A model to increase profit by optimizing the production process within a cutting station: A case study

En modell för att öka lönsamheten genom optimering av produktionsprocessen i en skärande bearbetningsstation: En fallstudie

Authors: Anton Petersson, Peter Hallberg
Supervisors: Matias Taye Hailemariam, Mirka Kans
Examiner: Basim Al-Najjar
External Supervisors: Alexander Bengtsson, Henrik Nilsson
Date: 2013-06-03
Course Code: 2SE09E, 15 credits
Subject: Terotechnology
Level: Bachelor

Department of Mechanical Engineering
Abstract

Studies have shown that it is necessary for manufacturing industries, in order to stay competitive and increase the profitability, to work with optimizations and continuous improvements of processes. Existing models and philosophies aiming for this, such as PDCA (Plan Do Check Act), IDEA (Investigate Design Execute Adjust), DMAIC (Define Measure Analyze Improve Control), and Lean Production, are either ambiguous or only focusing on one specific area or field. Due to this it is not suitable to apply these singly at a cutting station because root causes to problems can derive from many different factors. The purpose of this thesis has been to develop a model, with the advantage of having a clear and structured approach, and still considering all affecting factors of the cutting station. This leads to a better chance of finding the actual root causes, consequently maximizing the profits gained from the improvement solutions suggested. The model has been applied and tested on a case company and it has been proven to be suitable to use when optimizing a cutting station. Eight alternatives for possible improvements were found, where five of these were estimated to generate more than 800 000 SEK in cost savings each year. For the other three there were no estimations done due to the large extent of the suggestions, but it is believed that these will have an even larger impact on the profitability than the other alternatives. The results found will provide a solid foundation for the company in order to achieve the best possible outcome, when completing the rest of the model. The model has been developed for cutting stations but with small modifications it can be applied on any other production station in a plant.

Sammanfattning

Studier har visat att det är nödvändigt för tillverkande industrier, för att kunna bibehålla en hög konkurrenskraft och en ökad vinst, att arbeta med optimeringar och ständiga förbättringar av processer. Existerande modeller och filosofier som har detta som mål, såsom PDCA (Plan Do Check Act), IDEA (Investigate Design Execute Adjust), DMAIC (Define Measure Analyze Improve Control), och Lean Production, kan vara otydliga eller fokuserar endast på ett specifikt område eller fält. På grund av detta är det inte passande att applicera dessa individuellt på en skärande bearbetningsstation, då felorsaker kan härstamma från många olika faktorer. Syftet i detta examensarbete har varit att utveckla en modell som har fördelen att ha ett tydligt och strukturerat tillvägagångssätt, men fortfarande ta hänsyn till alla påverkande faktorer i den skärande bearbetningsstationen. Detta medför en större chans till att hitta den verkliga felorsaken, därmed också maximera den tjänade vinsten från förbättringslösningarna som föreslagits. Modellen har blivit applicerad och testad på ett fallföretag samt blivit bevisad att vara passande att använda vid optimeringar av skärande bearbetningsstationer. Åtta alternativ för möjliga förbättringar har hittats, varav fem av dessa var estimerade att generera mer än 800 000 kr i kostnadsbesparinger varje år. På de andra tre alternativen var inga estimeringar utförda på grund av storleken på förslagen, men dessa tros ha en ännu större inverkan på vinsten jämfört med de andra alternativen. Dessa resultat tillhandahåller företaget med en solid grund att stå på, för att kunna uppnå bästa möjliga utfall när resten av modellen slutförs. Modellen har utvecklats för skärande bearbetningsstationer men kan, med mindre modifikationer, även appliceras på vilken produktionsstation som helst på en fabrik.
Acknowledgement

We, the authors of this thesis, are two students studying Industrial engineering at Linnaeus University, Växjö. This thesis has been written as the final work before graduating and receiving our bachelor degrees.

During the thesis we have been in contact with several persons, who have made this study possible to conduct. First of all, we want to express our sincerest gratitude to all involved people at our case company, sharing valuable time, knowledge and information. Especially thanks to our tutors Alexander Bengtsson and Henrik Nilsson at the case company, for their commitment and guidance throughout the project. Also, thanks to the cutting operators for their time and information during the interviews.

Furthermore, we also want to show our appreciation towards our tutors at the university, Matias Taye Hailemariam and Mirka Kans, for their commitment, feedback and support during the study. They have, among other things, inspired and encouraged us when obstacles have been faced, and for this we are very grateful.

At last, we would like to thank the students and teachers that have taken their time to review and give feedback on our thesis during the different progress seminars.

Thank you all!

Alea iacta est ~ Julius Caesar (49 BC)

Växjö, 2013-06-03

Peter Hallberg

Anton Petersson
Key Definitions

In the list below it is presented definitions of terms that are recurring in this thesis. Most of the terms are frequently used in industrial contexts; therefore definitions are stated by well-known authors or published standards. Some of the terms are not recognized as standard terms, but are important in the understanding of this thesis. These terms are instead defined by the thesis authors and this is shown by the absence of reference in the definition.

Activity – Something which is done, especially something which is involved in creating a product or a service (Business Dictionary, 2013).

Criticality - A reference to the level of importance for something. A high criticality indicates that the impact will be severe if this is not functioning.

Distribution – The movement of goods and services from the source through a distribution channel, right up to the final customer, consumer, or user, and the movement of payment in the opposite direction, right up to the original producer or supplier (Business Dictionary, 2013).

Efficiency – 1) The ratio of useful work performed to the total energy expected (BS 3811: 1993).

2) A term expressed qualitatively to reflect the relationship between the output from, and the output to, an item or an activity (BS 3811: 1993).

Improvement potential - A reference giving a combined view of, both the current status for something and the possibility of improving this.

Lead time – Number of minutes, hours, or days that must be allowed for the completion of an operation or process, or must elapse before a desired action takes place (Business Dictionary, 2013).

Logistics – The transportation and distribution of goods and services (Russel, Taylor, 2011).

Maintenance – The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function (BS 3811: 1993).

Management – The organization and coordination of the activities of a business in order to achieve defined objectives. Management is often included as a factor of production along with, machines, materials, and money. Management consists of the interlocking functions of creating corporate policy and organizing, planning, controlling, and directing organization’s resources in order to achieve the objectives of that policy (Business Dictionary, 2013).

Operation – The combination of all technical and administrative actions intended to enable an item to perform a required function, recognizing necessary adaption to changes in external condition (BS 3811: 1993).
Optimization – Balance between maximum benefit and minimum costs by selection of the best combination of characteristics (BS 3811: 1993).

Process – A group of related tasks with specific inputs and outputs (Russel, Taylor, 2011).

Production – The processes and methods used to transform tangible inputs (raw materials, semi-finished goods, subassemblies) and intangible inputs (ideas, information, knowledge) into goods or services, Resources are used in this process to create an output that is suitable for the use or has exchange value (Business Dictionary, 2013).

Profitability – It is the best overall indicator of company performance; it measures the outcome of all management decisions about sales and purchase prices, levels of investment and production, and innovation, as well as reflecting the underlying efficiency with which inputs are converted into outputs (Rantanen, 1995).

Purchasing – The activity of acquiring goods or services to accomplish the goals of an organization (Business Dictionary, 2013).

Quality – 1) The characteristics of a product or service that bear on its ability to satisfy stated or implied needs (Russel, Taylor, 2011).

2) A product or service free of deficiencies (Russel, Taylor, 2011).

Utilization – The actual usage of resource compared with the maximum possible whilst it is available for use during a given period (BS 3811: 1993).
Abbreviations

PDCA – Plan Do Check Act
IDEA – Investigate Design Execute Adjust
DMAIC – Define Measure Analyze Improve Control
IDEF0 – Integration DEFinition for function modeling
QFD – Quality Function Deployment
CBA – Cost Benefit Analysis
MCDM – Multi Criteria Decision Making
CIPC – Criticality and Improvement Potential Comparison
# Table of Contents

## 1. Introduction

1.1 Background ............................................. 1  
1.2 Problem Discussion .................................... 2  
1.3 Problem Presentation ................................... 3  
1.4 Problem Formulation ................................... 3  
1.5 Purpose .................................................. 3  
1.6 Relevance ............................................... 3  
1.7 Delimitations / Limitations ............................. 4  
1.8 Time Frame ............................................. 5

## 2. Research Methodology .......................................................... 6

2.1 Research Approach ......................................... 6  
2.2 Research Perspective ..................................... 7  
2.3 Research Design ......................................... 7  
2.4 Research Strategy ....................................... 9  
2.5 Data Collection ......................................... 10  
2.6 Validity .................................................. 11  
2.7 Reliability ............................................... 12  
2.8 Generalizability ......................................... 12  
2.9 Our Research ........................................... 12

## 3. Theory ................................................................. 14

3.1 Process .................................................... 14  
3.1.1 Process Flowchart ................................... 14  
3.2 Production Process ..................................... 15  
3.3 Cutting Techniques ..................................... 16  
3.4 Profitability ............................................. 16  
3.5 Improvement Models ................................... 16  
3.5.1 Plan Do Check Act .................................. 16  
3.5.2 Investigate Design Execute Adjust .................. 17  
3.5.3 Define Measure Analyze Improve Control .......... 18  
3.5.4 Lean Production Improvements ..................... 19  
3.6 Decision Hierarchy Triangle ............................ 20  
3.7 Integration DEFinition for Function Modeling ..... 20

VI
| CONTENTS |
|-----------------|-----------------|
| 3.8 Quality Function Deployment | 21 |
| 3.9 Multi Criteria Decision Making | 22 |
| 3.10 Tree Diagram | 23 |
| 3.11 Brainstorming | 24 |
| 3.12 Fishbone Diagram | 24 |
| 3.13 Cost Benefit Analysis | 25 |
| 4. Model Development | 26 |
| 4.1 Theoretical Inspiration | 26 |
| 4.2 Introduction to the Developed Model | 27 |
| 4.3 Model Presentation | 28 |
| 4.4 Criticality and Improvement Potential Comparison | 33 |
| 4.5 Model Summary | 35 |
| 5. Empirical Findings | 36 |
| 5.1 Company Description | 36 |
| 5.2 Company Goals | 36 |
| 5.3 Cutting Process Description | 37 |
| 5.4 Profitability Measurement | 39 |
| 5.5 Future Improvement Plans | 39 |
| 6. Model Testing | 40 |
| 6.1 Evaluate and Choose Cutting Station to Improve – Step 1 | 40 |
| 6.2 Identify and Choose One Affecting Factor to Focus on – Step 2 | 41 |
| 6.2.1 Define Goals in Cutting Station – Step 2.1 | 41 |
| 6.2.2 Find Affecting Factors for the Cutting Station – Step 2.2 | 43 |
| 6.2.3 Evaluate and Choose Focus Factor – Step 2.3 | 46 |
| 6.3 Determine Suitable Improvement(s) – Step 3 | 47 |
| 6.3.1 Identify Activities Regarding Chosen Focus Factor – Step 3.1 | 47 |
| 6.3.2 Suggest Improvement(s) for Activities – Step 3.2 | 49 |
| 6.3.3 Evaluate and Choose Most Profit Generating Improvement – Step 3.3 | 54 |
| 7. Results | 58 |
| 7.1 Application Results | 58 |
| 7.2 General Study Results | 60 |
8. Conclusions ................................................................................................................. 61
  8.1 Answer to the Problem Formulation ........................................................................... 61
  8.2 Criticism of the Model .............................................................................................. 62
  8.3 Future Research ........................................................................................................ 62
  8.4 Recommendations ................................................................................................. 62

References ...................................................................................................................... 63

Appendix A: Literature Review

Appendix B: Pre-calculated Profile Lead Times and Costs

Appendix C: Project Results

Appendix D: Root Cause Explanations and Assessments

Appendix E: Time Measurements of Selected Process Activities
List of Figures

Figure 1: Our Research ........................................................................................................ 13
Figure 2: Process Flow Chart ............................................................................................. 15
Figure 3: PDCA Cycle ......................................................................................................... 17
Figure 4: IDEA Cycle ........................................................................................................... 18
Figure 5: DMAIC Cycle ........................................................................................................ 18
Figure 6: Decision Hierarchy Triangle ................................................................................ 20
Figure 7: Example of IDEF0 with Box and Arrows ............................................................. 21
Figure 8: Quality Function Deployment ................................................................................ 22
Figure 9: Example of a Tree Diagram .................................................................................. 23
Figure 10: Example of a Fishbone Diagram ........................................................................ 25
Figure 11: Developed Cutting Station Optimization Model ................................................ 28
Figure 12: Developed Cutting Station Optimization Model, with Suggested Tools .......... 35
Figure 13: General Steps for Cutting Processes ................................................................... 37
Figure 14: Product Path in the Cutting and Processing Area ................................................ 38
Figure 15: Diagram of Differences between Pre-calculations and Actual Outcomes .......... 40
Figure 16: Decision Hierarchy Triangle of Goals ................................................................. 42
Figure 17: IDEF0 of Manual Cutting Station ....................................................................... 44
Figure 18: Tree Diagram of Activities Regarding Operator Procedures ........................... 48
Figure 19: Fishbone Diagram of Operator Procedures ......................................................... 50

List of Tables

Table 1: Gantt Chart of Time Frame ..................................................................................... 5
Table 2: Example of a MCDM Matrix ................................................................................... 23
Table 3: Example of a CIPC ................................................................................................. 33
Table 4: Example of Project Results .................................................................................... 39
Table 5: Total Project Results, Jan-Mar 2013 .................................................................... 41
Table 6: CIPC of Manual Cutting Station ............................................................................ 47
Table 7: Assessments of Possible Root Causes ................................................................... 51
Table 8: Most Significant Root Causes ................................................................................ 58
1. Introduction

In this chapter the problem will be introduced to the reader through a background, problem discussion and a problem presentation. The purpose and relevance of the study will also be presented, as well as delimitations for the thesis. Lastly, a time frame of the study is shown.

1.1 Background

A common goal within most manufacturing industries today is to be profitable (Olhager, 1995), i.e. gain as much revenue as possible from the invested capital. In order to achieve a high profitability, one of the requirements is to have paying customers, which is, according to Bergman and Klefsjö (2012), the source to the entire business. To reach, and also to keep the customers, it is important for companies to produce products that provide a value for the customers. Selling prices should be set as low as possible according to the given quality, and delivery times should be kept within acceptable tolerance levels (Ingwald, 2009). Due to the escalating technology development during the last decades, communication and transportation between far distant locations has become more easily accessible. There has also been establishments of new trading agreements between countries, which both have resulted in a worldwide marketplace for customers (Russell, Taylor, 2011); (Martin, 2008). This globalization has contributed to a more competitive market, where the customers are given more alternatives in choosing and comparing different suppliers of similar products (Friedman, 2005); (Naumann, Hoisington, 2001). Due to differences in laws, regulations, and cultures depending on the geographical location, companies have different prerequisites, which will have large impacts on the manufacturing (Russell, Taylor, 2011). A major difference is for instance seen in the conditions of the employees. In high cost countries, there are high expenses of employees due to current work standards, such as salaries, insurances and other personnel related costs, which are regulated from laws and unions. On the contrary, low cost countries does not have similar regulations in the same extent and this is one of the reasons to that many costs can be kept lower, leading to that suppliers from these parts of the world can offer lower prices on the final products (Martin, 2008).

To be able to preserve production and maintain operation within high cost countries, such as Sweden, companies must find solutions for improvements and to lowering different costs, in order to compete with the low cost countries (Martin, 2008). One area that is connected with high expenses, but also has many opportunities for improvements, is the production area in a plant (Kinnander, Almström, 2006). According to Nyström, Harjunkoski and Kroll (2006), a possibility to decrease these expenses is by optimizing the production area and ensuring that its different resources are utilized efficiently.

Common activities in manufacturing industries, which could be the target for optimizations and improvements, are cutting (e.g. cutting, turning, milling, drilling, planing), grinding, sealing, hardening and assembling (Aganovic, Jonsson, 2001); (Tlusty, 2000). In order to optimize these activities, or even the entire production process and its resources, it is important to know the included resources and which factors that are affecting the production.
1.2 Problem Discussion

A production process can be divided into direct and indirect resources, where both are essential in order to transform raw material into a finished product. The direct resources are machines, personnel, and tools, while the indirect resources are energy, competence and facilities (Aganovic, Jonsson, 2001). According to Al-Najjar (1997), these resources, as well as the ability of manufacturing a product in a specific tolerance or to a given quality, will be affected by different factors. Some of the resources can be seen as affecting factors as well. The affecting factors, which both are resources and other factors, are: equipment (manufacturing, measuring), material (type, specification), people (operator, maintenance, skill), methods (training, age, experience, speed, temperature, load), environment (temperature, vibration), procedure (steps order, adjustment), service (lubrication, screw tightening), management (planning, support management) and marketing (customer requirements). The effect towards the resources differs depending on what type of industry or what type of product being manufactured. Although, regardless of type of industry, all factors will affect the production in some extent, and by achieving a high quality of the mentioned factors, the possibility of keeping tolerance levels and quality specifications within the production will increase (Al-Najjar, 1997).

Manufacturing companies are constantly striving to maintain a high overall quality in their production in order to stay competitive and increase the profitability. To reach this high level of quality, a necessity is to work with continuous optimizations and improvements (Bergman, Klefsjö, 2012). Improving and optimizing processes is a way to do things better, cheaper or faster (Flanigan, Scott, 1995). By doing improvements and eliminating problems in a production station, the process will run more efficient and productive, consequently increasing the profitability of the production station because costs will be decreased (Campbell, Jardine, McGlynn, 2011). Due to the mentioned factors that Al-Najjar (1997) describes affecting a production process, a problem could be to find ways to consider all factors when optimizing and improving a production process.

