry, among others, the market today is characterized by:

- Heavily increased prices of material, energy and manpower
- Markets and margins becoming tighter creating higher competition
- Customers increasing the value of quality
- Production capacity becoming a bottleneck

The change in the market forces change by the companies and the reason why the Kaizen strategy is becoming more popular is because it is adjusted to the new market.

For a kaizen guided management, an organizations work should always in the end aim to satisfy the customer. The customer is the foundation for every decision and improvement made in the organization (Imai, 1996).
Moreover, when it comes to management, a process oriented manager is not only interested in the results but the people’s efforts, commitment, communication etc. that led to the output of a process (Imai, 1996).
4 Model development

This chapter will present the model developed for improving productivity within aluminum profile producing companies. An introduction of the existing models used will be presented as well as the gaps filled to create the model developed by this study.

4.1 Model introduction

The model developed to solve the problem of how to improve productivity cost efficiently is based on the lean manufacturing strategy where the main focus is to eliminate waste and non-value adding activities (Petersson et al. 2009). While this model is a tool that aims to increase productivity, lean is a philosophy for management and the whole organization to apply that affects the whole production system and the attitude towards customers (internal and external) and other people involved in the organization (Liker, 2009). The model developed for this thesis aims to continuously with small steps introduce and implement the lean philosophy in an organization.

A commonly used tool in the lean philosophy is VSM (Value stream mapping) which is used to create a holistic process perspective of a production process. It provides information that helps to find steps in the production process where improvements could lead to higher productivity and shorter lead times (Rother & Shook, 2004). VSM mainly focuses on creating a continuous flow in the process which is desirable to reduce buffer sizes, storage or any other type of waste (Rother & Shook, 2004). A common problem with achieving a continuous flow in manufacturing companies is set up time (Petersson et al. 2009). Set up time may require buffer storage and can create constrains in the process. To eliminate this problem, the lean manufacturing tool SMED is used as a complement to VSM to reduce set up time as much as possible.

Why I have chosen to work with VSM in the model is partly to present the company to new angles of analyzing their production where finding improvements by a process perspective is emphasized. New problems that have not been found might be revealed when analyzing the process by this perspective, which can help the company to find new paths to improve productivity (Imai, 1986, Ljungberg & Larsson, 2012). Moreover VSM can identify constrains in the process. In the theory of constrains written by Dettmer (1997) every system and process is limited by the weakest link, the constraint. Every process must have at least one constrain and finding constrains can lead to an opportunity for improving the process as a whole.

To eliminate the impact process constrains and problems that causes losses in productivity, tools such as master production schedule and single minute exchange of die (SMED) is applied to suggest solutions that aims to increase productivity and reduce waste. The solutions suggestions will be used to create a map of a future state of the process that aims to create a process flow where value adding activates are emphasized and waste in the production is reduced as much as possible.
4.2 Model development

The model is created as a cycle where the first step is to identify company’s main strategy/vision and customer demands. These are then partially broken down to process strategies, critical factors for success and finally, process goals. The process goals are used to determine which process performance parameters that are of interest for improving productivity cost effectively and will eventually be used as a foundation for suggestion improvements and creating a future state of the process map.

The next step in the model is to identify where in the process problems are located that causes losses in productivity (constrains, low capacity etc.). By using value stream mapping (VSM) problems can be identified by an holistic perspective which helps to identify areas in need of improvement and avoid sub optimization from the start which can result in improvements not achieving any overall process improvements. (Rother & Shook, 2004). Process performance parameters of interest according to the process goals are in this step measured and documented.

The task for mapping the process should also include an analysis of how effectively the machines are producing to identify potential efficiency improvements. This can be found by for example analyzing the machines overall equipment effectiveness (OEE), which will also indicate if maintenance might need improvements (Ljungberg, 2000).

By analyzing the current state of the process, suggestions for improvements that aim to satisfy process goals can be made with the help of process improvements tools such as waste analysis, master production schedule and SMED.

With consideration to the lean philosophy, which aims to increase productivity by adjusting the process to create as much value to the customer as possible, and the suggestions for improvements (Liker, 2009), the desired future state of the process map can be created. An illustration of the desired future state of the process helps everyone involved in the process to know which improvements that needs to be done, creating a common goal and vision striving for satisfying the company strategy and customer demands. The common goals are recommended to be transformed into practical actions to make sure that the improvements are implemented (Rother & Shook, 2009).

If a low OEE is found in the processes equipment in step 2, improvements in the maintenance plan might need to be considered in the implementation phase to increase equipment capacity. By for example implementing operators maintenance according to Total productive maintenance (TPM), waste causing losses in productivity due to for example machine adjustments and stoppages can be reduced (Ljungberg, 2000). The implementation phase should therefor consider if operators needs education in equipment service to establish an effective maintenance plan.

The last part of the model circle is to review which effects the improvement actions have had on the process to evaluate deviations in the improvement process. Learning from mistakes is an important part of the model and knowledge from the improvement process will be used to start the circle again from step one. The model is developed in a circle orbit to make sure the company establishes an attitude towards continuous improvement.
The model is illustrated in the figure below where each process step is further described.

4.3 Illustration of the model

![Model Illustration]

Figure 4.2 a model developed for improving productivity by reducing lead time and finding waste and its root causes.

4.4 Description of the model

1. **Establish company’s strategic goals and customer needs.**
   It is important for all people involved in the project of improving productivity to be aware of the organization’s visions and strategic goals so changes can be presented and made according to them. To strive for a common goal is vital to achieve a result satisfying all involved purpose (Imai, 1986).
   It can also be necessary in this step to identify customer demands to find what in the process that adds value to the product and what is waste (Peterson et al, 2009). This is also necessary to identify what process performance parameters to measure in step 2.