There are several accepted models and philosophies used for improvements and optimizations, such as PDCA (Plan Do Check Act), IDEA (Investigate Design Execute Adjust), DMAIC (Define Measure Analyze Improve Control), and Lean Production (Langley, et al., 2009); (Bicheno, et al., 2013). Some of the models and philosophies are too general and do not include a practical methodology to follow. Other models include clear methodologies but are instead focusing on a specific area or field. These clear models are beneficial to use because it is important that an improvement model has a clear roadmap and is easy to understand and follow (Langley, et al., 2009), but they lack the possibility of considering all affecting factors in a production process. According to Hill (2005), the existing improvement approaches should be considered as a part of an overall philosophy instead of a list of independent alternatives, in order to achieve the best outcome.

All improvement models have similar goals; to increase efficiency, decrease costs, or make the process better, which all will increase the profitability. Some of the mentioned models are
aiming to do improvements that will have a positive impact on the quality, which will, according to Bergman and Klefsjö (2012), per se also increase the profitability.

Cutting, also known as chip removing, stands for the largest share of the activities in a manufacturing industry (Tlusty, 2000). Due to the commonness of cutting processes, it is important to optimize and continuously improve a cutting station. A cutting station, similar to many other stations in an industry, is affected by many factors (Al-Najjar, 1997), and all factors are not taken into account in existing improvement models. Research that has been made regarding this area has focused on optimizing tool utilization, material quality or feed speeds etc. and no research has attempted to treat a holistic optimization, where all affecting factors are being considered (see Appendix A).

1.3 Problem Presentation
Because no cutting station is flawless and there is always potential for improvements, it is important to find a suitable and efficient approach to optimize cutting stations in the best way possible. Some of the existing improvement models are ambiguous and hard to follow, and others are focusing on a specific area. Because a cutting station is affected by many different factors, it is not suitable to use an improvement model that is focusing on a specific area because it may lead to an unwanted exclusion of factors, which could be the factors containing the actual root causes to a problem.

1.4 Problem Formulation
How to optimize the production process within a cutting station in order to increase profitability?

1.5 Purpose
The purpose of this thesis is to develop a model that can be used to systematically identify root causes to problems in a production process within a cutting station, considering all factors affecting the process and still is structured and easily applied, in order to optimize the production process and consequently increase profitability.

1.6 Relevance
According to Tlusty (2000), cutting is the most common activity in manufacturing industries. Because of this, it is relevant to find ways to optimize or improve the cutting stations in a plant, in order to increase the profitability or the competitiveness.

Existing improvement models and approaches, such as PDCA, IDEA, DMAIC, and Lean etc. (Langley, et al., 2009); (Bicheno, et al., 2013), are either focusing on a specific area or are ambiguous and hard to follow. This leads to that all affecting factors, stated by Al-Najjar (1997), are not considered; alternatively it is difficult to use the models or approaches. It is relevant to develop a model that has a holistic perspective, considering all affecting factors in
a cutting station, and still has a clear and structured roadmap, making it possible to actually apply the model in practical cases.

A literature review has also been conducted (see Appendix A) to see if there has been research regarding improvements of cutting stations or processes. The hits that were found on the different searches were not showing any articles describing a holistic-viewed and clear optimization approach that was wanted. Instead the articles treated optimizations and improvements regarding tool utilization, material quality or feed speeds etc., making those articles irrelevant for this case. This increases the relevance of this study because an area, where no research has been found to be conducted before, is treated.

It will also be possible to translate or modify the developed model in order to use it for different types of production processes, making the model more relevant and useful due to its high compatibility and adaptability.

1.7 Delimitations / Limitations
This thesis includes both delimitations and limitations. One delimitation is that the model will only be tested at one single case company. Another delimitation will be that some measurements, which will be the foundation for the outcome estimations, will not have a preferable amount of samples in order to ensure a high level of significance. To compensate this, a supervisor and several operators will be consulted in order to receive more accurate estimations. Furthermore, a delimitation is that some estimations will not be possible to perform due to the extent of some of the improvement suggestions. As a result, to do adequate estimations of these suggestions, a more thorough analysis would have to be done, which would require a much longer time than is available for this study. These improvement suggestions will instead be discussed, and positive and negative aspects will be highlighted, in order to give the best possible estimation. Finally, the developed model is only intending to increase the profitability, and other aspects, such as safety, environment, business culture, change acceptance etc., will not be incorporated and considered.

The limitation will be the time frame of approximately ten weeks for the study (see Table 1), which leads to that implementation of the improvement suggestions cannot be done, consequently making it impossible to measure any effects from the improvements. This is because it is the management responsibility to take the decision to implement the suggestion or not, which is not possible to wait for. For this reason, the study will stop after the estimations and discussions regarding the improvement suggestions have been done. Recommendations will be stated, which the management can use as support when later taking the improvement decisions.
### 1.8 Time Frame

*Table 1: Gantt Chart of Time Frame*

<table>
<thead>
<tr>
<th>Chapter</th>
<th>M</th>
<th>March</th>
<th>April</th>
<th>May</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Introduction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methodology</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empirical Findings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjustments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submission</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Research Methodology

This chapter describes different research methods and approaches used in scientific studies. There will also be explanations of how to ensure a study to be valid, reliable and generalizable. Finally, it is presented how this thesis is conducted, with regards to the mentioned methods and approaches, as well as how the validity, reliability and generalizability are ensured.

2.1 Research Approach

A researcher strives to produce theoretical information that is close to the reality as much as possible. To enable that, basis in form of data and information is needed for the specific area. This type of basis is also known as empirical findings. A researchers’ ambition is to relate the theory to the reality, and this is a major challenge a researcher will repeatedly have to face throughout a study. There are mainly three different approaches for drawing conclusions when performing a scientific study of theory and empirical findings (Patel, Davidson, 2011). These are induction, deduction, abduction and these will be described in a more detailed way below the next three headings.

**Induction**

In an inductive approach of performing a study, no theory is needed in the first section of the study. Instead the approach allows the researcher to discover new findings in the chosen area. From data gathering through observations, empirical findings and other information, the researcher creates new theory to the science. The negative aspect with this approach is the reliability of the study. The theory might be harmful because the findings of the study only derive from one specific case, where the results of the findings could differ from reality due to the lack of generalization. An example of this could be if a study is performed on a particular group of people or a specific time of a year or day. A constructive way of looking at this approach is that the method enables the creativity of the researcher (Patel, Davidson 2011).

**Deduction**

According to Patel and Davidson (2011), a deductive way of approaching the study is to start by making use of already existing theory and then create conclusions based on those. The collected theory in a specific area will afterwards be tested on a specific case, where observations are made and empirical data are collected. The theory also determines which data that is needed for the research and how the information should be interpreted. The method enhances the objectivity of the study because of the usage of already existing theory, but the process of the research reduces the subjectivity of the author. A disadvantage of the method is that the collected data in the specific case might differ from case to case (Bryman, Bell, 2005).
Abduction
An abductive study is a combination of previously mentioned research approaches, the inductive and the deductive approach. In an abductive approach, the first part of a study is inductive and the second part will remind more of a deductive way of working. In the first part, the inductive part, the researcher gathers data from a particular case in order to form theoretical hypotheses. In the second step of the approach, the theoretical hypotheses are addressed to be tested on new cases. Doing like this will enable the existing theory to be continued or developed. The advantage of using this method is the transparency in the way of performing the study and this approach also prevent the researcher from being ingrained in the two earlier mentioned approaches (Patel, Davidson, 2011).

2.2 Research Perspective
According to Patel and Davidson (2011), a scientific study can be conducted from different perspectives, where the main two are positivism and hermeneutics. An explanation of these two will be presented in the next two paragraphs.

Positivism
Positivism derives from the natural science perceptions and appeal to the objectivity and positivity in data. According to Patel and Davidson (2011), positivism is based on logical and clear observations through logical reasoning, and other phenomena that are more complex should be reduced. The positivistic researcher builds the research upon empirical observations logic and achieves facts by observing the behavior. Patel and Davidson also states that positivism supports the uniform structure of knowledge and encourage that every new research should be developed from the same approach. The approach should also be based on general rules, where the interaction between causes and effects is treated. This approach implies that a researcher that has a positive perspective when conducting a study, often express the hypotheses and theories in mathematical terms (Bryman, Bell, 2005).

Hermeneutics
The approach is predominant in human- cultural- and social science. Unlike the objectivity of positivism, the hermeneutics allow the researcher to interpret and reflect the data in a more subjective way. This perspective takes the human behavior into account, such as thoughts, impressions, and feelings and takes advantages of that when interpreting the object of the study. The hermeneutics is often associated to a qualitative way of understanding and interpreting, while the positivism is more related to quantitative- and statistical methods of interpreting data, which are objective (Patel, Davidson, 2011).

2.3 Research Design
A research design is chosen when starting conducting a study and this choice is between qualitative or quantitative research. According to Creswell and Clark (2007), there is also a third research design, mixed methods, which is a combination of both the qualitative and quantitative design. These research designs define the plans and the procedures that the
research should strive towards. The choice of design should be based on which approach the researcher assumes that the study will take. This involves procedures of inquiry, which is strategies, and also the specific methods that should be used when collecting, analyzing and interpreting data. When choosing research design, it is also important to consider what kind of research problem that are being addressed, as well as personal experiences and which type of people or community the research is attempting to reach (Creswell, Clark, 2007). Below is a list with the three research designs, together with a belonging explanation:

**Quantitative Research**
Quantitative research is when the researcher is measuring factors, which can give a result presented in a numerical value of some sort. The values received could be used together with statistical tools in order to understand or solve a certain problem (Creswell, 2009). The data collected in this research design is close-ended and it could be gathered from e.g. different measuring instruments and close-ended checklists. Another example of data sources could be documents including statistical information, such as census records or attendance records (Creswell, Clark, 2007).

**Qualitative Research**
Qualitative research is a way to obtain a different and deeper knowledge of a subject, which quantitative approaches may not give (Patel, Davidson, 2011). This could be e.g. exploring and understanding how individuals or groups are working in a specific environment (Creswell, 2009). The data collection in this research design is presented in words, text or images and could be collected by asking questions to participants during interviews etc. Qualitative data could also be gathered from e.g. observations of participants or audiovisual materials, such as videotapes or audio recordings (Creswell, Clark, 2007). The information gathered in a qualitative research is open-ended, which means that it is the researchers’ responsibility to interpret the meaning of the data (Creswell, 2009). Due to this phenomenon, there are no stated procedures or routines the qualitative researcher can use, which leads to that there are many unique approaches when handling qualitative data. It is important that a qualitative researcher has a good overview and understanding of the qualitative research field in order to conduct proper studies when interpreting, categorizing and using the data (Patel, Davidson, 2011).

**Mixed Methods Research**
This is a combination of the quantitative- and qualitative research designs, with the aim to strengthen the study by making use of different aspects from both designs (Creswell, 2009). It is not about collecting both quantitative and qualitative data, but instead mixing the research designs when approaching a problem. This is done in order to give a better picture and understanding of the problem, compared to if the two research designs are used stand-alone (Creswell, Clark, 2007).
2.4 Research Strategy

Finding the best method or strategy for solving a given task could be hard enough. If the researcher is aware of the advantages and disadvantages regarding different strategies, the probability of choosing the right strategy will increase significantly (Dahmström, 2001). Some of the most common strategies will be briefly described in the next three headings.

Case Study

A case study is research and analyses regarding a single unit or a bounded system (Smith, 1978, cited in Merriam, 1998, p.19). Examples of cases are: an individual, program, event, group, intervention, or community. (Merriam, 1998) According to Wallén (1996), an advantage with conducting case studies is that it enables the researcher to see how the study tends in real situations, because it shows something about a specific business or process etc. However, Wallén also describes that it is not certain that the results found is the same on other objects, because only one or a few cases has been studied. According to Bryman (2011), case studies are often categorized as qualitative research, because it is rather common with qualitative methods in case studies, such as participating observations and unstructured interviews. Although, it is more appropriate not to categorize it, because in case studies often both qualitative and quantitative data gathering methods are used (Bryman, 2011).

Experimental Methods

When performing a new explicative investigation, it could be of interest to know if a new treatment of an object has any effect or not. Furthermore, it could be interesting to see if there is a connection between the treatment and the result. To receive an answer for this, statistical experiments need to be done. An experiment is characterized by having a number of units and then finding out which effect, treatment or action different tests have on the different units. When doing an experiment it is important to be able to interpret if the effect is caused by the treatment or if there are any other explainable reasons to the behavior (Dahmström, 2001).

Survey Studies

Studies based on surveys can be conducted in many ways. The aim with a survey is to obtain information from a sample of people, and from that sample present a result with the idea of covering an entire population. The most important here is to ensure that the sample of people actually conform and represent the entire population. The questions asked in a survey should be the same to every respondent and under the same conditions. The information can be gathered from questionnaires or through interviews. The purpose is to find out what a large amount of people think about a particular question, and then compare the answers. Conducting a survey study is a well-used strategy when the aim is to answer the questions what, where, how, and when, but it becomes more difficult when the researcher wants to know the question why (Dahmström, 2001).
2.5 Data Collection

There are different techniques for gathering data in order to receive the wanted knowledge. Depending on the current situation, some are more advantageous than others to apply. Which techniques to use in which situations are in some cases obvious but it could also be quite difficult to determine the most suitable collection technique in some situations. Choosing the right technique at the right moment will help the researcher to collect the most relevant data for the study (Merriam, 1998). In the next three headings a description of three common techniques will be described.

Observations

According to Patel & Davidson (2011), observations is something people are doing continuously in their daily life and it is a guidance for future actions, but it is also a powerful tool in science for gathering information. Unlike the daily observations, science observations have to be structured, planned and performed in a systematic approach. According to Merriam (1998), a participant observer uses his or her own existing knowledge and experience when interpreting new observations in order to make it more reliable. By doing observations, the researcher will get an understanding of how a process acts, by actually see or observe it. By observing a process in its natural environment, the researcher is enabled to see how the process is being affected by factors from real situations, instead of reading about it (Patel & Davidson 2011).

Interviews

According to Patel and Davidson (2011), conducting an interview is a technique for collecting data and it is based on that questions are asked by a researcher to one or several persons, where the purpose is to obtain information that someone else knows. Interviewing people is a useful technique when the needed information cannot be observed. Examples of such information are feelings, thoughts, or intentions. It could also be events that have occurred in the past. The challenge with this technique is to perform the interview in a way so that the questioned person allows sharing the wanted information. Interviews can be performed in different ways, where the most common way of choosing is by determining the amount of structure needed for conduct the interview. Merriam (1998) divide the different types of interviews as: highly structured, semi structured and unstructured. In highly structured interviews, the questions and the order of them are predetermined and the interviews reminds of an oral form of a written survey. A disadvantage with this type of interviews is the limitation of asking supplementary questions. An advantage is that these types of interviews gives a possibility to compare answers form different respondents. An unstructured interview is more like a conversation and allows the researcher to respond during the interview, but this method requires more creativity of the person asking the questions. A semi structured interview is a combination of a highly structured- and an unstructured interview and in this, the interviewer can ask different types of questions, making the interview more flexible (Merriam, 1998).
Patel and Davidson (2011), mention the importance of considering anonymity and confidentiality when conducting interviews. Also, the person that is being interviewed might be subjective and because of that it is important to explain the reason and the motive to the interview.

**Literature Review**

According to Merriam (1998), a literature review is a way to ensure that the research is contributing to the specific field that is studied and that the research made has not already been conducted by other researchers. By searching for existing studies in similar areas, the researcher can see how the current study can advance, refine or revise what is already known. The researcher can benefit or simplify his/her work by conducting a literature review because it is very helpful to know what has been done before, methods used, and problems faced (Merriam, 1998).

**2.6 Validity**

According to Creswell and Miller (2000 cited in Creswell, 2009, p.191), is validity based on “determining whether the findings are accurate from the standpoint of the researcher, the participant, or the reader of an account.” Creswell and Miller also mention that there are several terms used when describing validity, such as trustworthiness, authenticity, and credibility (Creswell and Miller, 2000 cited in Creswell, 2009, p.191).

Creswell (2009) suggests that a researcher incorporates validity strategies in order to ensure and convince the reader that the validity of a study is high. There are several different strategies for this and Creswell also suggests that it is a proper approach to use several of these and justify how they have been considered in the study, in order to increase the validity. Some of the strategies that Creswell are describing are presented in the list below:

- Triangulate different information sources regarding the same topic and compare them to each other in order to justify and confirm the trustworthiness of the content.
- Present negative and discrepant information regarding the topic as well as positive. This is because there are always several perspectives of a topic and by considering this, the validity of the study is increased.
- Use peer debriefing in order to ensure the accuracy of the study. This means that a person should review and ask questions about the study in order to ensure that it is not only the researcher that accounts for the study.

(Creswell, 2009)

Merriam (1998) has a similar opinion in the validity strategies and she describes also that repeated observations of the same phenomena can increase the validity and this can be linked to a point regarding spending prolonged time in the field, which Creswell (2009) is also mentioning.
2.7 Reliability
According to Merriam (1998), the reliability of a study refers to in what extent the research findings can be replicated. This means that a high reliability of a study indicates that it will be the same or very similar findings from another research that is conducted in the same manner. Reliability is based upon the assumption that there is only one “reality” and by studying something repeatedly, the same results will be obtained. This means that determination of reliability is often simpler when conducting quantitative researches but it is difficult to determine it in qualitative research because human behavior is not static and will not show the same results every time. Although it is not certain that a qualitative study is, just because human behavior is involved, not reliable. Similar to strengthening of validity, the reliability of a study will be increased by doing measurements or observations of the same phenomena repeatedly (Merriam, 1998).

2.8 Generalizability
According to Bryman (2011), generalizability is describing in what extent a study can be replicated on other situations or environments that differ from the one that has been studied. A high generalizability shows that the research findings received from a sample can be expected for a whole population. It is therefore important that the sample, which could be a case company in a study, is not too unique and can be seen as quite equivalent to the population, which could e.g. be industries in the same area of business. If this is true, a study made on only one type of industry could be applicable on several others (Bryman, 2011). Generalizability has, according to Merriam (1998), another well-used term for defining the same thing, which is external validity.

According to Bryman (2011) there could be problems regarding generalization in qualitative researches because these kinds of researches often contains participating observations or unstructured interviews with a small amount of individuals. Due to this, many critics has an opinion that qualitative researches are impossible to replicate to other environments. Although, according to Williams (2000 cited in Bryman, 2011, p.369) there are other authors who says that qualitative research can be made with “moderate” generalizability. This means that the individuals that have been studied can be seen as examples of a wider population with identifiable features, i.e. the results can be considered and compared with other studies that have similarities. This gives the research increased generalizability in a way but qualitative researches cannot reach the same generalizability that quantitative researches can, where statistics and probability can certify a high generalizability (Bryman, 2011).

2.9 Our Research
In this thesis, it has been chosen to conduct the study from a deductive research approach. This approach is chosen because already existing theory will be gathered and then used in developing a new theoretical model that will be tested towards a case company. The study will mostly be conducted qualitatively because the problem formulation is stated in a way, making it most suitable to conduct a case study, which is a qualitative research strategy. The
theoretical data will be gathered using literature searches, where relevant books and scientific articles are used for gaining enough knowledge, in order to solve the formulated problem. During the study, a literature review will be made in order first to confirm the relevance of the study. Both of the perspectives, positivism and of hermeneutic will be used through this case study. The positivism perspective will be required because the gathered information is based on approved scientific articles and literatures. The hermeneutic perspective will be necessary because some interpretations will be made during the study, especially in observations and interviews.

The validity of the research will be ensured by using peer debriefing, in form of reviews and criticism from other scientific researchers that are familiar with this thesis, such as supervisors, examiner and opponents. The validity will also be strengthened by triangulating different information sources, i.e. having several sources in order to justify and confirm the gathered information. Finally, the validity, as well as the reliability, of the study will be improved because repeated measurements and observations of the same phenomena will be conducted. The validity and reliability will also be increased because persons with a good understanding and knowledge of specific areas will be included in the study, through interviews and consultations. The generalizability of the study will be ensured by developing a model that is possible to replicate and apply in other industries facing similar problems with manual cutting stations.

A graphical figure of the methodology of this thesis is illustrated in Figure 1 below:

Figure 1: Our Research
3. Theory

This chapter will describe the necessary theoretical methods and concepts that are needed to conduct this thesis. First there will be topics regarding processes in order to understand the target for the developed improvement model. Existing relevant improvement models will also be described, serving as an inspiration and a support for understanding the developed model. Lastly, tools that are going to be suggested for the model will be explained.

3.1 Process

According to Bergman and Klefsjö (2012), a process can be seen as an activity that is done repeatedly. For example, when manufacturing products, usually the product will pass through different production stations in order to transform raw material to a finished product. In every station, some kind of activity is carried out containing of different inputs, mechanisms, and controls. The inputs for the different activities are often the same. These repeated activities are usually called processes. Furthermore, processes are activities that linking the past activities to the future actions and by doing that, it will make it possible to predict the further actions and have a better control of the activity field. Working with processes also facilitates the understanding of the actions in the activity field, which will contribute in finding improvements within the business. A process could be seen as something that is moving forward, which also is the meaning of the word “process” (Bergman, Klefsjö, 2012).

According to Johansson et al. (1993) can a process be defined as “a set of linked activities that takes an input and transforms it to create an output. Ideally, the transformation that occurs in the process should add value to the input and create an output that is more useful and effective to the recipient, either upstream or downstream.” The given definition may provide a more mechanical view of a process but in reality it is more than that. It is very much about coordination between humans, which interact with each other and together create value from their individual competence (Bergman, Klefsjö, 2012).

3.1.1 Process Flowchart

According to Bergman and Klefsjö (2012), a suitable approach for visualizing complex processes is by creating a flowchart where the main process is broken down into different boxes, illustrating the flow in a graphical way. This helps the viewer understand the process and also a possibility to find bottlenecks within a process. The most common types of box are the activity-box, which is illustrated by a rectangular box. Another common box is decision-box which is characterized by a diamond box. Every flow starts with a start-box and ends with an end-box. The different boxes are linked together by arrows, showing how the flow runs. The flowchart is a constructive tool to with rather small recourses needed to give a clear picture over an activity which is relatively easy to understand, even for someone that is not familiar with the method. An example of how a process flowchart can look like is presented in Figure 2 on the next page:
3.2 Production Process

A production process is a part of the business process at a company and, according to Campbell, Jardine, and McGlynn (2011), a business process is formed by persons working together in different areas. Many of these areas are included in a production process as well, because in order to achieve an efficient production, many aspects have to be considered. Some of the most common areas, that are apparent in both a business- and a production process, are listed below:

- Purchasing
- Logistics
- Production
- Maintenance
- Distribution

Quality is also an essential part in completing a business, as well as the management controlling the areas (Campbell, Jardine, McGlynn, 2011). In a production process, raw materials are transformed into a finished product and in order to do this transformation, different resources are needed. These resources can be divided into direct and indirect, where the indirect resources consist of machines, personnel, and tools. The indirect resources consist of energy, competence, and facilities (Aganovic, Jonsson, 2001). In a production process within manufacturing industries, many different activities are often included, where the most common are cutting (e.g. cutting, turning, milling, drilling, planing), grinding, sealing, hardening and assembling (Aganovic, Jonsson, 2001); (Tlusty, 2000).

There are, according to Al-Najjar (1997), some factors often affecting a production process and its resources in different degrees. These are shown in the list below, together with examples of what the factors could contain:

- Equipment (manufacturing, measuring)
- Material (type, specification)
- People (operator, maintenance, skill)
- Methods (training, age, experience, speed, temperature, load)
As seen, there are many different factors that affect a production process and it could be beneficial to remember and consider this when doing actions regarding a process.

3.3 Cutting Techniques
Cutting processes are, According to Tlusty (2000), the most common of activities in manufacturing industries. In cutting processes it is included cutting, turning, drilling, planning, and shaping. Metal cutting stands for the largest share of all cutting processes but it is also common to cut in other materials, such as tree and polymeric materials etc. Cutting is also known as chip removing, due to that small chips are curled and broken of the material that is processed. (Tlusty, 2000)

3.4 Profitability
According to Ax, Johansson, Kullvén, (2009), a profitable business commonly refers to that a company is gaining profit, which means that the income is higher than the expenses. But to judge if the gains are sufficient enough, it must be set in relation to something e.g. the invested capital. By doing this will increase the comparability over time, between different companies and projects. When calculating the profitability it is usually expressed as:

$$\text{Profitability} = \frac{\text{Results}}{\text{Invested capital}}$$

There are several accepted key indexes for calculating the profitability of a company e.g. return on equity. Another common way of calculating the profitability is by using a method called rate of return. Rantanen (1995) describes profitability as: *It is the best overall indicator of company performance; it measures the outcome of all management decisions about sales and purchase prices, levels of investment and production, and innovation, as well as reflecting the underlying efficiency with which inputs are converted into outputs.*

3.5 Improvement Models
There are several improvement models that have been developed during the last decades. In the following sections, four examples of common improvement models and ways of thinking regarding improvements will be mentioned and briefly described.

3.5.1 Plan Do Check Act
Plan Do Check Act (PDCA) is, according to Bicheno, et al. (2013), the most used improvement model but also the model that is the hardest to fully understand. A problem is
that many companies are focusing on the second step, Do, and haste through the others. Deming, the creator of the model, has stated that it is very important that all steps are used in a balanced way and equally focused upon (Bicheno, et al., 2013). PDCA is an ongoing process and according to Basu (2004), does the PDCA cycle strive to continuously look for better methods of improvement. Below is an explanation of the four steps in PDCA, followed by Figure 3, which shows an example of the PDCA cycle:

**P – Plan:** In this step a plan is constructed, with defined actions to do. This plan is based on analyses made from collected data (Basu, 2004). Actions made in the plan phase should include: define customer needs, identify the problem, state goals, collect data and analyze it, search for root causes, educate if needed (Bicheno, et al., 2013).

**D – Do:** This step is where the plan is executed and the improvement are implemented (Basu, 2004); (Bicheno, et al., 2013).

**C – Check:** In this step, results from the implementation are checked and compared towards the goals in order to see if the improvement work has been successful or not (Basu, 2004). Actions that should be made in this step are, according to Bicheno, et al. (2013): check if the goals were reached, re-check the root causes, confirm the results, evaluate the improvement work, and check if the problem has been eliminated.

**A – Act:** If the changes have been successful, these should be established, replicated on similar problems and standardized (Basu, 2004). There are some actions suggested for this step, which are: identify additional improvements, document and work according to a new standard, inform everyone about the new changes, ensure that the problem does not return, celebrate and thank the involved persons (Bicheno, et al., 2013).

### 3.5.2 Investigate Design Execute Adjust

According to Bicheno, et al. (2013), Investigate Design Execute Adjust (IDEA) is an improvement model that is developed by Toyota for innovation and design solutions. It is similar to PDCA in many ways, and it focus on continuous improvements. The four steps of IDEA are shown on the next page, together with a belonging explanation, followed by Figure 4 that is showing the IDEA cycle:
I – Investigate: There should be an investigation of the needed facts to be able to fully analyze the problem. These facts could be regarding the problem, customers, needs, purpose, earlier solutions, or other helpful information.

D – Design: In this phase, different ideas of solutions are generated. It is possible to use all existing design tools in order to help finding these ideas and design a solution.

E – Execute: In this step is an experiment is conducted and the suggested solution is tested and controlled in a small scale.

A – Adjust: If positive results are found from the experiment, the solution should be brought closer or included in the standards of similar upcoming products. (Bicheno, et al., 2013)

3.5.3 Define Measure Analyze Improve Control

Define Measure Analyze Improve Control (DMAIC) is a model that is used as a core component in the Six Sigma methodology. It derives from PDCA, but is much more detailed because it has a clearer path to follow and in the defined roadmap there are many suggested tools that can be used. The general approach is divided into five steps. In Figure 5 below, the different steps of the DMAIC cycle are shown together with an explanation from Langley, et al. (2009, pp. 457):

D – Define: Define process improvement goals that are consistent with customer demands and the organization’s strategy.

M – Measure: Measure the current process (defect focus) and develop baseline for future comparison.

A – Analyze: Analyze to verify relationship and cause and effect of factors. Attempt to identify all factors that could be relevant.

I – Improve: Improve or optimize the process on the basis of the analysis. Transition to standard processes.

C – Control: Control to ensure that any variances are corrected before they result in defects.

Figure 4: IDEA Cycle

Figure 5: DMAIC Cycle
Because DMAIC is a core model of Six Sigma, many of the tools used in the different steps require large amounts of numerical data. Stamatis (2004) describes that some types of tools suggested for DMAIC are Statistical process control, Measurement system analysis, Failure mode and effect analysis, and analyses of statistics etc.

### 3.5.4 Lean Production Improvements

Lean Production is a way of thinking and it derives from Toyota Production System. According to Langley (2009, pp. 463), Lean Production is defined as “a systematic approach to identifying and eliminating waste through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection”. In Lean there are three keywords that are frequently used, value-adding, non-value-adding, and waste. Value-adding refers to what the customer are willing to pay for, i.e. an activity that changes form, fit, or function. Non-value-adding is not adding anything for the customer, but must be done in present conditions. Waste is activities that the customer is not willing to pay for and one of the biggest purposes with Lean is to remove these wastes (Langley, et al, 2009). According to Black (2008), there are seven types of wastes connected to; Overproduction, time, transportation, processing itself, inventory, motion, making defective products.

Lean does not have a specific approach to follow but it is based on five principles, which are listed below:

- Defining value from the customer perspective
- Identifying value streams, which are the required activities in order to provide a customer with a product/service
- Make the value-added steps flow smoothly
- The customers “pull” the products and services when needed
- Everyone strives for perfection

(Langley, et al, 2009)
3.6 Decision Hierarchy Triangle

According to Kreitner (2009), the activities in a company can be divided into three different levels to illustrate the hierarchy within the company. The highest level is the strategic, the second is the tactical and the bottom level is the operational. To get a better understanding, a graphical Decision hierarchy triangle is often used when dividing goals or decisions into three sections or levels (see Figure 6). The triangle can also show in which time frames goals are set or decisions are taken for, where strategic level goals or decisions referring to a long term view, while the operational goals or decisions handles short time frames.

![Decision Hierarchy Triangle](image)

**Figure 6: Decision Hierarchy Triangle**

**Strategic:**
The strategic level involves the management and top section in a company and should focus at long term goals or decisions that will have an impact on the whole business. Example of this may be decisions regarding suppliers, manufacturing levels, manufacturing locations, marketing strategies and so on (Kreitner, 2009).

**Tactical:**
In the tactical level the focus will be to adopt the top management goals or decisions in such a cost effective way as possible. This could for example be to finding the most effective transportation way, developing a purchase strategy or to develop a method for a cost effective storage (Kreitner, 2009).

**Operational:**
On operational level, goals are set and decisions are taken more or less every day to solve small problems that for example may occur in the production. An example of this can be to restructuring the schedule for the day if someone is ill (Kreitner, 2009).

3.7 Integration DEFinition for Function Modeling

Integration DEFinition for function modeling (IDEF0) is a function modeling method designed to find the decisions, actions, and activities in a manufacturing company in a graphical and structured way. An accurate used IDEF0 provides the user with valuable knowledge about the structure of the production, which can be used for further improvement
work. This tool helps identifying the functions belonging to a production process and also the needed things to perform those (Soung-Hie, Ki-Jin, 2002).

The development of an IDEF0 model is a hierarchical decomposition of activities divided into different boxes. The boxes should represent the different activities composed from a more general process or activity. The boxes are connected with different arrow entering or leaving the box. The arrows enable the boxes to operate simultaneously together with each other by transforming the output from the previous box as one of the input for the next box. Except from the input data from the previous box, each box has related data relevant for the specific activity (Soung-Hie, Ki-Jin, 2002). An example of how these data correlates to the activity is shown in Figure 7, together with Kappes (1997) descriptions of the data:

**Inputs**: Data or material used to produce an output of an activity

**Controls**: Data that constrain or regulate the activity and hence the transformation of inputs into outputs.

**Outputs**: Data or materials produced by or resulting from the activity. It must include the input data in some form.

**Mechanisms**: Resources (usually people, machines, or systems) that provide energy to, or perform, the activity.

*Figure 7: Example of IDEF0 with Box and Arrows*

### 3.8 Quality Function Deployment

Quality Function Deployment (QFD) is a matrix based analytical method aiming for taking advantages of the customers’ requirements in a graphical and systematical way. The QFD technique is often used in the planning phase when a new product is being developed. Like other quality tools and methods, QFD was developed by the Japanese in the early 1980s and is today an accepted technique all around the world, especially in the manufacturing business. The model is based on four different phases, which are connected to each other. In the first phase the customer needs are compared and converted to the products characteristics and in the second phase the design concept is chosen. In the third phase the critical parameters is taken in consideration and in the fourth and last phase the manufacturing instructions are identified. (Walker, 2002) An example of the phase in the QFD is shown below in Figure 8, together with a short explanation of the most important sections:
Customer Requirement (Whats): In this section the requirements from the customer are listed and are only based on facts from the customers.

Technical Requirements (Hows): This section explains the different technical requirement the product may have.

Relationship Matrix: Here is the relationship between “customer requirements” and “technical requirements” presented and can be described by numbers, percentage or symbols.

Correlation Matrix: Also called the roof and shows how the different “Technical requirements” affect each other. A common way to show this is by putting a plus or a minus in the square.

Target values: This area contains of recommended specifications of the product.

Figure 8: Quality Function Deployment

3.9 Multi Criteria Decision Making

People are continuously facing the challenge of taking superior decisions whether it is in their daily life or in professional context. The alternatives have to be carefully weighed against the multiple criteria, making the final decision naturally for the current situation. Decision in the trade and industry branch normally contains of multiple criteria, where the main criteria repeatedly consists of cost or price. Other common criteria are time, recourses or quality. One of the most well-known analysis concepts for structuring complex problem with multiple criteria is the Multi-Criteria Decision Making (MCDM). Making use of a MCDM allows the author to analyze and compare the different criteria against the decisions, leading to more information and better decisions. There are many approaches and methods for performing a MCDM, such as AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), and WSM (Weighted Sum Model). The choice of approach is depending on the available data or inputs (Agrell, 1995). Usually a MCDM analysis is expressed in a matrix, where the alternatives are set against the different criteria. It is possible that the different criteria is more or less important than the other and because of that, every criteria is often connected with a specific importance rate (Triantaphyllou, 2000). An example of a MCDM matrix is shown in Table 2, on the next page:
Table 2: Example of a MCDM Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria 1</td>
<td>0.2</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Criteria 2</td>
<td>0.3</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Criteria 3</td>
<td>0.5</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>ΣX</td>
<td>ΣY</td>
<td>ΣZ</td>
<td></td>
</tr>
</tbody>
</table>

3.10 Tree Diagram

The tree diagram allows the user to break down a problem, idea or other topics in a systematical way. The principal with the diagram is very simple but still targeted. The subject of the tree diagram is broken down into different levels in order to find the different components of the subject. This is best accomplished if it is performed in a group and if the subject is clear defined. The tool is suitable to use when a finding different causes to a specific problem. If this is done in group, a preferable approach is to let all the members of the group write possible solutions to the problem on different post-it-patches. When this section is over, the arising problem should be grouped with similar problems. The final step is to naming the similar problems into a heading. An example of how a tree diagram could look like is shown in Figure 9 below:

![Tree Diagram Example](image-url)
3.11 Brainstorming

According to Paulus and Nijstad (2003), brainstorming is a proven and well-used method for generating new ideas. It has been used to create ideas for many different types of problems or situations for hundreds of years. When brainstorming sessions are conducted, it is often emphasized and encouraged to prioritize quantity over quality of the idea generation, where as many ideas as possible should be found and then filtered in order to choose the most suitable. There has been research on whether brainstorming should be performed in groups or made individually. This research has shown that it is often more productive to brainstorm alone, i.e. a brainstorming group generates less ideas, compared to if all persons in this group would have work individually instead. Although, there are many benefits from working in groups, if the groups are assembled in a proper way, there can be a team spirit that increases the motivation in the group, leading to better ideas. It can be suitable to use a combination of both individual and group brainstorming in order to achieve the best results, where ideas can first be generated individually and then the results are consolidated in groups, which will lead to a high productivity and still keeping a high motivation in the team. (Paulus, Nijstad, 2003)

3.12 Fishbone Diagram

When trying to solve a problem there are often many possible root causes to the specific problem. The available methods for finding the different root causes are several and could be more or less applicable depending on the current situation. One way of doing this is by taking use of the cause and effect diagram, commonly called a fishbone diagram. This tool allows several people to cooperate through a brainstorming session aiming to find the potential causes to the problem or effect. When a root cause is identified, the tool is constructed to enable further, more detailed, reasons to the different root causes in order to ensure that all the possible causes will be found. The fishbone diagram organizes the causes in a graphical diagram, comparable to the bones of a fish, which gives a good overview of the current situation (Ishikawa, 1984).