2. **Map process**
   By mapping processes the organization can get an overview of how parts of the company interprets with each other and get an understanding how the process creates a value to the customer and the companies business goals. Revealing this information can give employees that are not in any contact with customers an understanding of how their work provides a value to the process chain and the customer. This holistic understanding of a process decreases the risk of a process being sub optimized, meaning that one
process station is improved with no consideration to how it is connected to the other process stations (Ljungberg & Larsson, 2012).

Using VSM to illustrate the products flow is an effective tool to find process steps where improvements can beneficially be made to improve the whole productions productivity (Peterson et al, 2009).

3. **Evaluate process performance parameters and find solutions to achieve process goals.**

Before creating a future state of the process, areas in need of improvements is analyzed further to find solutions to reduce waste and non-value adding activities. Using step one together with step two helps adjust the process according to the demand from the customer and companies goals.

As the model is developed for industries with cutting and drilling production stations, reducing set up time can effectively help the company to implement a continuous flow in the process, increase flexibility and reduce lead time (Shingo, 1985). Applying tools such as SMED can be an alternative as a part of a lean strategy to eliminate time waste and decrease lead time.

The process planning can also be analyzed with the help of master production schedule to balance the storage levels needed with respect to set up time by determining order quantities (Segerstedt, 2009).

4. **Develop a plan for a future state of the process with new conditions**

Mapping a process itself to find problems will not improve the process in any aspect. After creating a map of the process, a plan for an improved future state of the process needs to be created together with the suggestions for improvements and a focus on a production flow with a low amount of waste (Ljungberg & Larsson, 2012). It is important to use information from step one and develop a plan according to the goals from the company and customers’ demands.

This step is used together with step two as new facts may be required for developing the future process map while new ideas may appear with new facts (Rother and Shook, 2004).

5. **Implement plan**

It is important after determining the process goals and creating a future state of the map that actions are decided how to reach the goals and adjust the process according to the new process map. The map is important to create a common vision, making everyone involved in process aware of what is needed to be done to reach the common process strategies, and company strategy (Rother & Shook, 2004).

The implementation phase should consider if operators needs education to establish operators maintenance that aims to increase equipment efficiency (see chapter 3.7.3). The action order for implementing the plan for improving the process should according to Rother & Shook (2004) be determined by the process that employees have most knowledge about at the moment and gives the fastest improvement results (costs, productivity etc).
6. **Review results, and repeat (Continuous improvement)**

According to the Kaizen philosophy, higher efficiency in a company is most effectively made by small continuous steps towards improvements (Imai, 1986). This increases the chance for improvements being implemented, reduces the risk of negative consequences due mistakes and helps the organization improve their strategy by reviewing the results continuously. It also forces the company to learn from mistakes, making sure they are not repeated and increases the chance of succeeding in the future.
5 Empirical findings

The empirical findings present data gathered about the company. The chapter is divided into three parts where the first part includes a presentation of the company, the second general data about the production and the last part specific additional data needed to solve the problem.

5.1 Company description

Hydro is a Norwegian organization founded by Sam Eyde and Kristian Birkeland in 1905. They are today mainly focused on metal mining and sustainable energy and are located in 28 countries all over the world where Sweden is one of them.

The organization Hydro operates by three main principles, their reason for being (mission), their talent and their values. This includes creating a more viable society by developing natural resources and products in an innovative and efficient ways. Considering the environment and showing respect to the people living in area where they operate is a mandatory part of their organization. By for example replanting and restoring grounds they have gathered resources in, they make sure the least amount of harm possible is made to the environment they operate in.

My case company is a unit for fabrication and processing of aluminium extrusions. They are located in Vetlanda Sweden and have a production mainly based on cutting and drilling aluminium profiles by CNC machines. Their largest customers are Scania and Ericsson which are organisations operating in the transport and telecom industry

5.2 Data information gathering

In this section, existing data about the company, the process and the product is gathered from the case company needed for using the model developed in chapter four and solve the problem presented in chapter one.

5.2.1 Product description

Their product manufactured in the process that this study will investigate is an aluminium profile part of the fuel pump in some of Scania´s trucks. Scania is one of the world’s largest manufacturers of trucks in the world and have several locations in Sweden where Hydro delivers this product.

The product is manufactured in 19 different models. Each model uses the same production process stations but differs in the operations. Because this product is used in a fuel pumping mechanism, any loose parts on the material can have a large negative impact on the finished product (the vehicle). Scania has therefor high standards on the quality particularly for this product. They demand that every product produced is tested so no leakage or loose particles can be found on the product.

5.2.2 Production process

The production process consists of three main operation stations and are explained and illustrated below:
**Cutting:** When raw material is delivered it is first sent to the cutting station where parts are sawed in the correct length according to the articles specifications.

**Drilling:** The drilling is being processed in a CNC machine operating two different parts at the same time. The drilling process looks different for each product but uses four different fixtures that include all operations. Two fixtures can however be attached at the same time which makes it possible to process two different products with the same operation.

**Quality test:** The quality test consists of an operator testing every product separately by a vacuum test, making sure no leakage is found on the final product.

---

Figure 5.1 an illustration of the production process for producing the fuel spline for Scania

### 5.2.3 Customer orders

Together with a unit in Norway, Scania sends estimation each of how many of the 19 products that needs to be produced each week/day for a year ahead. This estimation is continuously being changed according to Scania’s demands and it is not until 48 hours before the products should be delivered that the order “freezes” and they know for sure which amount of each product Hydro are going to send to Scania. In the situation as it is today, the production planner will try to produce as many products of the same model possible to avoid set up times. This is however not always easy with the constantly changing orders and only 48 hours until the products needs to be delivered when they know for certain which products to send.