The construction of the fishbone diagram starts with one horizontal line where the problem or effect is attached. From this main line there are several smaller lines coming out and each of these lines ends with a possible main cause or categorize to the problem. After this has been arranged, the brainstorming session can begin, finding different causes to the stated categories. For each identified cause, the process continues with trying to find out why the causes have occurred. These more detailed causes are linked with smaller bones connected to the previous cause (Ishikawa, 1984). An example of how a fishbone diagram can look like is shown in Figure 10 on the next page:
Cost Benefit Analysis (CBA) is a systematic analytical method, usually used in projects, with the intent to weight the benefits against the costs. One of the purposes of using a CBA is to determine whether a project is a good investment or not. Another purpose is to have the CBA as a foundation for comparing different alternative projects with each other in order to find out which alternative entailing the best investment. The cost and benefits are expressed in monetary terms which mean that every benefit and cost is expressed in the same terms of value, which in a CBA often is money. In some cases this could be complex because a benefit is not always connected to a stated sum of money. For example it is hard to set a value on a good environment. The CBA treats the costs and benefits in a life cycle perspective, enabling to see the effect in a long-term of view. When doing this, the time value of money is incorporated so the values can be expressed with the interest rate over a longer period of years (Sugden, Williams, 1978).
4. Model Development

In this chapter the developed model for solving the problem will be described. The theoretical inspiration is first presented, followed by an introduction to the model. The model will then be presented, both graphically and in text, describing the different steps thoroughly. Lastly, a graphical summary of the model is presented, showing the steps once more, together with the suggested tools to use.

4.1 Theoretical Inspiration

The problem in this study is to find a proper approach to optimize a cutting station, leading to an increment of profitability. Because optimization is in focus, the approach should consist of improvement methods of different types. According to Langley, et al. (2009), it is very beneficial to have a consistent framework or roadmap when conducting improvement initiatives at a company. In this study, this will be done by developing a model, which will have a clear structure and a logical approach.

To ensure the relevance and reliability of this improvement model, inspiration is taken from existing improvement models and a foundation is built on this. In the search for existing models, which was conducted by searching books and article databases, PDCA (see Chapter 3.5.1) was often recurring in the search results. This improvement model has a holistic and general view on improvements and it does not clearly describe an approach to follow, therefore leading to the fact that the model is hard to grasp when applying. Another improvement model found in the searches was IDEA (see Chapter 3.5.2), which is a model developed by Toyota. Similar to the PDCA, this model has a holistic way of thinking and the approach is ambiguous, with no stated tools to use. DMAIC (see Chapter 3.5.3), which is a core model mainly used in Six Sigma, was also found in the searches. In contrast to the two earlier mentioned models, DMAIC has a more structured approach, with a specified roadmap and suggestions of tools to use. Because DMAIC is a large part of Six Sigma, where the main focus is to decrease deviations in the production, many of the suggested tools are statistical and require much numerical data. According to De Mast and Lokkerbol (2012), the requirement of statistical tools can be a problem in industries with lack of numerical data. The nature of the problem in this study, where many different types of factors should be considered, makes it difficult to translate empirical situations into measurable values. Subjective assessments are needed to be done, resulting in that DMAIC is not completely suitable for this problem because most of the tools suggested in DMAIC have to be replaced or modified in order to allow subjectivity. Another way of working with improvements comes from Lean Production (see Chapter 3.5.4). There is no specific roadmap for working with Lean improvements but there are a few principles that it is based upon, which together aims to eliminate waste in the production (Langley, et al., 2009). Because the focus is limited to eliminating waste only, Lean improvements are not suitable in this study. This is because problems within a cutting station may derive from other causes than waste, and it is important to consider those causes in the problem identification phase.
4.2 Introduction to the Developed Model

The mentioned improvement models are different in several ways, but when analyzing them, the same basic way of thinking regarding improvements is apparent in all the models. Even if this is not explicitly stated, all models have similar phases; define goal(s), identify problem(s), find an improvement solution, implement and follow up the improvement. This way of thinking will be the foundation for the improvement model developed in this study.

The model is contributing to the industrial field because of its uniqueness in considering many factors, both quantitative and qualitative as well as value- and non-value adding activities, leading to that unwanted exclusions of possible root causes to problems are minimized. Even though the model is holistic, it is easy to apply because the approach is structured and simple to follow, with clear steps and a suggested set of tools, which together leads to a more optimized cutting station, generating more profits.

In order to find a suitable set of suggested tools to use when applying the model, the purpose for all steps is first determined. When the purpose for each step is known, the steps are analyzed to see what is needed in order to complete the different tasks. These needs are the requirements that the tools must fulfill. When the requirements are known, searches for tools with the sought features are conducted, using books and internet. This approach makes it possible to have a holistic view regarding choice of tools, not focusing on only one type of tools, but instead choose tools that are depending on the purpose of the specific steps, regardless of area they are usually treating. The suggested tools in this model come from different areas, such as quality, management, and finance.

The steps and the tools suggested in the model will be more thoroughly explained in Chapter 4.3.
4.3 Model Presentation

The different steps in the created model are presented in Figure 11 below, followed by an explanation of the steps and the suggested tools to be used for each step:

- **Step 1:** Evaluate and choose cutting station to improve
- **Step 2:** Identify and choose one affecting factor to focus on
- **Step 3:** Determine suitable improvement(s)
- **Step 4:** Implement improvement
- **Step 5:** Evaluate outcome from improvement

*Figure 11: Developed Cutting Station Optimization Model*
It is important to work with continuous improvements in a company in order to keep a high competitive level. When all steps in the model has been conducted (after Step 5), the model should be iterated so improvements are made continuously in cutting stations.

In the model explanation below, there will be several occasions when it is described that data should be collected. This data collection should, if possible, be gathered from several sources. Sources could be interviews with persons having a significant understanding and knowledge about the cutting process, observations of different situations in the process, or measured data from different instruments or systems. The reason for having several data sources is to ensure the reliability of the input data for the model. Although, having several input sources require more resources, leading to more expenses. This is a choice the user of the model will have to take, prioritizing less usage of resources or increment of data accuracy.

Step 1: Evaluate and choose cutting station to improve
If a company is using several cutting machines, the improvement initiative starts with a choice of machine to focus on. This choice is done by first examining data regarding all cutting machines, and then choosing one machine that is not performing preferable from an economical point of view. The reason for observing only the economic situation is that the model is aiming to increase the profitability of a cutting station. The collected data will serve as a reference point and will be later compared to the outcome after the improvement suggestion has been implemented. There will not be a suggestion for a specific profitability measurement tool to be used. This is because profitability could be measured in many different ways at companies and therefore it is not suitable to focus on only one approach for doing this. Although, this will not make any significant difference because the most important with this measurement is that it is conducted in the exact same way, both before and after the implementation.

Step 2: Identify and choose one affecting factor to focus on
This step is done in order to identify factors affecting the goals of a cutting process and then choose a specific factor to focus the improvement work on.

This step is divided into three smaller sub-steps, describing more detailed what has to be done and what tools use in order to choose a factor to focus on.

2.1 Define goals in cutting station
If the goals are unknown, a suggestion for determining these are by using a Decision hierarchy triangle (see Chapter 3.6), where the strategic and tactical goals in the business are narrowed down into operational goals regarding a cutting station. To achieve the best possible outcome of the Decision hierarchy triangle, it is preferable to conduct interviews or get guidance from persons with significant understanding and knowledge of the business goals and visions.

2.2 Find affecting factors for the cutting station
In order to efficiently determine the affecting factors in a cutting station, it is suitable to make use of several inputs. There are, according to Al-Najjar (1997), several factors that
are affecting a production process in different degrees. These are shown in the list below, together with examples of what the factors could contain:

- Equipment (manufacturing, measuring)
- Material (type, specification)
- People (operator, maintenance, skill)
- Methods (training, age, experience, speed, temperature, load)
- Environment (temperature, vibration)
- Procedure (steps order, adjustment)
- Service (lubrication, screw tightening)
- Management (planning, support management)
- Marketing (customer requirements)

This list can be used as a template for defining factors that affect a cutting process and it is possible to modify or remove factors to fit the specific case or terms used in the company. The template list of factors is a theoretical foundation and is advantageous to make use of it when trying to identify affecting factors. Although, it is not suitable to only use this list because the factors in the list has a strong relation and a high integration between each other. It is also difficult to assign specific activities to the template list factors, which is necessary for further steps, making a stand-alone usage of this list inappropriate for this model.

Due to this, it is advantageous to also create a process map of the chosen cutting station and use it as another input. A suitable tool for creating a process map, in order to help identifying affecting factors, is the IDEF0 because it considers every input, output, mechanism, and control for the process (see Chapter 3.7). The content of the IDEF0, which represent the current situation at the company, should be compared to the template list, which represents the theoretical aspect of affecting factors. From this comparison, modifications can be made on the template list. By modifying factors from the template list, based on what is identified from the IDEF0, new renamed factors will be stated, leading to a more suitable set of affecting factors for the specific case.

A reason for dividing the above mentioned template list factors is that the affecting factors, used for further steps in the model, should be separated from each other as much as possible. Also, it should be possible to connect specific activities to each factor, which is difficult with the template list of affecting factors, where most factors integrate with each other too much. One example of this is the people factor, which can be included in many of the other factors. Determining activities regarding people would lead to a requirement of describing almost all activities in the production process of the cutting station. The template list should instead be used as a checklist, controlling that all factors has been covered in some extent.
2.3 Evaluate and choose focus factor

In this step, the different factors are evaluated and their criticality towards the goals, as well as their potential of being improved, is found. The tool used in finding this is the CIPC (Criticality and Improvement Potential Comparison), which is a tool created by the thesis authors and is inspired from QFD (see Chapter 3.8) and MCDM (see Chapter 3.9). The main reason for creating the CIPC is because existing tools, found in searches, did not treat improvement potential as an important part in finding a focus factor, which is preferable in this model. This tool is described further on in Chapter 4.4. The factor receiving the highest value from the CIPC is the one to focus further improvements on.

If the results from the CIPC show no factors with especially high criticality or potential for improvements, there should be a step backwards in the model and Step 1 should be iterated. If this happens, it could be a sign of that the insufficient profitability results from the machine are actually caused by something outside the cutting station. This is the reason for iterating Step 1, which may lead to a different choice of cutting machine that improvements should be focused on.

Step 3: Determine suitable improvement(s)

In this step, suitable improvement suggestions for specific activities regarding the chosen focus factor are found. This step is, similar to Step 2, divided into three smaller sub-steps, describing more detailed the actions that should be made in order to find the best improvement suggestion(s) to implement.

3.1 Identify activities regarding chosen focus factor

To more easily identify the different activities, the chosen factor should be broken down into specific activities that are performed in the cutting station. A suggestion for doing this is by using a Tree diagram (see Chapter 3.10) because this enables the model user to organize and structure the activities efficiently.

3.2 Suggest improvement(s) for activities

In order to improve something, it is important to identify the root causes to problems and then suggest solutions to these. This is done by conducting brainstorming (see Chapter 3.11) sessions and documenting every idea of a root cause that possibly could be the reason for problems in the observed cutting station. When performing the brainstorming, a suggested tool is the Fishbone diagram (see Chapter 3.12). The Fishbone diagram is a preferable tool when trying to identify possible root causes to problems in a structured way. Contrary to the usual categories in a Fishbone diagram, the activities identified in Step 3.1 can instead be used as categories for the branches connected to the main arrow representing the goal, which will be profitability regarding the specific focus factor. Onto the branches (activities), possible causes to problems within that branch are attached. There can be sub-branches added to the causes as well if there are believed to be underlying problems. This adding is repeated until the actual root cause is believed to be found. Because a brainstorming session is conducted, the root causes shown in the Fishbone diagram are only potential causes and it is essential that these are confirmed to
be true for the specific case before proceeding suggesting improvements. This confirmation is done by observing the process, focusing on the specific activities and see if the potential root causes could be reasons for problems regarding the activity. Another suggestion to confirm the potential root causes is by conducting interviews with persons, having a good understanding and experience of the process or the specific activity.

When the list of potential root causes has been analyzed and it has been found which of the potential causes that are confirmed to be actual problems, the improvement suggestions for these should be initiated. If the same root cause is found in different activities, it could be beneficial to focus more on this when suggesting improvements, because a solution for this root cause will probably improve several activities. The improvement suggestions are done by conducting a brainstorming session and when a suitable amount of suggestions has been stated, it is time to proceed to the next step in the model, evaluation.

If there are not enough improvement suggestions found for the activities, there should be a step backwards in the model and Step 2.3 should be iterated, which then will perhaps show different results, leading to a new choice of focus factor.

3.3 Evaluate and choose most profit generating improvement
This step will consist of a comparison between the different improvement suggestions, using a CBA (see Chapter 3.13), in order to find the alternative generating most profit. Even if more alternatives are estimated to generate profit, it is preferable to not implement the improvements simultaneously. This is because it is difficult to measure the actual outcome of each improvement after the implementation if they have not been done singly.

If no improvement suggestions are found suitable to implement, there should be a step backwards in the model and Step 3.2 should be iterated in order to find more suggestions of improvements.

Step 4: Implement improvement
When an improvement suggestion has been chosen, the next step is to change the cutting station according to this.

Step 5: Evaluate outcome from improvement
It is important to evaluate the outcome of the implemented improvement, with respect to profitability, in order to see if the changes have affected the production process within the cutting station positively. Effects are seen by first measuring new data in the same way as before the improvement work started. This data should then be compared with the old data, the reference point, mentioned in Step 1. It is very important that the measurements in Step 1 and 5 is conducted in the same way in order to ensure that the comparison become as reliable and realistic as possible.
4.4 Criticality and Improvement Potential Comparison

Criticality and Improvement Potential Comparison (CIPC) is a tool created by the authors of this thesis, aiming to find a specific factor to focus further improvements on. The tool is mainly inspired from QFD and it also has similarities to the way of thinking in a MCDM. An example of how a CIPC could appear is shown in Table 3 below:

*Table 3: Example of a CIPC*

<table>
<thead>
<tr>
<th>Goals within cutting station</th>
<th>Factors affecting goals</th>
<th>Goal weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goal 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goal 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goal 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Criticality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement potential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the left column, the *What*-section, the goals for the chosen cutting machine are stated. These goals should also be divided into weights, i.e. the importance of the goals in comparison to each other. This weight is a value between 0 and 1, representing a percentage of importance for each goal. Because it is representing a percentage, the sum of all goal weights should be 1 (100%). In the top row, the *How*-section, factors having an effect towards the goals are stated.

In the grid, right to the *What*-section, values in an interval from 0 to 9 should be inserted. The number 0 represent no effect, the number 1 represent a very small effect and the number 9 represent a very high effect toward the specific goal. The values for these are set from observations and interviews with persons with a good understanding of the process and the different factors. For each factor, the impact values towards all goals are multiplied with the corresponding goal weight and then added together; this sum is put in the row saying criticality.
The improvement potential is a value that is telling how things regarding the factors are currently running. This includes how well the process is currently performing as well as if there are good possibilities to improve the process, with respect to that specific factor. The improvement potential value is a number in the interval 0 to 9, similar to the criticality grading. It is preferable to interview persons with a good knowledge and experience in order to set this value as accurate as possible.

The result is the product of a multiplication between the criticality value and improvement potential value for each factor. The factor receiving the highest result is the one to focus further improvements on.
4.5 Model Summary

To summarize this chapter, Figure 12 below is presenting a graphical view of the model once more, together with added boxes that are showing suggested tools and methods to use:

**Figure 12: Developed Cutting Station Optimization Model, with Suggested Tools**
5. Empirical Findings

In this chapter a short description of the case company will be presented, followed by the company goals, stated by the management. Also, there will be a description of the cutting processes at the company, which is necessary because the developed model is focusing on improving cutting stations. Finally, it is presented how the case company is measuring profitability of their production. Due to confidentiality, the name of the case company and the business branch they are operating in are not mentioned. In Appendix B, C, and D, different types of information about the company are found. This information have been modified in order to not show customers, profile IDs etc. No numbers or values have been modified in order to achieve an accurate and realistic study.

5.1 Company Description

The model developed in this thesis will be tested on a production process in a case company named. The case company is manufacturing customized products to customers and is working in a project-based approach. The company was founded in 1987 and has today grown to be the market leader in its branch. The turnover is approximately 600 million SEK and the company is certified with both ISO 9001 and ISO 14001. The headquarters is located in Växjö, Sweden, where the production is located as well. Since the customers are spread all over the world, the case company has sales agents located in several countries in order to offer a better communication towards the customers. The total number of employees amounts to 160, where the majority of these are located in Växjö. The case company is not aiming to offering the cheapest solution on the market, but instead offers the highest quality to the given price. One of the case company’s strengths is that they offer tailored and unique solutions, which is highly attractive for customers. Although, this approach leads to that it is difficult to have a totally standardized way of working and there are many different types of projects to manage simultaneously.

The production is divided in different areas where the main areas are: cutting and processing, steel and assembly of profiles. In the cutting and processing area, aluminum profiles are cut and processed according to the customer needs.

5.2 Company Goals

The core values of the case company are based on nearness, involvement and clarity in every sense of duty. The goal is to produce the best products in their branch in terms of quality, with a total concept from idea to turnkey product. The company offer unique and custom fitted complete solutions where the customers’ values are function and quality. The product is fully adapted to the customers’ requirements, but still developed through a standardized work approach. Even though the price is set to the upper range, the price is more competitive over a life cycle view.
5.3 Cutting Process Description

In the cutting and processing area at the case company there are six different cutting machines, able to process aluminum profiles. The machines differ from each other in many ways but a general approach can be seen, which is applied in order to complete work orders effectively, independently of type of machine used. This approach is shown in Figure 13 below:

![Figure 13: General Steps for Cutting Processes](image)

The planning step is including the work needed before the production can be initiated and this is based on the customer order. First there will be a production plan created, checking the availability of resources in the cutting and processing area, making sure it will work according to the specifications stated in the customer order. Parallel to the production plan, planning regarding the material for the customer order is conducted, defining amount, profile type etc. In the material planning it is also decided when to purchase the profiles in order to have them delivered in time for the start of production. In the planning phase, a maintenance plan is included as well, deciding when to perform preventive maintenance. The production at the case company is project based and there are large variations in number of customer orders received. If there are several projects simultaneously planned, the orders are prioritized by a supervisor, based on importance of the order, delivery times, complexity of order etc. From the planning step, prioritized work orders for the operators are generated, describing specifications of needed profiles for the different projects.

The next three steps in the general work approach are done by the operators. Preparation of cutting station includes setup of machine, retrieve the correct set of profiles and then prepare the profiles for cutting. Cutting of profiles is the value-adding operation, where the profiles are cut according to the specifications defined in the work order. The final step, preparing finished profiles for next production step, includes loading the profiles onto a transportation wagon/pallet and also tape and mark the profiles with necessary data for next step, such as project ID, profile codes, length, amount, and work order number. If there are several lengths or types of profiles for the same project, each unique set of profiles must have separate taping and marking. This procedure is a requirement in order to fulfill the ISO standards at the case company. After the taping and marking, the operator moves the profile wagon/pallet to the next step of production, also stated in the work order, and then register the work order as finished. When filling the registration, the operator states information such as processing time, operator ID, status, quality problems etc.
As mentioned, there are six different cutting machines in the cutting and processing area at the case company. A flowchart is presented in Figure 14 below and this is showing the machines and the path that a profile can take, from profile storage to the assembly hall:

![Flowchart](image)

*Figure 14: Product Path in the Cutting and Processing Area*

Two of these are automatic cutting machines, which also have an opportunity to process the profiles further if the work order specification does not require very detailed processing. These machines take the largest profiles and the majority of all profiles are going through these machines. These machines will be called Quadra 1 and 2 from now on. Then there is another cutting machine that also has an opportunity to both cut and mill the profile by using a blade. This machine will need an operator for most profiles but for some profiles, this machine can be automatic and the operators just have to refill incoming material and collect the complete products. This machine will be called T150 from now on. The final two cutting machines are manual and they do not further processing the profiles. These manual cutting machines will be referred to as Manual machine 1 and 2. If there is a need for further processing, profiles from the Manual machines goes to a milling machine, called T3 from now, after the cutting.

All jobs made are connected to a work order, and in this order it has been stated which of the machines that the profiles should go through. The choice of path for the profiles is decided in the planning phase and this decision is based on experience and project specifications, e.g. amount, profile type, and profile length. The profiles that have been going through the Quadras are always going directly to assembly afterwards. It is the same case for the profiles going through the T150. For the Cutting machines there are two possible ways to go. First the profiles should go to T3 if there is a need to process them more. Otherwise they will go directly to assembly, similar to the other machines.
5.4 Profitability Measurement

In order to ensure the profitability and to maintain a financial control in the production, the case company is conducting pre-calculations for every project and then compares these to the actual outcome when the project has been finished. Each area in the production has their specific way of doing pre-calculations. In the cutting and processing area, the needed manpower of operators, measured in hours, is compared to the amount of manufactured profiles. The operators cost is calculated to an average cost per hour for each machine (see Appendix B) and the cost for the profiles is calculated with respect to the time it takes for each profiles to be cut (see Appendix B). The parameters in this calculation are mainly based on profile size and type. The amount of needed profiles for every project is known, which makes it possible to predict the total cost for every project in the cutting station by multiplying the total cutting time with the operators cost. After each finished project, this cost will be compared to the actual cost, which is based on times that are logged by the operators.

The financial goal with the production is that the pre-calculation should correspond with the actual outcome with the smallest margin of error as possible. In the calculation, the cutting machines are divided into two groups, cutting, and processing. The cutting group consists of Manual cutting machine 1 and 2. The processing group consists of the other machines in the cutting and processing area, Quadra 1 and 2, T3, and T150. In Table 4, it is shown an example of how a project result is shown. All project results, done from January to the end of March 2013, can be seen in Appendix C.

Table 4: Example of Project Results

<table>
<thead>
<tr>
<th>Project: I</th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>21 664.00 SEK</td>
<td>27 980.41 SEK</td>
<td>-6 316.41 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>9 139.50 SEK</td>
<td>19 585.61 SEK</td>
<td>-10 446.11 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td>-16 762.52 SEK</td>
<td></td>
</tr>
</tbody>
</table>

5.5 Future Improvement Plans

When observing the results from Appendix C, it is seen that there are losses in both cutting and processing. The case company is aware of these profit losses and an investigation has been made regarding the processing. This investigation has shown that one of the machines, T3, is the major cause for these losses. Due to this, a decision has been made to invest in a new machine. This investment is a punching machine, which will replace most of the tasks made in the T3 today. By punching the profiles instead of milling them, fewer resources are needed and many costs will be decreased. In order to have enough space in the facility, it has also been decided to remove the T150 machine and install the new punching machine on that position. The keeping of T150 cannot be justified due to its age and small work occupation. Even though the new punching machine will receive much workload from the T3 machine, the T3 is still needed for some profiles and therefore cannot be removed from the facility.
6. Model Testing

In this chapter, the model will be tested towards the case company according to the different step instructions of the model. The two final steps, Step 4 and Step 5, will not be executed and the responsibility of completing those will be handed over to the management at the case company.

6.1 Evaluate and Choose Cutting Station to Improve – Step 1

In order to choose the most suitable cutting station to focus improvements on, the profitability measurements, shown in Appendix C, is analyzed. From these, a diagram is made, showing the difference between pre-calculations and actual outcomes for the finished projects, from January until the end of March 2013. The aim for each project is to reach zero, i.e. there is no difference between the pre-calculation and the actual outcome. This diagram is shown Figure 15 below:

![Diagram of Differences between Pre-calculations and Actual Outcomes](image)

Figure 15: Diagram of Differences between Pre-calculations and Actual Outcomes

From the diagram it can be seen that both cutting and processing are often generating negative values, which could mean that both areas are in need of improvements.

As it has been mentioned in Chapter 5.5, an investigation has been done by the case company regarding the losses in processing. From this it was found that T3 is causing the majority of problems here and because of this, many tasks in this machine will be replaced with a new punching machine. Because an improvement plan already has been made regarding the processing, the cutting will be in focus for this study. From a quick observation of Figure 15, it may look like processing is running worse than cutting, due to the high variance. However,
from the lines showing the average result from each project it is shown that cutting has an average of -5103 SEK per project, which is worse compared to processing that has an average of -4642 SEK per project. Below, Table 5 shows the total results for cutting and processing for 2013 from January to March:

<table>
<thead>
<tr>
<th>Total Results, Jan-Mar 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
</tr>
<tr>
<td>-83 551.06 SEK</td>
</tr>
<tr>
<td>Cutting</td>
</tr>
<tr>
<td>-91 849.73 SEK</td>
</tr>
</tbody>
</table>

Because the cutting area only consists of two manual cutting machines, Manual machine 1 and 2, one of these is chosen to focus further improvements on. It does not make any difference which one of the cutting stations surrounding the machines that are chosen, because these machines are identical. For simplicity, the cutting station surrounding Manual machine 1 will be the choice of station to focus further improvements on in the model testing.

### 6.2 Identify and Choose One Affecting Factor to Focus on – Step 2

In the upcoming sub-steps, the affecting factors for the cutting station will be compared towards the goals in the station. From this comparison, one of the affecting factors will be chosen to focus further improvements on.

#### 6.2.1 Define Goals in Cutting Station – Step 2.1

To identify the operational goals in the cutting station, a Decision hierarchy triangle is used. The identification process starts with considering the strategic goals and then breaking down these goals, first into a tactical level, and then into an operational level, which are showing the goals at the cutting station. Since this is a subjective assessment where data is gathered from interviews, various people with the right knowledge have been involved in this step, in order to strengthen the reliability of the data. The roles of the interviewed people in this case have been the production manager and the production planner, who are two persons with a very good insight in this area. The different levels of goals are presented in Figure 16 on the next page, showing a decision hierarchy triangle with a belonging explanation of the current goals regarding the cutting station at the case company:
Strategic level:
- Market leading in their branch
- Best quality and functionality in the branch
- Offer unique and customized solutions

Tactical level:
- Reach or exceed the preliminary calculation of work orders

Operational level:
- Maintain a high quality of profiles
- Decrease lead times
- Decrease waste pieces of profiles
- Make marking of profiles more efficient
- Better utilization of operators

*Figure 16: Decision Hierarchy Triangle of Goals*

**Maintain a high quality of profiles**
The company is well concerned about the quality of their products and this is something that is reflected in the strategically level for the finished product as well as on every unique profile cut in the cutting stations.

**Decrease lead times**
Continuous improvements is something the company is striving for and one of the most important issue concerning this is to always try to decrease the lead times in the production. This is something that is treated in the cutting station as well. The goal is to keep or even exceed the current quality with a decreased lead time.

**Decrease waste pieces of profiles**
One of the largest raw materials that the company is working with is aluminum profiles. The profiles arrive in long lengths and are to be cut by the company. When planning a project, a material planner calculates how many full length profiles that are needed to be purchased. This planning is done so the cutting should be done in an optimized way, i.e. get as many finished profiles from each full length with the least possible waste. A problem could be if the operators do not cut according to this plan and instead in a way that seems more smoothly, e.g. cut all largest profiles first. The most important is that the operator and the material planner is synchronized in the approach that should be used, in order to decrease waste or unnecessary waiting time due to shortage of profiles.

**Make marking of profiles more efficient**
Since the company offers unique and customized solutions, a large amount of the profiles have unique lengths and types, causing the consequence that marking of the different profiles
is a frequent task in the cutting station. The goal is to make this marking method as efficient as possible in order to reduce unnecessary time spending on marking.

**Better utilization of operators**

Since the operator cost in the cutting station is relatively high, the company has the goal to utilize the operators in a better way than today. This could for example be to take advantage of the operators’ knowledge or plan the production better in order to reduce the time the operators spend on waiting.

### 6.2.2 Find Affecting Factors for the Cutting Station – Step 2.2

In order to find factors affecting the goals at the cutting station, an IDEF0 will first be created to see needed inputs, outputs, mechanisms and controls for the process. By doing this, an overview of the actual situation at the cutting station is given and the necessary components of the process are identified. The components found in the IDEF0 will be compared with the template list of affecting factors, found in Chapter 4.3, in order to see similarities. As mentioned in Chapter 4.3, it is suitable to do this comparison and then modify the template list, receiving a new set of factors that are more appropriate for the specific case.

The IDEF0 is describing the production process regarding the cutting station, from planning until preparation of finished profiles for the next step in the production. These are the steps in the general approach used in the cutting and processing are at the case company, described in Chapter 5.3, and it is suitable to use these as activity boxes for the IDEF0, which is shown on the next page in Figure 17:
In the IDEF0 it is shown that the production process in the manual cutting station starts with a customer order as a first input. This is processed in the planning phase by several persons, working in different fields. By using different computer programs, as well as analyzing the work schedules in the plant, together with specifications stated in the customer order, a work order is created for the production. In the next step of the IDEF0, an operator prepares the cutting station for cutting of profiles according to the work order. Tools are used to setup the machine, together with a test profile that will help the operator to adjust the machine fittingly. When this has been done the actual cutting starts, which is the third step in the IDEF0, cutting of profiles. The operator cuts profiles according to the work order and within stated tolerance levels. When the cutting has been finished, the final step in the IDEF0 is initiated. In this step,
the operator loads the finished profiles onto a pallet/wagon and then tape together profiles of the same length or type. On the tape, the operator writes information regarding the profiles needed for further steps in the production, which is according to ISO standards at the case company. The pallet/wagon with finished profiles are then moved to the next designated station in the production, using a pallet truck, fork lift, or sometimes by pushing, depending on the weight of the pallet/wagon.

When the production process has been understood, the content of the IDEF0 can be compared to the template list of affecting factors in a production process, which is shown below:

- Equipment (manufacturing, measuring)
- Material (type, specification)
- People (operator, maintenance, skill)
- Methods (training, age, experience, speed, temperature, load)
- Environment (temperature, vibration)
- Procedure (steps order, adjustment)
- Service (lubrication, screw tightening)
- Management (planning, support management)
- Marketing (customer requirements)

When comparing the IDEF0 to the above list of factors, renamed factors were found, more fitting for the situation in the cutting process at the case company. The new factors were defined from a discussion, where the aim was to find a few similar areas or general activities, separated from each other. The new factors also had to have a connection with both the IDEF0 and the template list of factors. Finally, it was required that the new factors had a possibility to be broken down into detailed activities, because this is needed for further steps in the model.

The new list of affecting factors is shown below, followed by an explanation of how the list is connected to the content in the IDEF0 and the template list of factors:

- Production planning
- Material planning
- Maintenance
- Operator procedures

Production planning is a large part of the production process in the cutting station, deciding how everything should be done regarding the work order; priorities of profiles, time schedules, specifications etc. In the IDEF0, the production planning is included in the first step, planning. In the template list of affecting factors, production planning includes most of the factors; equipment, people, methods, environment, procedure, management and marketing. The reason to the high amount of included factors is that production planning is a large step in the production process and it consists of many aspects.
The material planning is deciding how much and what type of material that should be used for each project or work order. The material planning also includes ordering of needed material in time for the production, so the production is not interrupted due to lack of material. The material planning in the cutting process is included in the first step in the IDEF0, planning. The factors from the template list of factors that are included in material planning are equipment, material, methods, environment, management and marketing.

The maintenance factor is included in the planning step of the IDEF0 because it covers planning of preventive maintenance on the cutting machine. From the template list of affecting factors, equipment, people, methods, environment, procedure, service, and management are covered in the maintenance factor.

Operator procedures is a large factor in the production process in the cutting machine. This includes everything that the machine operator is connected to; cutting of profiles, auxiliary tasks regarding the cutting process, knowledge/skill etc. In the IDEF0, the operator procedures are included in the three last steps; preparation of cutting station, cutting of profiles, and preparing finished profiles for next step. Operator procedures is covering the following factors from the template list: people, methods, procedure, and service.

As described, the new affecting factors are covering all factors from the template list in different ways. They are also more suitable to use further on in the model, compared to the template factors, because they are separated from each other, as well as it is possible to connect specific activities to them.

6.2.3 Evaluate and Choose Focus Factor – Step 2.3

In this step the results from Step 2.1 and 2.2 are combined and used in order to find one affecting factor to focus improvement on. To find this one specific factor, a created tool called CIPC is used. From Step 2.1 it was found that the goals in the cutting station was to: maintain a high quality of profiles, decrease lead times, decrease waste pieces of profiles, make marking of profiles more efficient, and to have a better utilization of operators. These goals will represent the What-section in the CIPC. From Step 2.2, affecting factors were found; production planning, material planning, maintenance, and operator procedures. These factors will represent the How-section in the CIPC. The CIPC is presented in Table 6 on the next page, showing the criticality from the factors towards the goals, as well as the improvement potential for the different affecting factors:
6.3 Determine Suitable Improvement(s) – Step 3

In this step the chosen factor, operator procedures, will be analyzed in order to determine specific activities within it. Improvement suggestions will be made regarding root causes to problems in the activities. Finally, a comparison between the improvement suggestions will be made in order to choose the most suitable alternative to implement.

6.3.1 Identify Activities Regarding Chosen Focus Factor – Step 3.1

In order to identify the activities included in operator procedures, the factor is broken down into different categories. From the IDEF0 in Step 2.2, it was found that the factor, operator procedures, was included in the three steps: preparing cutting machine, cutting of profiles, and preparing finished profiles for next step. In order to structure the search for activities, these IDEF0 steps are defined as categories for operator procedures. Each category is
observed in the production process in order to identify the activities effectively. The findings of this observation are inserted in a Tree diagram and this is presented below in Figure 18, followed by an explanation of what is included in the activities:

**Figure 18: Tree Diagram of Activities Regarding Operator Procedures**

**Receiving work order and profiles**
This preparation activity is happening when a cutting station operator receives a work order. From the work order it is seen which profiles that should be cut. A pallet with these profiles is often ready to take from a nearby intermediate storage. There are several pallets in the intermediate storage, stored on top of each other. In order to obtain the wanted pallet, the operator uses a traverse and moves and put the pallet onto a wagon, making it possible to then push the pallet to the cutting station.

**Setup machine**
In the work order it is stated which profiles that are to be cut and what specifications these should have. From this information, the operator inserts values into the machine, through a display next to the machine. These values are specifying the length the finished profiles should have, possibly a tilt as well, if the profile should not have a 90 degree angle in the edge. There are two or more supports, which the profile lies on when being cut and these are sometimes changed as well depending on the lengths of profiles. One test profile is often taken from the pallet with profiles when setting up the machine in order to help the operator adjusting the supports properly.

**Preparing profiles for cutting**
In this activity, the operator removes wrapping from the profiles and prepares the wagon so that the cutting can be done smoothly, without unnecessary disruptions. It is also included to
prepare an empty pallet/wagon to stash the finished profiles on. This empty pallet/wagon can be found at a specific location at the plant.

**Load cutting machine**
In this step, a profile is taken from the pallet/wagon and then put on the cutting machine. The piece is attached to the machine at the right position, using clamps. Depending on length and thickness, some types of profiles can be cut simultaneously. It is impossible to cut several profiles at once if the profiles are to be tilted.