The table below shows the weekly demand of each product from last years production, counted from april 2013. Numbers might have been adjusted due to restrictions from the case company
5.3 Additional data gathering

This section includes additional data gathered that is necessary to apply the model developed in the research and solve the problem.

5.3.1 Problems with the production

Hydro believes today that the production needs to increase its capacity in their drilling station to fulfil customer demands. They have the perception that the drilling station is a bottleneck in their production and by finding ways to improve productivity mainly in this area they could reduce costs by for example not having to outsource production as they do today.

Hydro also believes that safety storage would reduce the risk of not being able to deliver the products in time to Scania, if for example an unexpected stop would occur in the production. This is however difficult to achieve today as production is running at its maximum capacity and this barely is enough to produce according to the demand.

5.3.2 Articles and related fixtures

The drilling process uses four different fixtures and can operate with two fixtures at the same time. Articles that are operated with each fixture is listed in the table below together with its weekly volume taken from last year’s production.

The last mentioned title “Okuma” is a machine that operates beside the drilling machine and is therefore not affected by changes of fixtures etc.

![Table 5.2 Customer demand, storage and used fixture for each article from april 2013](image-url)

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<th>Article</th>
<th>Production-volume year</th>
<th>Production-volume week</th>
<th>Fixture: 91-fix</th>
<th>86-fix</th>
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Table 5.3 Article list with production volume and matching fixture for each product

The information in the table will be used to analyse the current production planning and how this could be improved.

5.3.3 Articles and related fixtures

Set up times, cycle times and machine capacity can be of interested to calculate how to optimize machine capacity. The number presented in the table 5.4 includes an average of last production year’s daily demand and estimations of daily machine capacity, the cycle time to produce one product, the time for a fixture change and the costs for a fixture change and storing one product per day (actual production numbers might have been changed due to restrictions from the case company). The products have been categorized by which fixture they are produced with.

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<tr>
<td>Set up costs</td>
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*Table 5.4 production times and storage information for each product group*
6 Analysis – Model application

This chapter includes a comparison between the theory collected in chapter three and the empirical findings to make analysis how applying the model developed in this thesis effects productivity, lead time etc. The solutions suggested in section 6.3 is presented by the topic and then analyzed to evaluate its effects on the company’s production.

6.1 Company goals and customer demands

Together with the staff at Hydro, company’s strategies and customer demands have been analysed and connected with the production process and created process goals. This step is necessary to identify which factors in the process that is important to emphasize to fulfil the organizations strategies and customer demands (Ljungberg & Larsson, 2012).

The process goals that are identified have been limited to the scope of the thesis which means that they will be limited to the only the production process (Sales for example will not be included).

The importance of making process improvements according to company strategies has been highlighted earlier in the thesis. In this step, the company’s main strategy will partially be broken down to process goals, to see how satisfying the company’s main strategy is achieved in the process. The figure below illustrates how the company strategy is translated into process goals:

![Figure 6.1 company strategy and customer demands being subdivided into process goals](image-url)
With the main strategic goal for the company being “complete solutions based on customer demands”, the process strategy is set according to what the customer needs. It translates the organizations main strategy to survive as a business to a process strategy with consideration to the customer demands. Deliveries on time and complete process quality are a direct strategy according to customer demands while flexibility is desired to be able to offer fast deliveries to different type of orders.

Critical factors for success is set to short lead times and quality controls which aims to eliminate any possible quality errors and minimize time to produce products so customer orders can be delivered when promised.

The chart finally results in three process goals which will be used as a main target to satisfy the company strategy and customer demands. Reducing non-value adding activities, eliminating waste and minimizing quality errors all aims to reduce the process lead time (from delivery of raw material to finished product delivery to customer) and assure the customer that products will be of the required quality.

I the next step, a map of the process itself is created to find where improvements needs to be made.

6.2 Process map

The process map will be used to find where in the process improvements needs to be made to satisfy company goals and customer needs. From interviewing operators at Hydro, an overview of cycle times and setup times are analysed with a relation to each other. The process is illustrated and explained in the following paragraph:

Compared with the drilling and quality test, cutting has a relativity low set up time and cycle time. Improving this station will therefore not improve lead time but quality should still be considered to not affect the other work stations. The last station, quality test, has a high capacity due to the resources needed to increase capacity being operators. This makes it possible to easily increase capacity if necessary.

Drilling is in this case the production station where improvements will benefit the production process. The set up time indicates that waste and non-value adding activities are high compared with other stations in the production.
The striped arrows between the process steps show that Hydro is using a push system to deliver products internally. This means that products are ordered to be produced from the production control to all stations separately. The process stations then produce what is needed for the specific order and sends the product to the next station in the production. This will in Hydro’s case create an interim storage before products can be produced at the drilling station as cycle times and set up times are longer here compared with the cutting station.

With the relatively high amount of product variation and short amount of time before the order freezes (48 hours), the production planner has a difficult task with planning a production flow with low waste due to for example set up times. If the more products could be produced of the same type, changes of the machines fixtures wouldn’t be necessary in the proportion as it is now. This would reduce the amount of time wasted when the machine is not operating.
6.3 Evaluate process performance parameters and find solutions to achieve process goals

Mapping the process has showed that the cutting station is the constraint in the process and improvements here can benefit the whole process according to the customer demands and company strategies. The product variety creates large amount of set up time in this station which in a customer point of view do not create a value to the product. With consideration to the process goals identified in step one, several tools can be used to reach a more productive process.