**Cutting execution**
This step is the actual cutting of the profile, where the operator presses a button next to the machine and two cutting blades rises and cut the profile in the wanted length.

**Unload cutting machine**
The operator takes the newly cut finished profile and put it on a pallet or transportation wagon.

**Quality control**
This activity is done to ensure a high overall quality of the profiles. The operator measures the profile and control that the measurement values correspond to the specifications and tolerance levels, stated in the work order. This quality control is done on the first and last piece of every unique profile length or type. If there are large batches of the same length or type, every 50th piece should be controlled.

**Marking**
In this step, the operator tapes together profiles of same length and type and then uses a pen to write information on the tape, which is needed for further steps in the production and also a requirement for the ISO certification.

**Movement**
When all profiles has been cut and marked, the operator moves the pallet/wagon with finished profiles to the next production station, which could be the assembly or further processing at the T3 machine. If the pallet/wagon is not too heavy, the operator uses manual power, either by pushing it or using a pallet truck. If it is heavier pallets/wagons, a fork lift have to be used to move the profile to the designated station.

**Report finished order**
The last activity is to report the order as finished. This is done at a computer nearby the cutting station, where the operator inserts information about the work order, such as processing time, operator ID, quality problems etc. This information is later used by supervisors and management for follow-ups of the projects.

**6.3.2 Suggest Improvement(s) for Activities – Step 3.2**
In order to find improvements for the activities, possible root causes for problems regarding the activities must first be found. This is done with a Fishbone diagram, where operator
procedures will represent the main line and the found activities will be the branches in the diagram. The problem, which is the effect from the root causes, is in this case time losses regarding operator procedures. The created Fishbone diagram is shown in Figure 19 below:

![Fishbone Diagram of Operator Procedures](image)

**Figure 19: Fishbone Diagram of Operator Procedures**

When the possible root causes to problems has been stated, the different activities in the production process will be observed once again, with the aim to determine if the stated root causes actually are problems or not in the cutting station. Parallel to the observations, there will also be interviews made with one supervisor and two operators that are working in the cutting station. The interviews will consist of questions about the possible root causes in order to get their aspect of the situation.

An interpretation of the above mentioned observations and interviews will be made by the authors. A conclusion of this interpretation, together with an explanation of the possible root causes has been conducted and can be seen in Appendix D.

The assessments of the mentioned potential problems, made from observations and interviews with a supervisor and operators, has been summarized into a table and graded in three different levels. The grading is depending on how comprehensive the possible problems actually are at the case company. The levels in the grading are categorized into *none*, *moderate*, and *significant*, where *none* is referring to a non-existing problem and *significant* is referring to a recurring or apparent problem. A fourth alternative is also present if it is not possible to do an adequate assessment of the potential problem. This alternative is referred to as *N/A* (Not Available) in the table. In Table 7 on the next page, all assessments are presented:
### Table 7: Assessments of Possible Root Causes

<table>
<thead>
<tr>
<th>Possible root cause</th>
<th>Observation</th>
<th>Supervisor</th>
<th>Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missing / hard to find profiles</td>
<td>None</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>Incorrect information</td>
<td>N/A</td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td>Bad communication</td>
<td>N/A</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>Inefficient moving methods</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Pallets/wagons not packed according to production plan</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Many different profile lengths and types</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Wrongly calibrated measurement settings</td>
<td>N/A</td>
<td>N/A</td>
<td>Moderate</td>
</tr>
<tr>
<td>Inefficient preparation instructions</td>
<td>Significant</td>
<td>Significant</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hard to find pallets/wagons for finished profiles</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Improper position of profiles to be cut</td>
<td>Significant</td>
<td>Significant</td>
<td>None</td>
</tr>
<tr>
<td>Ungainly profiles</td>
<td>Moderate</td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td>Complex specifications</td>
<td>N/A</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Cutting specifications improperly followed</td>
<td>N/A</td>
<td>N/A</td>
<td>None</td>
</tr>
<tr>
<td>Improper approach/place for stashing finished profiles</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Misplaced measurement tools</td>
<td>N/A</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>Improper measurement tools</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Inefficient quality control instructions</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Unnecessary information</td>
<td>None</td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td>Improper method for marking</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Long distances</td>
<td>Moderate</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>Lack of storage space</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Different delivery points</td>
<td>None</td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td>Time consuming reporting method</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

From Table 7 it is shown that some root causes are more apparent than others and are in need of further analyses in order to find improvement suggestions for them. The most apparent root causes are listed below:

- Pallets/wagons not packed according to production plan
- Many different profile lengths and types
- Inefficient preparation instructions
- Hard to find pallets/wagons for finished profiles
- Improper position of profiles to be cut
- Improper method for marking
- Lack of storage space

A new brainstorming session is conducted, focusing on each of the above listed root causes separately. The purpose with this brainstorming is to find possible suggestions of changes, leading to that the activity connected to the specific root cause, is improved. The possible
improvement suggestion(s) for each significant root cause are listed below, together with an explanation of the suggestion:

**Significant root cause:** Pallets/wagons not packed according to production plan  
**Improvement suggestion:** Include profile packing order in production plan

- There is much time wasted on moving around profile pallets in the intermediate storage with a traverse. A possibility to substantially reduce these time losses, is by arranging the intermediate storage so that it is packed according to the production plan, i.e. the profiles that should be cut first are on top, leading to no unnecessary re-arrangements of the different pallets. A solution for doing this is that the fork lift driver at the case company is included in the planning phase and arranges all incoming profile pallets according the production plan. If this solution it is not possible, due to high occupancy of the fork lift driver etc., another solution could be to negotiate with the profile supplier in order to see if it is possible for them to do this arrangement, leading to that no extra work has to be done when the profiles are delivered to the case company. Apart from time savings, this improvement will lead to less usage of the traverse, increasing the safety of the employees.

**Significant root cause:** Many different profile lengths and types  
**Improvement suggestion 1:** More standardized profile lengths

- Today there are many different lengths of profiles because the case company is working with project-oriented production, where the different projects often have unique specifications. A solution for this problem could be to do an overhaul of the construction plans for the products in order to see if there is a possibility to produce products with more standardized measurements, which would lead to less time spent on setups, quality control, and marking in the cutting station.

**Improvement suggestion 2:** Decrease amount of profile types

- Another suggestion for improving this problem is to investigate if the amount of different profile types actually is necessary. It could be found that some profile types are more universal and can replace several other profiles. If it is found that some profiles are superfluous and is possible to replace by other already used profiles, time savings can be made in the cutting station regarding setups, quality control, and marking of profiles. Another solution could be to investigate the product range of different profile suppliers to see if they have more universal profiles that can replace several of the existing profiles. Alternatively the case company could attempt to develop an in-house solution for universal profiles.

**Significant root cause:** Inefficient preparation instructions  
**Improvement suggestion:** A standardized procedure for preparing the cutting station

- Today there are no specific instructions for the operators to follow when preparing the cutting station. This leads to that the different actions that should be done in the
preparation are performed in different ways and pace. By having a standardized instruction that everyone follows, time savings can be made because there will be less confusion regarding the order to execute actions. It will also be beneficial for new personnel, operating the cutting machine, because they will learn the procedures and start work efficient more quickly if there is a stated instruction to follow.

**Significant root cause:** Hard to find pallets/wagons for finished profiles  
**Improvement suggestion:** Ensure availability of empty wagons/pallets at a dedicated point

- Today, much time is spent on searching for empty pallets/wagons that are used for stashing finished profiles. There is a designated place for obtain those, but there are often no pallets/wagons available. A solution for this could be to inform the employees of the importance of returning the empty pallets/wagons to the designated place when not needed anymore. If this does not help, another solution could be to purchase more pallets/wagons, which will increase the availability.

**Significant root cause:** Improper position of profiles to be cut  
**Improvement suggestion:** Restructure the facility layout of the manual cutting stations

- The cutting stations are today not positioned so that the material flow is going in a “straight” line, but instead have to move in a more complicated way. By relocating the machines, the distance for the material path will decrease, as well as it will be easier for the operators to load and unload the profiles if the material is moved and processed in only one direction. This improvement will decrease the lead time of the cutting process.

**Significant root cause:** Improper method for marking  
**Improvement suggestion:** Replace manual marking with printed notes with information

- Today the marking is done by first taping unique sets of finished profiles and then write information on the tape, needed for further steps. By having already printed notes with the necessary information on, the operators would not need to write anything, but instead just attach the notes onto the profiles.

**Significant root cause:** Lack of storage space  
**Improvement suggestion:** A dedicated delivery point

- Much time is spent by the operators on different movements of profiles. A solution for this could be to designate a delivery point nearby the cutting station, where the operator can put all finished profiles. This will reduce the time for transports and movements done by the operators. Furthermore, this suggestion will probably eliminate the time spent on searching for available storage slots, making it possible for the operators to focus more on the value-adding activity, the actual cutting. However, someone will have to do these movements instead of the operators. A solution could be to include the fork lift driver more in these transportations and if that is not possible, a designated material handler in the assembly hall could solve this problem.
This material handler will be responsible for all storage related tasks in the assembly hall and will not only handle the goods from the manual cutting machine. By having one person deciding how to structure the storage, it is easier to have a good control of the storage and it will decrease the risk of lack of space, compared to if everyone is involved.

6.3.3 Evaluate and Choose Most Profit Generating Improvement – Step 3.3

In this step, a simplified version of a CBA is conducted. The reason for that the CBA will be simplified is that, due to the scope and time of this study. Time measurements made regarding the suggestions, which will be generalized for all projects, will not be performed in the preferable extent in order to ensure a high significance level. To compensate this problem as much as possible, persons familiar with the process will be involved for estimations of times. These time estimations will be used together with the measurements done, in order to achieve as accurate and reliable values as possible.

Secondly, due to the large extent of many of the improvement suggestions, it is not possible to conduct extensive investigations regarding all costs and benefits, which would be preferable before fully implementing. Some alternatives will need much time and can be considered as a separate improvement project. Although, there will be discussions regarding all alternatives, where possible positive and negative outcomes is described.

There will not be a choice of alternative made in this step because this decision has to be taken by the management at the case company. The time span of the study do not allow to wait for this decision to be taken, which means that the study will end at this step, leaving the responsibility for completing further steps in the model to the case company. The alternatives discussed and evaluated in this step will serve as a foundation for the management of the case company in their decision making regarding improvement suggestion to implement.

When estimating benefits and costs regarding the improvement suggestions, both manual cutting stations will be included instead of just one of them. This is because these machines are identical and it is more understandable if impacts on both machines are described. From discussions with a supervisor and the production manager, average data regarding the manual cutting stations were found. This data is used for estimating benefits and costs on longer time spans, which in this case will be over a project and over a year. The average data is shown below:

- Average projects per year: 200
- Average wagons/pallets per project: 12
- Average number of different profile lengths and types per wagon/pallet: 3.5
- Operator cost per hour: 677 SEK

All improvement suggestions are listed below as alternatives, together with belonging discussions and in some cases measurements, regarding potential benefits and costs (or negative aspects):
Alternative 1: Include profile packing order in production plan

From measurements it was found that the average time spent on obtaining a wanted wagon/pallet from the intermediate storage was 9.37 minutes. This measurement should preferably have been done with more samples in order to ensure a high significance level, but due to unfortunate timing of measurement sessions, it was not possible to obtain more samples of this activity. To compensate this, two operators and a supervisor were asked to give an estimation of the average time for this activity. They all had a similar opinion of this, which was 10 minutes. This time is close to the average seen from the measurements, so 10 minutes will be the time used for further calculations. By implementing this suggestion and pack the profile wagons/pallets according to the production plan, this activity is estimated to instead take approximately 3 minutes to perform, which is, according the operators, the time it takes to obtain a wagon/pallet when it is on top in the intermediate storage. This time can be translated into cost savings, where for each wagon/pallet obtained, 80 SEK will be saved. There is an average of 12 wagons/pallets for each project, leading to estimated cost savings of approximately 1 000 SEK/project. The annual cost savings, gained from implementing this alternative, are therefore estimated to be 200 000 SEK.

This implementation requires that the fork lift driver, alternatively the profile supplier, arrange the wagons/pallets according to the production plan. It should be investigated if the fork lift driver is possible to do this; if time-schedules allow such a change. Otherwise it should be a negotiation with the profile supplier in order to see the additional costs for arranging the wagons/pallets before delivery, leading to no extra work for the fork lift driver, compared to today.

Alternative 2: More standardized profile lengths

By doing an overhaul of the existing product range at the case company it may be found that the profile lengths can be more standardized, leading to less machine setups, quality controls and marking of profiles, consequently decreasing the lead time in the cutting process.

It is difficult to measure the benefits and also to estimate the costs from this improvement suggestion because it will need an extensive investigation to see whether it is beneficial or not. Although it is recommended to do this investigation because it could have a large impact on the profitability if it is possible to standardize the lengths, not only regarding the cutting station, but also in many other parts of the company.

Alternative 3: Decrease amount of profile types

An overhaul of the existing product range can also lead to a finding that same profile type can be used for several purposes, instead of having one type for each purpose. This will, similar to standardizing of profile length, lead to less machine setups, quality controls and marking of profiles, which will decrease the lead time.

This improvement suggestion is also difficult to measure the benefits from and estimate the costs to implement, due to the extent of the improvement. Similar to the previous improvement suggestion, it is recommended to conduct an extensive investigation because it could be very beneficial for the company if the range of different profile types is decreased.
Alternative 4: A standardized procedure for preparing the cutting station

The time for performing the procedure for preparing the cutting stations varies very much, depending on the extent of setup needed for specific profiles. From measurements it was found that the average time spent for each preparation, which occurs between each set of unique profile lengths or types, is approximately 1.9 minutes. During these measurements, it was noted that the setups were not particularly complicated and there were only small machine adjustments needed between the different sets. When consulting with two operators, the estimated time for doing uncomplicated preparations were told to usually be 2-3 minutes. For more complicated preparations, which occur quite often, this time can reach up to 15 minutes. From these available inputs, an assumption is made that a general average time for this activity is 4 minutes. This has to be assumed because it is not known how often the most, respectively the least, complicated preparations occur. This time of 4 minutes will be used for further calculations.

A discussion was made with the supervisor and production manager and from this, an estimation was made that by having stated instructions, the preparation time will be decreased to approximately 2.5 minutes. This time difference will generate cost savings of 17 SEK for each time the machine are being prepared for a new unique set of profiles to be cut. Each project has an average of 40 unique sets of profiles, which means that the cost savings will be 680 SEK/project, leading to annual cost savings of 136 000 SEK.

The cost for creating a preparation instruction for the operator is difficult to estimate, but it will not be expensive because not much time has to be spent developing it. A risk is that, even though there is a stated instruction, the operators will not follow it due to old habits etc.

Alternative 5: Ensure availability of empty wagons/pallets at a dedicated point

When discussing with the operators, an estimation was made that the average time spent on searching for empty wagons/pallets was approximately 15 minutes per wagon/pallet. By ensuring the availability at the dedicated returning point, the process for obtaining a new wagon/pallet is estimated to instead take 3 minutes. Because the cost/hour is 677 SEK, this difference of 12 minutes will mean 135 SEK in losses for every empty wagon/pallet got. Because the estimated average number of wagon/pallets per project is 12, there will be cost savings on approximately 1 600 SEK/project. The average number of projects/year is 200, which leads to that the annual cost savings is estimated to be 325 000 SEK if the availability on empty wagons/pallets at the dedicated point is ensured.

To inform the employees of the importance of returning empty wagons/pallets to the dedicated location will not cost anything. If this does not help improving the availability, more wagons/pallets should be purchased. Each wagon/pallet cost approximately 1 500 SEK and an investigation over the amount of wagons/pallets that is needed has to be done at the company. By comparing the total costs with the mentioned benefits above it can be seen if it will be a profitable investment.
Alternative 6: Restructure the facility layout of the manual cutting stations
This is an alternative that will not be measured but only discussed. From observations it has been seen that the placement of the manual cutting stations can be restructured in order to get a smoother and straighter production flow. The supervisor has a mutual opinion in this as well. By improving this, the material will move shorter distances, as well as the loading and unloading of profiles will be facilitated for the operators, leading to a shorter lead time.

Because this is a large change in the factory, no estimations of costs or financial gains will be done. Although, it is suggested that the case company investigates this, because this improvement shows much potential of being beneficial.

Alternative 7: Replace manual marking with printed notes with information
The taping and marking of profiles that is done today is quite time consuming if there are many different lengths and types of profiles in a project. From the measurements done, the average time for this activity was 1,43 minutes for each unique set of profiles. If divided separately into taping and writing, the taping has an average time of 0,88 minutes and the writing has an average of 0,55 minutes. By having an already prepared note with the necessary information on that the operator attaches to the profile set, the time of taping will be the same but the writing is estimated to be decreased by a couple of seconds, which not is enough to have a large impact on cost savings. However, implementing this will ensure the information flow in the production process at the company.

The cost for the prepared notes will be quite similar to the cost saved from this method, making the costs in relation to benefits break even. A suggestion to increase the profit more is to find an alternative for taping that still fulfills the ISO requirements.

Alternative 8: A dedicated delivery point
This alternative will lead to that the operators spend less time on transporting the finished profiles, as well as searching for available storage slots, and could instead focus more on the cutting. The operators estimate that the average time for moving a wagon/pallet with finished profiles, from the cutting station to the assembly hall, is 8 minutes. By having a dedicated delivery point, this time is estimated to be decreased to 2,5 minutes, which translated in cost savings is 62 SEK per pallet/wagon moved. For each project, there is an average of 12 wagons/pallets moved, leading to estimated cost savings of 750 SEK/project. There is an average of 200 projects every year, which means that the estimated annual cost savings will be approximately 150 000 SEK.