Hydro is today sending production orders to all production stations ordering to produce what is demanded from the customer 48 hours before delivery of the products. If a supermarket system was to be implemented, Hydro could integrate this storage with the forecast to get an overview of which products that are available and which products that are needed to be produced. By integrating actual orders with the forecast and supermarket storage, Hydro could have real-time data of how the production needs to be planned to be able to deliver customer orders.

This process will be analysed with the use process improvement tools to help achieve the process goals of minimizing non-value adding activities and eliminating waste

6.3.1 Supermarket pull system

According to the lean philosophy, a process should strive for a continuous flow as much as possible to avoid interim storage and overproduction (Rother & Shook, 2004). This type of system only produces what the next step of the process needs, creating a pull system where the last step of the process uses the customer order to demand products upstream in the process. Waste in the form of overproduction, as mentioned, is with this system reduced and the risk of declining large batches due to quality errors is reduced as each product is produced one at a time, therefore tested one at a time.

A continuous flow is however not possible in every type of producing industry and interim storage will be created if it is wanted or not. This is mainly the case for processes where a production station has high amount of set up time or longer cycle times then the other stations in the same process.

In Hydro’s case, the drilling station has the highest amount of set ups and longest cycle time. Planning for a supermarket storage after the drilling station can help production planning become more efficient and easier to plan. Instead of planning the production individually to each production station, the planning will only effect the last step of the process, quality control, which pulls necessary articles from the supermarket storage implemented after the drilling station. Stock levels at the supermarket then indicates what is needed to be produced by the process stations upstream, drilling and cutting. With this system, the drilling station wouldn’t have to produce every single product in every order. Only the products that is needed to fulfil the supermarket storage which means that the production can continuously produce the same article in larger amounts, avoiding set up changes.

Implementing a supermarket system simplifies the production planning as they can focus on planning and ordering product deliveries only to one step of the production. The processes
upstream are only controlled and produce in order of what is required in the supermarket storage. To make this possible, capacity of the machine may need to be considered or increased as Hydro today are barely able to produce what is demanded from the customer.

Figure 6.3 supermarket system implemented after the drilling station

Compared with the current state of the process, the supermarket installed between the drilling station and the quality control makes it possible to send production planning orders to only the quality control station which gathers its needed products from the supermarket storage. Whatever is needed from the storage is then sent to as a production order to the drilling station so safety storage levels are satisfied. The levels of safety storage needed in this particular process will be discussed and analysed further in the following sections.

6.3.2 Master production schedule (MPS)

Master production schedule is used to translate orders into planned production with the goal to use resources available optimally. With Hydro, an effective production planning can help reduce delivery times, increase delivery assurance and reduce time wasted in the production (for example reduce time waste due to fixture changes). An effective master production schedule can as well support sales by providing information about when deliveries can be made and make sure that orders can be delivered when demanded from the customer.

The table below illustrates how daily production could be planned for one product with respect to the forecasted orders and current storage.
Table 6.1 an illustration of how production planning is integrated with storage and forecast

Table 6.1 shows in the first row a forecast of the daily demand of the specific product. The MPS section compares the current storage with the demand each day and orders to produce a set amount of products when the storage level falls under a certain amount. The number of products that is produced each time (order quantity) and the needed storage before ordering production is analysed further in the order quantity section and safety storage section in this chapter.

With the current situation, the production planner can only know for sure two days ahead what needs to be delivered. It is possible that the forecast for day three and further in the future might change. By integrating the MPS with the forecast and current storage, the system can adjust what is needed to be produced intact with the order forecast and storage to make sure products can be delivered on time. If for example the order forecast would change, the system recognizes this and orders to produce products adjusted to the new conditions. In the table 6.2, forecast have been changed which demands more products to be produced each period as this is controlled by the mean value of the daily forecast. The MPS has also changed the production order for day 6 to day 7.

Table 6.2 production planning of article 19...48 with changed conditions

Order quantities

When several products are using the same machine to be processed with set up time between the different products, production order quantity can have a large impact on the production time and costs (productivity). The challenge and the goal is to find a well-balanced order quantity for each product with the least amount of set up cost in relation to storage cost, with respect to still produce enough products to satisfy customer demands. According to Segerstedt’s (2009) model for planning production with several products processed by one machine, several factors needs to be considered to find the most cost efficient order quantity. These include customer demand, machine capacity, set up time/cost, storage cost and current storage.

The numbers necessary for calculating the optimal order quantity is presented in table 6.3 together with necessary data from the empirical findings and table 5.4. Products using the same fixture and are not in need of any set up changes between production have been calculated together to make the case more understandable.
### Table 6.3 Demand, storage and costs for producing the fuel pump at Hydro

Set up and storage costs are assumed to be 0.2 kr per product per day and 600 kr every time the machines fixtures need to be changed. This is calculated mainly considering the time needed to change the fixtures. The MCR is calculated by dividing the cycle time with the machine capacity that is available each production day. This ratio is used to calculate how much of the products demanded use the machines capacity.

Before proceeding with analysing how different order quantities effect the production, the least amount of production days that is needed to produce the product demand in these production days needs to be calculated. This is to make sure that it is possible to produce the products demanded with the current set up times and cycle times. The least amount of production days needed to produce each product demand at least once is calculated with the formula 3.14a;

\[
T_{min} = \Sigma Si / (1 - \Sigma Demand \times MCR)
\]

In Hydros case, T_{min} is equal to 2.19 which indicate that it is possible to produce all products with the current capacity. This also shows that it would take 2.19 production days to produce each product category according to the current demand. The reason why it takes more than one day to produce the product demand is due to the set up changes. If the set up time would be lowered would this result in significantly less production days needed to produce each product.
once (If the set up time was half of 14400 would this mean that every product according to its demand could be produced once each production day).