This implementation will require that someone else will have to do the transportations of profiles to the designated stations instead of the operators. It is difficult to estimate a cost of this but a suggestion is to investigate if it is possible that the fork lift driver will take this responsibility. If this is not possible, another suggestion is to designate a person responsible for material handling in the assembly hall, who can perform these movements. This material handler is responsible for the entire storage in the assembly hall, which is beneficial for more stations than only the cutting. Even if it require one more person at the plant, it could be worth to investigate the possibility because it could show that it will be beneficial for the company.
7. Results

In this chapter there will be two types of results presented. First the application results from the different steps in the model, and secondly the general results from the study. In the application results, the two final steps, Step 4 and Step 5, will not be mentioned for the simple reason that they have not been executed.

7.1 Application Results

When applying the model it was found that the case company had most problems with the manual cutting stations. In these cutting stations it was found that operator procedures was the factor that was in most need of improvements. Specific activities regarding this factor was found and then root causes to problems within these activities were identified. The most significant root causes are shown in Table 8 below:

Table 8: Most Significant Root Causes

<table>
<thead>
<tr>
<th>Possible root cause</th>
<th>Observations</th>
<th>Supervisor</th>
<th>Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallets/wagons not packed according to production plan</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Many different profile lengths and types</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Inefficient preparation instructions</td>
<td>Significant</td>
<td>Significant</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hard to find pallets/wagons for finished profiles</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Improper position of profiles to be cut</td>
<td>Significant</td>
<td>Significant</td>
<td>None</td>
</tr>
<tr>
<td>Improper method for marking</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
<tr>
<td>Lack of storage space</td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
</tr>
</tbody>
</table>

For these root causes, eight different alternatives for improvement solutions were generated. These are listed below, together with estimated costs and benefits:

**Alternative 1: Include profile packing order in production plan**

*Estimated benefits:* 1000 SEK/project, 200 000 SEK/year

*Estimated costs:* This alternative will require more time of fork lift driver. Alternatively, there will be an additional cost to the profile supplier, who will arrange the wagons/pallets according to the production plan, instead of the fork lift driver. Negotiations with the profile supplier should be done in order to see this cost.

**Alternative 2: More standardized profile lengths**

*Estimated benefits:* More standardized profiles lengths will result in less machine setups, quality controls, and marking of profiles, consequently decreasing the lead time. A recommendation is to investigate this possibility.

*Estimated costs:* More extensive investigations need to be done by the case company in order to do an adequate estimation of this.
Alternative 3: Decrease amount of profile types

Estimated benefits: A decreased amount of profiles types will result in less machine setups, quality controls, and marking of profiles, consequently result in a decreased lead time for the cutting stations. A recommendation is to investigate this possibility.

Estimated costs: More extensive investigations need to be done by the case company in order to do an adequate estimation of this.

Alternative 4: A standardized procedure for preparing the cutting station

Estimated benefits: 680 SEK/project, 136 000 SEK/year

Estimated costs: No cost estimations has been done for this, but the cost for creating preparation instructions will not be significantly expensive.

Alternative 5: Ensure availability of empty wagons/pallets at a dedicated point

Estimated benefits: 1 600 SEK/project, 325 000 SEK/year

Estimated costs: Informing the personnel of the importance of returning wagons/pallets do not cost anything. If this do not help, it is suitable to purchase more wagons/pallets. These cost 1 500 SEK per new wagon/pallet and an investigation to see the needed amount is recommended to conduct.

Alternative 6: Restructure the facility layout of the manual cutting stations

Estimated benefits: This will lead to shorter distances for the material to move. It will also facilitate the loading and unloading of profiles, leading to a shorter lead time.

Estimated costs: More extensive investigations need to be done by the case company in order to do an adequate estimation of this.

Alternative 7: Replace manual marking with printed notes with information

Estimated benefits: The benefit gained is negligible but it will ensure the information flow in the plant. More benefits could be gained from this if the taping can be replaced by another method, still fulfilling the requirements of the ISO standard.

Estimated costs: The cost and benefits will more or less break even.

Alternative 8: A dedicated delivery point

Estimated benefits: 750 SEK/project, 150 000 SEK/year

Estimated costs: This requires that someone else is responsible for the transportations of profiles to the following stations instead of the operators. This could be done by the fork lift driver or a designated material handler in the assembly hall.

Benefits were estimated in five of the eight alternatives, and the total cost savings for these exceeds 800 000 SEK each year. Furthermore, the implementation costs for these are trivial or non-existing, which facilitates a shorter decision making and implementation process. One of these alternatives, alternative 7, did not affect the profitability at the cutting station directly, but instead it ensures a well-functioning information flow in the plant, which could be very
beneficial if looking from a company-wide aspect, instead of only the cutting area. The other three alternatives, alternative 2, 3, and 6, are believed to have even more positive impact on the profitability than the other five. This is because these changes would affect the entire approach of working and not only small activities. Due to time limitations of the study it is not possible to estimate these but it is recommended that the case company conduct investigations about these because there could be much earnings generated.

7.2 General Study Results
The main result from this study is the model that has been developed. This model has been tested and proven to work when improving a cutting station. By using the model, a profitability problem is approached from a holistic view and then broken down systematically in order to find the correct root cause for the problem. When the actual root cause has been found, solutions can be generated, leading to an increased profitability for the cutting station. Also it has been shown that it is easy to apply the model because of the structured roadmap and clear instructions. The tool developed for one of the steps, CIPC, has also been found to be a suitable tool, giving a structured and comprehensive aid when choosing the affecting factor to focus on. The other suggested tools were also suitable when applying the model. Due to their generalizability, it was possible to use them for the chosen factor in this case and would probably also have been suitable in another case, regardless of factor to focus improvements on. The main goal with the study was to find ways to increase the profitability of a cutting station and the case study has proven that this is possible to achieve by using the model.
8. Conclusions

In this chapter, the thesis will be concluded and the problem formulation will be answered. Criticism towards the developed model, as well as suggestions of future research in this area, will be presented. Finally, some recommendations to the case company will be presented, based on the results from the study.

8.1 Answer to the Problem Formulation

The stated problem in this study is formulated as a question and in this phase of the study, it is now possible to answer this. The formulation of the problem is presented below:

- How to optimize the production process within a cutting station in order to increase profitability?

For solving this problem, a model has been developed, serving as a foundation for systematically identify root causes for problems and then find solutions to those, which will increase the profitability of the production process.

If a cutting production process is showing unsatisfying profitability results, there is a possibility that the source to this problem originates from any of the affecting factors of the cutting process. When the origin of the problem is unknown, it is essential to be logical and realistic when searching for the problem. An easy mistake is to decide in advance a specific focus factor, like many other existing improvement models do, leading to an exclusion of factors that might be containing the actual root cause. This is one of the largest strengths with the developed model, where this model considers and analyzes all possible affecting factors, increasing the chance of achieving the best possible outcome of the improvement work.

Due to the wide scope of considered factors, it can be difficult and time consuming to, in an efficient way, break down and identify the right root causes. This is another of the main strengths with the model, where the stated approach, with the combination of methods and tools, breaks down the problem in a very structured and efficient way, making it possible to find the correct root causes. An essential phase in this break down process is done by a tool called CIPC, which is developed by the thesis authors, where both criticality and improvement potential are considered, which none of the found existing tools are treating. This consideration is important because if something is critical, it is no certainty that it is in need of improvements.

An advantage with the developed model is the clear and structured roadmap, which makes application of the model easy and efficient when performing improvement initiatives. This is a problem with some other well-established improvement models, where the approach is ambiguous and hard to fully understand. The model is developed for, and tested on, a cutting station, but the thesis authors cannot see any obvious limitations for applying the model in other production processes. With some modifications, the model can be used for optimizing almost any production process, in order to increase profitability.
8.2 Criticism of the Model

The advantages with the developed model are many, and the chances of achieving improved results after applying it are high. Still, there are some weaknesses with the model that is important to be aware of and consider. First, a problem could be the high level of subjectivity regarding the data collection in the suggested tools, leading to a risk of poor data quality. The reason for using this approach anyway, is that it is difficult to determine common denominators and use mathematical and statistical methods for data collection, due to the width of scope regarding affecting. In this thesis, this problem was compensated by using several input sources in order to increase the reliability of data.

Secondly, the tools suggested may have alternatives that would be more suitable and advantageous for specific areas and affecting factors. The reason for keeping these tools anyway, is to maintain a high generalizability of the model application, with tool suggestions feasible for the intended task, regardless of area or affecting factor.

8.3 Future Research

A suggestion for future research regarding the model is to investigate alternatives to the data collection, in order to decrease the subjectivity, leading to a reduced risk of poor data quality. Another suggestion is to find ways for incorporating other aspects which is not currently considered in the model, such as safety, environment, business culture, change acceptance etc.

8.4 Recommendations

From the model applied at the case company, eight improvement suggestions were found. These suggestion alternatives are presented in the list below:

- **Alternative 1:** Include profile packing order in production plan
- **Alternative 2:** More standardized profile lengths
- **Alternative 3:** Decrease amount of profile types
- **Alternative 4:** A standardized procedure for preparing the cutting station
- **Alternative 5:** Ensure availability of empty wagons/pallets at a dedicated point
- **Alternative 6:** Restructure the facility layout of the manual cutting stations
- **Alternative 7:** Replace manual marking with printed notes with information
- **Alternative 8:** A dedicated delivery point

We, the authors, recommend the case company to complete the rest of the model. This should be done by taking a decision regarding which alternative to implement. To take the best possible decision, we recommend using our estimations and discussions regarding the outcome of the alternatives (see Chapter 7.3 and 6.3.3) as an input and a decision support. Some alternatives might be in need of further investigations in order to increase or ensure the reliability of the outcome estimations, which also has been described in the result chapter.

By following these recommendations, which will lead to a more optimized cutting station, the chance of a profitability increment at the cutting station is high.
References

Articles:


Books:


Standards:


Websites:


Figures:

*Figure 3: PDCA Cycle:*

*Figure 4: IDEA Cycle:*
http://4.bp.blogspot.com/_rCUAP2MfayA/SdFn0K7Qm3I/AAAAAAAARY/twDJJ-dai6M/s320/IDEA+loop.png

*Figure 5: DMAIC Cycle:*

*Figure 6: Decision Hierarchy Triangle:*

*Figure 7: Example of IDEF0 with Box and Arrows:*
http://www.idef.com/IDEF0.htm

*Figure 8: Quality Function Deployment:*

*Figure 10: Example of a Fishbone diagram:*
http://www.vertex42.com/ExcelTemplates/fishbone-diagram.html
## Appendix A: Literature Review

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Database</th>
<th>No. of hits</th>
<th>Filtering methods</th>
<th>Additional keywords</th>
<th>No. of hits after filtering</th>
<th>Relevant articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting process optimization</td>
<td>Science Direct</td>
<td>32892</td>
<td>Only title, abstract &amp; keywords, Published last 5 years</td>
<td>Improvement models</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Cutting process optimization</td>
<td>Emerald</td>
<td>786</td>
<td>Search all except full text</td>
<td></td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Cutting process optimization</td>
<td>BSP</td>
<td>16</td>
<td>-</td>
<td></td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Cutting process optimization</td>
<td>OneSearch</td>
<td>5847</td>
<td>Only online fulltext, Published last 5 years, Abstract only</td>
<td>Improvement models</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Cutting station improvement</td>
<td>Science Direct</td>
<td>13833</td>
<td>Only title, abstract &amp; keywords</td>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Cutting station improvement</td>
<td>Emerald</td>
<td>827</td>
<td>Search all except full text</td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Cutting station improvement</td>
<td>OneSearch</td>
<td>948</td>
<td>Abstract only, Published last 5 years</td>
<td></td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Optimization model</td>
<td>Science Direct</td>
<td>516132</td>
<td>Only title, abstract &amp; keywords</td>
<td>Cutting station</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Optimization model</td>
<td>Emerald</td>
<td>6754</td>
<td>Search all except full text (1st keyword)</td>
<td>Cutting station</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Optimization model</td>
<td>BSP</td>
<td>4205</td>
<td>Abstract only, Published last 5 years</td>
<td>Cutting</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Optimization model</td>
<td>OneSearch</td>
<td>625703</td>
<td>Abstract only</td>
<td>Cutting station</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
Appendix B: Pre-calculated Profile Lead Times and Costs

<table>
<thead>
<tr>
<th>Profile ID</th>
<th>Processing</th>
<th>Cutting</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.50 Min</td>
<td>0.00 Min</td>
<td>4.50 Min</td>
</tr>
<tr>
<td>2</td>
<td>4.50 Min</td>
<td>0.00 Min</td>
<td>4.50 Min</td>
</tr>
<tr>
<td>3</td>
<td>4.50 Min</td>
<td>0.00 Min</td>
<td>4.50 Min</td>
</tr>
<tr>
<td>4</td>
<td>4.50 Min</td>
<td>0.00 Min</td>
<td>4.50 Min</td>
</tr>
<tr>
<td>5</td>
<td>0.00 Min</td>
<td>0.67 Min</td>
<td>0.67 Min</td>
</tr>
<tr>
<td>6</td>
<td>1.25 Min</td>
<td>0.50 Min</td>
<td>1.75 Min</td>
</tr>
<tr>
<td>7</td>
<td>0.75 Min</td>
<td>0.50 Min</td>
<td>1.25 Min</td>
</tr>
<tr>
<td>8</td>
<td>0.75 Min</td>
<td>0.50 Min</td>
<td>1.25 Min</td>
</tr>
<tr>
<td>9</td>
<td>0.08 Min</td>
<td>0.00 Min</td>
<td>0.08 Min</td>
</tr>
<tr>
<td>10</td>
<td>0.00 Min</td>
<td>0.20 Min</td>
<td>0.20 Min</td>
</tr>
<tr>
<td>11</td>
<td>1.50 Min</td>
<td>0.00 Min</td>
<td>1.50 Min</td>
</tr>
<tr>
<td>12</td>
<td>3.50 Min</td>
<td>0.00 Min</td>
<td>3.50 Min</td>
</tr>
<tr>
<td>13</td>
<td>3.67 Min</td>
<td>0.00 Min</td>
<td>3.67 Min</td>
</tr>
<tr>
<td>14</td>
<td>3.83 Min</td>
<td>0.00 Min</td>
<td>3.83 Min</td>
</tr>
<tr>
<td>15</td>
<td>4.00 Min</td>
<td>0.00 Min</td>
<td>4.00 Min</td>
</tr>
<tr>
<td>16</td>
<td>0.00 Min</td>
<td>0.50 Min</td>
<td>0.50 Min</td>
</tr>
<tr>
<td>17</td>
<td>0.00 Min</td>
<td>0.50 Min</td>
<td>0.50 Min</td>
</tr>
<tr>
<td>18</td>
<td>0.00 Min</td>
<td>0.50 Min</td>
<td>0.50 Min</td>
</tr>
<tr>
<td>19</td>
<td>0.00 Min</td>
<td>0.50 Min</td>
<td>0.50 Min</td>
</tr>
<tr>
<td>20</td>
<td>0.00 Min</td>
<td>0.50 Min</td>
<td>0.50 Min</td>
</tr>
<tr>
<td>21</td>
<td>1.67 Min</td>
<td>0.00 Min</td>
<td>1.67 Min</td>
</tr>
<tr>
<td>22</td>
<td>2.67 Min</td>
<td>0.00 Min</td>
<td>2.67 Min</td>
</tr>
<tr>
<td>23</td>
<td>3.67 Min</td>
<td>0.00 Min</td>
<td>3.67 Min</td>
</tr>
<tr>
<td>24</td>
<td>4.00 Min</td>
<td>0.00 Min</td>
<td>4.00 Min</td>
</tr>
<tr>
<td>25</td>
<td>4.50 Min</td>
<td>0.00 Min</td>
<td>4.50 Min</td>
</tr>
<tr>
<td>26</td>
<td>5.00 Min</td>
<td>0.00 Min</td>
<td>5.00 Min</td>
</tr>
<tr>
<td>27</td>
<td>6.00 Min</td>
<td>0.00 Min</td>
<td>6.00 Min</td>
</tr>
<tr>
<td>28</td>
<td>6.50 Min</td>
<td>0.00 Min</td>
<td>6.50 Min</td>
</tr>
<tr>
<td>29</td>
<td>7.00 Min</td>
<td>0.00 Min</td>
<td>7.00 Min</td>
</tr>
<tr>
<td>30</td>
<td>3.00 Min</td>
<td>0.00 Min</td>
<td>3.00 Min</td>
</tr>
<tr>
<td>31</td>
<td>0.00 Min</td>
<td>1.00 Min</td>
<td>1.00 Min</td>
</tr>
<tr>
<td>32</td>
<td>0.00 Min</td>
<td>1.50 Min</td>
<td>1.50 Min</td>
</tr>
<tr>
<td>33</td>
<td>0.00 Min</td>
<td>1.50 Min</td>
<td>1.50 Min</td>
</tr>
<tr>
<td>34</td>
<td>0.00 Min</td>
<td>1.50 Min</td>
<td>1.50 Min</td>
</tr>
<tr>
<td>35</td>
<td>1.50 Min</td>
<td>0.00 Min</td>
<td>1.50 Min</td>
</tr>
<tr>
<td>36</td>
<td>2.50 Min</td>
<td>0.00 Min</td>
<td>2.50 Min</td>
</tr>
<tr>
<td>37</td>
<td>1.00 Min</td>
<td>0.25 Min</td>
<td>1.25 Min</td>
</tr>
<tr>
<td>38</td>
<td>0.33 Min</td>
<td>0.25 Min</td>
<td>0.58 Min</td>
</tr>
</tbody>
</table>
### Costs of Areas

<table>
<thead>
<tr>
<th></th>
<th>Operating cost/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>677.00 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>677.00 SEK</td>
</tr>
</tbody>
</table>
# Appendix C: Project Results

## Project: A

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>9 816.50 SEK</td>
<td>18 170.68 SEK</td>
<td>-8 354.18 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>4 062.00 SEK</td>
<td>5 964.37 SEK</td>
<td>-1 902.37 SEK</td>
</tr>
</tbody>
</table>

Results: -10 256.55 SEK

## Project: B

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>10 832.00 SEK</td>
<td>25 814.01 SEK</td>
<td>-14 982.01 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>4 739.00 SEK</td>
<td>8 455.73 SEK</td>
<td>-3 716.73 SEK</td>
</tr>
</tbody>
</table>