The time interval 2.19 production days is the fastest possible production rate that each product could be produced in a cycle. Producing the products demanded fast with low amount of products each production cycle might however not be the most cost efficient approach. A low amount of products produced each production cycle will result in small storage needed but requires more fixture changes (set ups). In the 2.19 production days, 3 set ups will be required which would mean that of the 165 564 seconds of production time available in these days, 43 200 would be wasted due to set up changes. It might instead be more efficient to increase the production order quantities and produce more of one product group (increase the production quantity) before starting the next product production and needing to change the fixture. How long the storage can provide products and the cost of storage still needs to be considered so products do not run out in the storage and costs due to storage are not too high.

The quantity of each product that should optimally be produced during a time interval needs to be analysed with consideration to set up cost for each product and storage cost for each product à day. The chart below illustrates how the order quantity affects the costs per day due to storage and set ups. Storage costs and set up costs are also illustrated to show how they are affected separately as well.

![Chart 6.1](chart61.png)

*Chart 6.1 Costs/P.day, set up costs/day and storage costs/day with conditions according to table 6.3*

The arrow points at which order quantity that the costs per production day will be the lowest, which is also the point on the x-axis where the storage cost and set up costs line crosses each other. If Hydro would produce the product with the lowest amount of production days possible ($T_{min} = 2.19$) would this result in a cost of 4200 kr each production day. It is therefore more
cost efficient to analyse and find an order quantity that optimizes costs related to waste and non-value adding activities.

**Production priority**

Another important task is the production order, or order prioritization. If a product is not produced before the storage level divided with product demand is below zero, the company can’t deliver products ordered by the customer. Product group A48/A62/A54 has for example a ratio between the storage and demand of 1,927 (see table 6.6) which means that the storage of this product group will last for 1,927 production days before running out of stock and needs to be produced again. The order that the products should be produced needs to be set so the products with the lowest storage/demand ratio are produced first.

The total amount of production days needed to produce all products once according to table 6.5 is 9.6 production days. The “Gap” indicates the difference between when the production must be started for the storage to not run below zero minus the accumulated time that has elapsed. A negative “gap” would indicate that the production will be started to late and storage will run out before production is ordered.

The critical P.start shows the production day in this production cycle which production day this specific product must be produced. It is calculated by subtracting the number of production days the storage will last for with the set up time. Settings according to the numbers in table 6.6 would be feasible for the storage to not become negative.

<table>
<thead>
<tr>
<th></th>
<th>91-fix</th>
<th>86-fix</th>
<th>53-fix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage/P.day</td>
<td>1,92</td>
<td>5,37</td>
<td>8,75</td>
</tr>
<tr>
<td>Order quantity (oi)</td>
<td>1050</td>
<td>718</td>
<td>280</td>
</tr>
<tr>
<td>Set up + Oq*Oi</td>
<td>4,91</td>
<td>2,87</td>
<td>1,82</td>
</tr>
<tr>
<td>Acc. Time</td>
<td>4,91</td>
<td>7,78</td>
<td>9,60</td>
</tr>
<tr>
<td>Critical P.start</td>
<td>1,73</td>
<td>5,2</td>
<td>8,6</td>
</tr>
<tr>
<td>&quot;Gap&quot;</td>
<td>1,7</td>
<td>0,3</td>
<td>0,8</td>
</tr>
</tbody>
</table>

*Table 6.6 Production prioritization with numbers according to table 6.5*

This would mean that the order quantity would decrease to 2048 which is approximately 100 products less than the optimal 2153, meaning slightly increased set up costs but is still necessary for making production possible.

The order prioritization is set so the products with less storage/P.day is produced first and should be updated continuously so changes in customer demands are accounted for which might demand changes in the product order. A product can also skip a production cycle if the gap would be larger than the cycle time, as this indicates that the products in store would be enough to last until the next production cycle.

**Safety storage**

The safety storage in Hydros case is calculated by formula 3.2, 3.3 and 3.4 found in the theory chapter 3.3.2 which considers the deviation in the production demand to determine the
minimum number of products needed in store to cover for changes in customer orders. The higher the actual customer orders differs from the forecast, the more amount of products will be needed in storage. The probability of which the safety storage will be accurate is also considered with the amounts of 99, 97, 95 and 95 percentage.

<table>
<thead>
<tr>
<th>Safety storage accuracy (%)</th>
<th>91-fix</th>
<th>86-fix</th>
<th>53-fix</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>136,58</td>
<td>16,67</td>
<td>62,83</td>
</tr>
<tr>
<td>97</td>
<td>110,79</td>
<td>13,52</td>
<td>50,97</td>
</tr>
<tr>
<td>95</td>
<td>96,72</td>
<td>11,80</td>
<td>44,50</td>
</tr>
<tr>
<td>90</td>
<td>75,03</td>
<td>9,16</td>
<td>34,52</td>
</tr>
</tbody>
</table>

Table 6.7 safety storage required with an accuracy range between 90-99 %

Table 6.7 shows the amount of products needed in store to cover for deviations in customer demands which is nesseary to consider for ordering when products needs to be produced.

6.3.3 Single minute exchange of die (SMED)

SMED aims to identify internal activities and convert those to external activities, reducing the time of set up when the machine is not operating. As set up time is directly a non-value adding activity, set up should be reduced as much as possible. Reduced set up time would result in lower amount of waste and non-value adding activates which satisfies two of the three process goals and the process strategy of a flexible production.

Reducing the set up time would mean reducing non value adding activities in the production which would have an effect on several factors in the production. Lowering the set up time by half would for example decrease the total cost per day due to storage and set up with 29 % and decrease the amount of production days for one production cycle. This means that fewer products are needed in storage lowering the storage costs as well as the set up costs.

The chart below shows how reducing set up time effects costs/P.day.
By using a spaghetti diagram together with the SMED techniques to reduce set up time, waste due to unnecessary movements during tools changes can be identified and eliminated which would make set up changes even more effective. 5s can as well be applied in this labour area to further structure and standardize the set up changes.

6.3.4 MPS planning with new conditions

With order quantities calculated to optimize the balance between products in storage to set up costs, the master production schedule would be designed as illustrated in table 6.8. The expected demand for each day is adjusted with formula 6.3 which uses the average demand from the previous day with consideration to the deviation with the actual order and the forecasted order. The actual orders and forecast from the customer is found in the forecast row. The MPS system will however react on the expected demand as this takes into consideration the probability of changes in the forecast, which is determined by the mean absolute deviation (MAD). An order will be ordered when the current demand/storage falls below one production day plus the safety storage. This makes sure that storage will be enough to provide products every production day according to the customer demand. By integrating the MPS with production planning system, number in the forecast row can constantly be updated which then effects the demand and production order.
### Table 6.8 Master production schedule with new conditions

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>day 27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>01</th>
<th>02</th>
</tr>
</thead>
<tbody>
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<td>137,0</td>
<td>164,6</td>
<td>170,7</td>
<td>158,5</td>
<td>152,8</td>
<td>122,3</td>
<td>97,8</td>
</tr>
<tr>
<td>Forecast</td>
<td>139,6</td>
<td>205</td>
<td>275</td>
<td>195</td>
<td>110</td>
<td>130</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MAD</td>
<td>20</td>
<td>18,26</td>
<td>18,93</td>
<td>20,15</td>
<td>20,03</td>
<td>19,36</td>
<td>19,15</td>
<td>21,41</td>
</tr>
<tr>
<td>Storage-safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>storage</td>
<td>225</td>
<td>1070</td>
<td>795</td>
<td>600</td>
<td>490</td>
<td>360</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Storage/P.day</td>
<td>1,87</td>
<td>7,8</td>
<td>4,8</td>
<td>3,5</td>
<td>3,1</td>
<td>2,4</td>
<td>2,9</td>
<td>3,7</td>
</tr>
<tr>
<td>MPS</td>
<td>1050</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
<td>0,0</td>
</tr>
</tbody>
</table>

6.3.5 Increase productivity and minimize quality errors with TPM

With Hydro’s current situation, the capacity of the drilling process station is at its maximum capacity. Because of the high product demand the machine must operate whenever available, leaving little time for maintenance. The risk with not prioritizing maintenance is products being produced with deviations in quality due to poor equipment condition and machines capacity not being utilized to its potential. The poor tool conditions can according to Al-Najjar (2001) lead to a vicious cycle where product errors creates scrap and rework, which increases the production costs and requirements of the machine capacity, leaving even less time for maintenance. The cycle then starts again as less time for maintenance worsen equipment conditions even more.

An ideal maintenance plan, according the Total productive maintenance (TPM) concept, is achieved when the operators is performing continuous maintenance of the machines where they work. It is the operator that has the most experience of the machine and it is a waste of human resources to not include them in maintaining the machines in good condition. This maintenance approach requires that the maintenance department cooperates with the operators and their work are combined and not separated. The operators task to improve machine conditions should according to TPM include cleaning machine parts and find causes for contamination, continuously inspect the machine and its process output and organize the workspace according to for example to the 5S method. These tasks require educating the operators for them to know what is important for the machine output (what is the product requirements from the next process step) and what in the machine to inspect to assure high machine condition.

With an effective maintenance plan, product variations can decrease and rework minimized, creating a positive circle that reduces production costs and increases capacity of the machine. Reducing quality variations can lead in Hydro’s case to not needing to perform a quality control in every product, which would reduce even more costs in the production.

6.4 Future state of map

The future state of the process map is created in this section with the process goals as a foundation. Improvements have been taken into consideration according to the calculations in 6.3. The future state of the process map is explained in the paragraph below.
The production planner is only sending production orders to the quality control station which gathers products needed in the supermarket storage after the drilling process station. The supermarket storage orders and pulls what is needed from the drilling station. Recommended order quantities is determined by the calculations in the 6.3 section which is set to make sure that the production is cost efficient and has products enough to support demand from the customer. Installing a supermarket storage with raw material would decrease the lead time when the drilling process starts its production. Instead of ordering material from the supplier, raw material will be available in the factory when products are demanded from the drilling station. This means a shorter path for material to reach the drilling production station when demanded, in other words shorter production lead time in this station.

As discussed in section 6.3, reducing set up time would decrease the process lead time and reduce costs due to non-value adding activities. This is set as a process goal which is prioritized at the drilling station as reducing set up time here would have the largest impact on the productivity. The star indicates that a kaizen approach is used to improve this factor which means that the approach to improve this factor will be with small continuous steps to achieve the long term goal.
To reduce the lead time even further when products are ordered for production in the drilling station, supermarket storage could be implemented after the cutting station as well.

![Diagram of the aluminium manufacturing process at Hydro with additional supermarket storage system before and after cutting production station.](image)

**Figure 6.5 alternative map of the desired future state of the aluminium manufacturing process at Hydro with additional supermarket storage system before and after cutting production station**

Installing this storage would theoretically mean that the lead time would be equal to the cycle time (assuming the time for gathering products from the storage can be neglected). The amount of products in the safety storage calculated in 6.3 can with these conditions decrease significantly, as the safety storage is determined partially by the production lead time (see formula 6.1).

### 6.5 Implement plan

With the future state of the process map being constructed, a plan to implement it is needed to make sure this work was not for nothing. Instead of trying to change the production radically it is more efficient according to the kaizen strategy to take small steps to achieve the wanted future state of the production process. The new process map might require improved conditions evaluated in step three for implementation to be possible. A list of the process goals is listed in the table below together with actions that aims to improve conditions and achieve the goals.
<table>
<thead>
<tr>
<th>Process goal</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce waste and non-value activities</td>
<td>Implement a supermarket storage after the drilling process</td>
</tr>
<tr>
<td></td>
<td>Reduce set up time in the drilling station</td>
</tr>
<tr>
<td></td>
<td>Implement storage with raw material and storage after the cutting station</td>
</tr>
<tr>
<td>Minimize quality errors</td>
<td>Establish an maintenance plan where operators are continuously monitoring the machines</td>
</tr>
</tbody>
</table>

The order for improvements is recommended to be as the actions are listed in the table. Implementing the supermarket storage after the drilling process station would make the production planning in section 6.3 feasible which would have the most positive results for improving productivity (compared with the other actions to reduce waste and non-value adding activites).

6.6 Review results, repeat

The review phase is important to identify and analyse deviations in the implementation plan. This means that this phase should mainly be focused on what actions has not been satisfying according to the process goals. This helps the company to learn from their mistakes and adjust actions when the cycle is repeated (Rother & Shook, 2004).

Reviewing the results from the improvements actions helps establish a cycle of continuously improving the process. It also decreases the negative impact of improvements deviations by identifying these and analysing how the goals can be achieved with corrections of the actions. The phrase “trial and error” can be used which allows mistakes but requires correcting actions and adjustments in improvements actions.
7 Results
This chapter will present the results from comparing theory with the empirical findings by each step of the model.

7.0 The model
The main result of this thesis, which has been tested on a case company, is the model developed in chapter four. By applying the model on a case, an analysis could be conducted to see how improvements in production productivity could be made. The model developed in the thesis helped the company identify what parameters in the process that should be considered to satisfy the company’s strategic goals and found where in the process that improvements needs to be made to improve the whole process chain. Suggestions to improve the process was then presented by analysing the current state of the process with process improvement tools such as master production schedule, single minute exchange of die, total productive maintenance etc. The effects of the process and maintenance improvement methods on the process productivity was analysed to give the case company and foundation for improvement decisions. The analysis found that by increasing productivity with optimizing production planning and implementing an effective maintenance plan, products quality could be increased and costs due to waste and quality errors could be reduced, increasing in a long term the company’s competitive advantage. Conclusions could also be made that maintenance has an effect on productivity by reducing scrap and rework, minimizing the risk of stoppages and optimizing machine process speed. The analysis therefore showed how improving maintenance effects productivity positively as well.

The model finally uses a desired, more productive and efficient future state of the process map which is used as a common layout so everyone involved in the process has an understanding of what needs to be improved to increase the company’s customer satisfaction.

Chapters 7.1-7.6 will explain in more details the results found in the research by each step of the model.

7.1 Company goals and customer demands
The first step of the model was to identify together with the staff at Hydro the main company strategy, which was then partially broken down to process strategy, critical factors for success and finally process goals. To satisfy mainly the company strategy and the customer demands, the process goals resulted in reducing non value adding activates, eliminating waste and minimizing quality faults. Achieving these goals would result in a more flexible and cost efficient process with its main goal to satisfy customer needs.

7.2 Process map
The next step of the model was to create a map of the current state of the process. The scope of the process map was to be from receiving raw material to delivery of finished products. From talking to the staff at Hydro, a relation between the set up times and cycle times could be found which showed that the drilling process station had the relativity highest process lead time with
consideration to its capacity. The result from the process map showed that the drilling station was the constraint in the process considering production process lead time and focus for improvements was to mainly be put here.

Mapping the process also showed how information was sent to the production station and how products were sent between the stations as well. Sending production orders to each production station created a push system where products was produced according to what was ordered from the customer and then sent to the next production station. This resulted in a bottleneck at the drilling station as this process step had longer cycle times and set up times.

7.3 Analyze process performance parameters and find solutions according to process goals

In the next model step, process performance parameters was analysed to find solutions that would improve the process according to the company strategy. The first suggestion was to implement supermarket storage after the drilling process which would enable production planning to only send production orders to one production station instead of all. The production station (quality control) would then gather needed items from the supermarket storage which would pull products needed upstream in the process. The supermarket storage is in the solution integrated with the production planning system which ordered the production from customer forecasts. Knowledge about the forecasts and current storage is then the foundation of creating a production planning solution that aims to reduce non-value adding activities and create a cost efficient production.

The minimize costs in the production, a planning system is suggested which uses cycle times, set up times/costs, storage costs etc. together with storage stock balance and customer demand forecast. With the use of these parameters, an order quantity of each product group could be determined for each production cycle that balance the storage costs for each product with the set up costs.

A table of which product group that should be prioritized for each production cycle was also determined using parameters from the same table. The prioritization makes sure that the stock level of a product group will not fall below zero, making sure that products can be delivered in time to the customer (one of the two customer demands). The table is updated continuously by integrating it with the production planning system and the current result with the term as it is now is presented in the table 6.6.

To finally determine that stock levels would not fall below zero, safety storage was calculated which was decided as a result of the accuracy of the forecast and a constant that was set according to how high the probability is needed to make sure the safety storage will cover variations in the demand. The analysis showed how lowering lead time would result in significantly smaller safety storage required, which would lower costs due to storage costs.

An analysis was also made to find how the set up time affects the production process with consideration to time and costs. Chart 6.4 showed that the cost á production day due to storage
and set up would decrease with 29% and the production cycle would could decrease with 20 days, which means that fewer products needs to be stored (lower storage costs).

### 7.4 Future state of the process map

The future state of the process map was created as a result of the solutions suggested in step three of the improvement model. The greatest difference suggested in the process map was the implementation of the supermarket storage after the drilling process which simplified and enabled production planning to order a more cost efficient production. The same suggestion was then implemented for the raw material after the drilling process which would result in lowering the production process steps lead time (from ordering material until finished product). This would also suggest that the production stations more or less only produce what the next production station needs due to the pull system.

Another goal set to improve the process was to reduce the set up time at the drilling station which positive effects have been discussed in chapter 7.3. By including this in the process, everyone involved in the production is aware of improvements that need to be made so a common vision and goals is created.

### 7.5 Implement plan

The plan of the new process map is implemented by using the process goals from model step 1 and plan actions that needs to be taken to achieve the goals. Moreover is the map of the wanted state of the process used as a layout to make sure that everyone involved in the process is aware of what needs to be improved. To reduce waste and quality errors, the results from the analysis suggests that operators could beneficially be educated in machine service to establish a continuous maintenance plan according to TPM. The result of the actions that is suggested to improve the process is presented in the table below:

<table>
<thead>
<tr>
<th>Actions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implement supermarket storage after the drilling process.</td>
<td>Creates a pull system upstream in the process which enables a cost efficient production planning.</td>
</tr>
<tr>
<td>Reduce set up time in the drilling station.</td>
<td>Increases flexibility in the process which reduces the need of storage and increases cycle times.</td>
</tr>
<tr>
<td>Implement storage with raw material and storage after the cutting station.</td>
<td>Reduces the time from ordering production to finished product in a production station and therefore reduces the amount of products needed in a safety storage.</td>
</tr>
</tbody>
</table>
Educate operators in machine service to establish a continuous maintenance plan according to total productive maintenance. Reduces the risk of stoppages and results indirectly in higher product quality by ensuring good tool and machine condition.

7.6 Review results, repeat
Reviewing the outcome of the process improvement actions can help the company adjust the actions taken to achieve the process goals and company strategy. It helps the people involved in improving the process to learn and evaluate reasons for mistakes. The review results and repeat step also establishes continuous process improvement which is an important part of the lean philosophy and kaizen production strategy.
8 Conclusions

8.1 Answer to the problem formulation
The model developed in this thesis aims to help companies find problems in their production which limits productivity. Finding the parts in the production that constrains the production flow is the first step to improve the production process. Regardless to what the company strategy is, reducing costs due to waste and partially non-value adding activities will be beneficial for an organization. The model therefore suggests improvement tools and methods that can reduce waste and non-value adding activities.

The results from the case study at Hydro, which was an investigation of cutting and drilling process operations, showed how balancing the production order quantity can help optimize set up costs in relation to storage costs. It also showed and motivated how reducing set up time can affect productivity and can increase the cost efficiency in a production process, if the bottleneck in the process is first identified.

Increasing productivity by cost effectively planning the production will not only cut costs but also save production time. Time that can be used for example maintenance which would avoid unexpected stoppages and increase quality due to better tools conditions etc. Higher quality products due to an effective maintenance plan will not only result in higher customer satisfaction but increased productivity as well as less scrap is produced an less rework is necessary.

8.2 Recommendations
A list of actions recommended to cost effectively improve productivity in my case company’s aluminium production process is presented below:

- Integrate an MPS system between sales forecasts and production.
  - By doing so, the company can cost effectively plan production order and order quantities. This also aids to make sure that products in store and in production will be enough to satisfy expected customer demand.
- Implement a supermarket storage after drilling station.
  - A supermarket storage after the drilling station would establish an pull system instead of an push system making production planning simpler and more efficient as an effect of a pull system is that each process station only produces what is needed from the next process step.
- Strive for reducing set up cost at the drilling process station with the use single minute exchange of dies techniques.
  - The analysis shows how reducing set up time in this production station would decrease the need of a safety storage significantly and reduce total costs per production day. Reducing set up time as well increase flexibility of the process meaning fewer products can be produced each production cycle which reduced the need of storing products.
- Establish a maintenance plan by evaluating number of quality errors in the production.
Conditions of tools and machines are in many aspects related to the condition of the output. Reducing scrap and rework will help the company increase their already small capacity of the production process.

8.2 Future research
My recommendations to future research are to test the model on more cases to increase validity and find new tools which could strengthen the results of applying the model.

Due to lack of data and time, actual numbers such as quality errors and previous forecast deviations could not be incorporated with the model for solving the problem formulation. Using real data in a case company and evaluating the result could provide interesting knowledge about how different production areas affect each other.

Applying the suggestions for a company could also develop the implementation phase where an actual situation could be studied and learned from where theory has its restrictions.
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Appendix 1 – Normal distribution table

NORMAL DISTRIBUTION TABLE

Entries represent the area under the standardized normal distribution from $-\infty$ to $z$, $\Pr(Z < z)$
The value of $z$ to the first decimal is given in the left column. The second decimal place is given in the top row.

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<tr>
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<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
<th>0.06</th>
<th>0.07</th>
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</tr>
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Values of $z$ for selected values of $\Pr(Z < z)$

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Source: [Online].
Appendix 2 – Table showing how order quantities effects set up and storage costs (T is the number of days needed in the production cycle to produce the number of products ordered).

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<th>T</th>
<th>Cost/P.day</th>
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<th>Set up cost/day</th>
<th>Storage costs/day</th>
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