Results: -18 698.74 SEK

## Project: C

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>21 664.00 SEK</td>
<td>20 533.41 SEK</td>
<td>1 130.59 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>9 139.50 SEK</td>
<td>18 055.59 SEK</td>
<td>-8 916.09 SEK</td>
</tr>
</tbody>
</table>

Results: -7 785.50 SEK

## Project: D

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>8 801.00 SEK</td>
<td>3 107.43 SEK</td>
<td>5 693.57 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>3 723.50 SEK</td>
<td>10 832.00 SEK</td>
<td>-7 108.50 SEK</td>
</tr>
</tbody>
</table>

Resultado: -1 414.93 SEK

## Project: E

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>18 279.00 SEK</td>
<td>22 936.76 SEK</td>
<td>-4 657.76 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>7 785.50 SEK</td>
<td>12 510.96 SEK</td>
<td>-4 725.46 SEK</td>
</tr>
</tbody>
</table>

Results: -9 383.22 SEK

## Project: F

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>17 263.50 SEK</td>
<td>25 922.33 SEK</td>
<td>-8 658.83 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>7 447.00 SEK</td>
<td>7 047.57 SEK</td>
<td>399.43 SEK</td>
</tr>
</tbody>
</table>

Results: -8 259.40 SEK

## Project: G

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>64 653.50 SEK</td>
<td>94 546.70 SEK</td>
<td>-29 893.20 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>27 418.50 SEK</td>
<td>32 231.97 SEK</td>
<td>-4 813.47 SEK</td>
</tr>
</tbody>
</table>

Results: -34 706.67 SEK

## Project: H

<table>
<thead>
<tr>
<th></th>
<th>Pre-calc</th>
<th>Outcome</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>35 204.00 SEK</td>
<td>34 926.43 SEK</td>
<td>277.57 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>14 894.00 SEK</td>
<td>16 694.82 SEK</td>
<td>-1 800.82 SEK</td>
</tr>
</tbody>
</table>

Results: -1 523.25 SEK
## APPENDIX C

<table>
<thead>
<tr>
<th>Project: I</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>21 664,00 SEK</td>
<td>27 980,41 SEK</td>
<td>-6 316,41 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>9 139,50 SEK</td>
<td>19 585,61 SEK</td>
<td>-10 446,11 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-16 762,52 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: J</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>20 987,00 SEK</td>
<td>21 122,40 SEK</td>
<td>-135,40 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>8 801,00 SEK</td>
<td>9 329,06 SEK</td>
<td>-528,06 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-663,46 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: K</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>13 878,50 SEK</td>
<td>15 983,97 SEK</td>
<td>-2 105,47 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>5 754,50 SEK</td>
<td>12 578,66 SEK</td>
<td>-6 824,16 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-8 929,63 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: L</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>24 033,50 SEK</td>
<td>35 772,68 SEK</td>
<td>-11 739,18 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>10 155,00 SEK</td>
<td>15 422,06 SEK</td>
<td>-5 267,06 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-17 006,24 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: M</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>33 511,50 SEK</td>
<td>47 965,45 SEK</td>
<td>-14 453,95 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>14 217,00 SEK</td>
<td>14 162,84 SEK</td>
<td>54,16 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-14 399,79 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: N</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>15 571,00 SEK</td>
<td>13 736,33 SEK</td>
<td>1 834,67 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>6 431,50 SEK</td>
<td>9 369,68 SEK</td>
<td>-2 938,18 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-1 103,51 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: O</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>68 377,00 SEK</td>
<td>63 710,43 SEK</td>
<td>-4 666,57 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>29 111,00 SEK</td>
<td>37 729,21 SEK</td>
<td>-8 618,21 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-3 951,64 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: P</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>50 775,00 SEK</td>
<td>38 098,91 SEK</td>
<td>12 676,09 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>21 326,00 SEK</td>
<td>32 848,04 SEK</td>
<td>-11 522,04 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>1 154,05 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: Q</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>18 617,50 SEK</td>
<td>20 987,00 SEK</td>
<td>-2 369,50 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>7 785,50 SEK</td>
<td>16 730,31 SEK</td>
<td>-8 944,81 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-11 314,31 SEK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project: R</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-calc</td>
<td>Outcome</td>
<td>Difference</td>
</tr>
<tr>
<td>Processing</td>
<td>13 540,00 SEK</td>
<td>19 704,23 SEK</td>
<td>-6 164,23 SEK</td>
</tr>
<tr>
<td>Cutting</td>
<td>5 754,50 SEK</td>
<td>9 985,75 SEK</td>
<td>-4 231,25 SEK</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td>-10 395,48 SEK</td>
</tr>
</tbody>
</table>
## Total Results, Jan-Mar 2013

<table>
<thead>
<tr>
<th></th>
<th>Processing</th>
<th>Cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-83 551.06 SEK</td>
<td>-91 849.73 SEK</td>
</tr>
</tbody>
</table>

## Monthly Results, Jan-Mar 2013

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Processing outcome</strong></td>
<td>245 957.75 SEK</td>
<td>162 561.24 SEK</td>
<td>142 500.57 SEK</td>
<td>551 019.56 SEK</td>
</tr>
<tr>
<td><strong>Pre-calc processing</strong></td>
<td>186 513.50 SEK</td>
<td>129 645.50 SEK</td>
<td>151 309.50 SEK</td>
<td>467 468.50 SEK</td>
</tr>
<tr>
<td><strong>Cutting outcome</strong></td>
<td>111 793.01 SEK</td>
<td>80 447.91 SEK</td>
<td>97 293.31 SEK</td>
<td>289 534.23 SEK</td>
</tr>
<tr>
<td><strong>Pre-calc cutting</strong></td>
<td>79 209.00 SEK</td>
<td>54 498.50 SEK</td>
<td>63 977.00 SEK</td>
<td>197 684.50 SEK</td>
</tr>
</tbody>
</table>
Appendix D: Root Cause Explanations and Assessments

**Missing / hard to find profiles**
When the operator should retrieve profiles to be cut, a potential problem is that the profiles could be missing from storage or that the profiles is hard to find due to many other unsorted pallets in the storage.

- **Observations:** No problem has been observed regarding this.
- **Supervisor:** Missing profiles is not a problem, but that there are occasions where the operators have to search for profile pallets in the intermediate storage, causing unnecessary time wastes.
- **Operators:** This is not a problem.

**Incorrect information**
The work order that is given to the operators might include wrong information, or even is an entirely different work order than the one that should be executed.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.
- **Supervisor:** This is not a problem.
- **Operators:** This is not a problem but there have been a few occasions where information has been incorrect.

**Bad communication**
A problem could be poor communication between the involved persons which in this case is the operator, truck driver and shift leader. This might lead to delays in the production.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.
- **Supervisor:** The communication is good, but it could sometimes be more communication than necessary for maintaining this high level.
- **Operators:** This is not a problem.

**Inefficient moving methods**
This is a problem that might affect two of the activities, moving and receiving work order. The problem refers to that the moving method used for transportation of profiles between different locations, such as pallet truck, fork lift, and pushing, is not the most efficient approach possible.

- **Observations:** No problem has been observed regarding this.
- **Supervisor:** This is not a problem.
- **Operators:** This is not a problem.
Pallets/wagons not packed according to production plan

If the profile pallets/wagons in the intermediate are not packed according to the production plan that has been made, the operator will have to spend much unnecessary time on moving around pallets/wagons in order to obtain the wanted set of profiles that should be cut.

- **Observations:** This has been observed and this is a large problem because much time is wasted on moving around the pallets/wagons.

- **Supervisor:** It is a big problem that the pallets/wagons in the intermediate storage are not stashed in order according to the production plan.

- **Operators:** This is a recurring problem, unless luck plays a part and the wanted pallet/wagon is on top so nothing has to be moved.

Many different profile lengths and types

This is a problem that might affect three of the activities, setup machine, quality control, and marking. If a project contains of many different profile lengths and types, a new machine setup has to be done more often. The quality control, as well as the marking of profiles, also has to be made more frequent with a larger span of different lengths and types, which will be more time consuming.

- **Observations:** This has been found to be a problem when observing the process.

- **Supervisor:** This is a large problem because if a project consists of many different lengths and types, much time will be spent on setting up the machine and marking the profiles.

- **Operators:** It is a large problem with projects having many lengths and types, most because there will be much time spent on quality control and taping profiles.

Wrongly calibrated measurement settings

If the measuring system in the cutting machine, which is involved when the operator inserts the preferred settings into the machine before cutting, are wrongly calibrated it will lead to incorrectly cut profiles.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.

- **Supervisor:** There is not much problems with quality but it happens sometimes. In these cases, the supervisor is not entirely certain if this problem is caused by faulty calibrations in the machine or that the specification is not properly followed from the operators.

- **Operators:** This happen sometimes and it is more apparent on longer profiles, where it can be necessary to compensate this error by setting the machine to add a few more millimeters.
Inefficient preparation instructions
Because it is several actions to do in the cutting station before the cutting execution can be initiated, a potential problem could be that these actions is done in a more time consuming and inefficient way than necessary.

- Observations: From observations it was seen that the preparation step were not done in an optimal way and it seemed like there could be improvements regarding this.

- Supervisor: This is a big problem because much unnecessary time is spent because there are no stated instructions, leading to an inefficient and unstructured way of working.

- Operators: This is a problem in the beginning when the operator does not have much experience by the machine, but after time the preparation procedure gets more efficient.

Hard to find pallets/wagons for finished profiles
A potential problem could be to find a new pallet/wagon for stashing the finished profiles on after the cutting. If there are lack of pallets/wagons, or if they are misplaced, the operator has to spend much unnecessary time searching for those.

- Observations: From observations it has been seen that the operators often spend time searching for pallet/wagon for stashing finished profiles on.

- Supervisor: There are problems when preparing new empty pallets/wagons to load finished profiles in. Today there is much time spent if there are different types of stashing methods to use between batches, e.g. if a wagon should be used for the first batch and a pallet should be used for the second.

- Operators: It is a serious problem because there is much time wasted on searching for empty pallets/wagons. There is a dedicated point where pallets/wagons should be found, but often there are not any available there.

Improper position of profiles to be cut
Due to the large amount of profiles to be cut, it is important that the pallet/wagon with the profiles is properly located, relatively to the cutting machine, in order to facilitate the loading of profiles onto the machine.

- Observations: It has been observed that the pallet/wagon containing profiles to be cut is located in a place forcing the operator to turn around every time when taking a profile and putting in onto the machine, which could be seen as time waste.

- Supervisor: This is a problem because the operator has to stand and work between the profile wagon and the cutting machine. This makes the flow not optimal because it is not is a “straight” line.

- Operators: This is not a problem.
Ungainly profiles
If the profiles are heavy and difficult to carry, there could be a problem to lift the profiles onto the cutting machine.

- **Observations:** There has not been seen many ungainly profiles so this is not considered as a problem.

- **Supervisor:** There are not many ungainly profiles so this is not considered as a problem.

- **Operators:** It is not happening often but when it does, a single operator cannot lift the profile singly and has to ask someone else to help. When having help, this procedure is fast but it will still be some time waste for the person helping.

Complex specifications
A potential time consuming problem could be if the profiles should have complex specifications, such as a specific tilt (not 90 degree angle on cutting edge) or other factors, making it impossible to cut several profiles simultaneously.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.

- **Supervisor:** This can be a problem but there are not very often projects with complex specifications are done.

- **Operators:** In newer products that are being manufactured, more profiles with complex specification are produced, leading to much time spent due to this. Still, this is not common, compared to profiles manufactured with simpler specifications.

Cutting specifications improperly followed
If the operator does not follow the given specifications, stated in the work order, it will cause problems because the profiles will not be correctly cut, leading to much rework.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.

- **Supervisor:** There is not much problems with quality but it happens sometimes. In these cases, the supervisor is not entirely certain if this problem is caused by faulty calibrations in the machine or that the specification is not properly followed from the operators.

- **Operators:** This is not a problem.

Improper approach / place for stashing finished profiles
A potential problem could arise when the profiles have been cut and should be stashed onto a new pallet/wagon. If the pallet/wagon is not positioned in a suitable place, relatively to the machine, it could be time consuming for the operator to load the profiles onto this. Another
problem cause could be that the pallet/wagon is not optimal for the type of profiles that has been cut.

- **Observations:** This is not a problem.
- **Supervisor:** This is not a problem.
- **Operators:** This is not a problem.

**Misplaced measurement tools**
Much time could be wasted if the measurement tools for the quality control are misplaced, leading to that the operator spend unnecessary time to search for tools.

- **Observations:** Not enough observations has been done regarding this to be able to do an adequate assessment, therefore this cannot be neither confirmed nor excluded.
- **Supervisor:** There are occasions when the tools are not located in the dedicated place but this does not happen very often.
- **Operators:** This is not a problem.

**Improper measurement tools**
A problem could be that the tools used for quality controls are not optimal and other tools could be more time efficient to use.

- **Observations:** This is not a problem.
- **Supervisor:** This is not a problem.
- **Operators:** This is not a problem.

**Inefficient quality control instructions**
If the quality control should be performed in a specific order, a problem could be that steps within these are not done in an optimal way, leading to time wastes.

- **Observations:** This is not a problem.
- **Supervisor:** This is not a problem.
- **Operators:** This is not a problem.

**Unnecessary information**
This is a problem that might affect two of the activities, reporting and marking. Unnecessary time could be wasted if some of the information, stated by the operator on the work orders and the tape, is not essential to document.

- **Observations:** Because this in a requirement for the ISO-certification at the case company, it is found that the information is necessary.
- **Supervisor:** This is not a problem.
- **Operators:** It is not a major problem but it should be enough to write lengths on the unique sets and then tape all unique sets together and write the required information on that tape.

**Improper method for marking**

Much time could be spent if the method of marking of the profiles, which today is done by taping and writing information on the tape, is not the most suitable. There could be different ways of doing this, making this activity much more time-efficient.

- **Observations:** It has been seen that much time are spent on marking, especially in projects with many small sets of different lengths and types, making this a rather large problem.

- **Supervisor:** This is a problem because the methods for marking is today made by hand, which takes time to write and increase the risk for mistakes, as well as it could be hard for the next production step to interpret what has been written.

- **Operators:** This is a problem in projects with many different lengths and types because all unique sets have to be separately marked.

**Long distances**

If the delivery point for the next production step after cutting is located far away from the cutting station, it might cause unnecessary waste due to much time spent on transportation of profiles.

- **Observations:** It has been seen that the operators are walking long distances sometimes when moving finished profiles. It seems like it is possible to transport more profiles simultaneously during these movements, but this is not done at present time, which is inefficient.

- **Supervisor:** This is mostly not a problem. There is one specific type of the profiles that has to be moved quite far.

- **Operators:** This is not a problem.

**Confusion regarding delivery points**

This problem cause has been found to have two root causes, which are explained below:

**Lack of storage space**

If there is lack of storage space when the operator should deliver the pallet/wagon to the next production step, much time could be spent on searching for available storage space.

- **Observations:** It has been seen that there are much goods in the assembly hall storage and because of that, lack of space for new incoming goods.
- **Supervisor:** This is a large problem due to lack of space. Much time are spent on finding empty spots and also to move other wagon/pallets in order to make the new one fit.

- **Operators:** This is a serious problem because much time is spent on looking for empty spots for the finished profiles.

**Different delivery points**
The other root cause to confusion regarding delivery points could be if there are several delivery points to choose between.

- **Observations:** It has been observed that there are a few different delivery points for finished profiles, but this does not seem to be a problem for the operators.

- **Supervisor:** This is not a problem.

- **Operators:** This is not a problem, unless there is someone new at the cutting station.

**Time consuming reporting method**
A potential problem could be if the method used for reporting finished work orders is not the most optimal and time-efficient solution.

- **Observations:** This process goes rather fast and is not considered as a problem.

- **Supervisor:** This is not a problem.

- **Operators:** This is not a problem.
Appendix E: Time Measurements of Selected Process Activities

The measurements made were done on four selected activities in the production process. The measured activities are combinations or parts of earlier mentioned activities. The reason for changing the current activities is that these are more suitable to measure for the specific improvement suggestions.

*Obtain a new wagon with profiles* is a part of the activity *receiving work order and profiles*, where this activity only consists of obtaining the wagon/pallet from the intermediate storage. The measurement starts when the operator starts using the traverse and it ends when the wanted wagon/pallet has reached the cutting station.

*Setup machine / prepare cutting station* is a combination of the activities *setup machine* and *preparing profiles for cutting*. The measurement starts when a unique set of profiles has been finished and it ends when the first profile in the next unique set is cut.

Both *taping* and *writing* are parts of the activity *marking*. Measurements for *taping* start when the operator reaches for the roll of tape and it ends when the last piece of tape has been attached. Measurements for *writing* start when the operator takes his pen out of his pocket and measurements are ended when the pen is returned in the pocket.

<table>
<thead>
<tr>
<th>Obtain a new wagon with profiles</th>
<th>Setup machine/prepare cutting station</th>
<th>Taping</th>
<th>Writing</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:45</td>
<td>01:54</td>
<td>01:24</td>
<td>00:33</td>
</tr>
<tr>
<td>13:15</td>
<td>01:41</td>
<td>01:15</td>
<td>00:40</td>
</tr>
<tr>
<td>05:07</td>
<td>01:55</td>
<td>00:50</td>
<td>00:39</td>
</tr>
<tr>
<td></td>
<td>02:47</td>
<td>00:45</td>
<td>00:40</td>
</tr>
<tr>
<td></td>
<td>02:35</td>
<td>00:49</td>
<td>00:46</td>
</tr>
<tr>
<td></td>
<td>01:44</td>
<td>00:33</td>
<td>00:13</td>
</tr>
<tr>
<td></td>
<td>01:07</td>
<td>00:47</td>
<td>00:28</td>
</tr>
<tr>
<td></td>
<td>01:45</td>
<td>00:41</td>
<td>00:28</td>
</tr>
<tr>
<td></td>
<td>01:29</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average time</strong></td>
<td><strong>09:22</strong></td>
<td><strong>01:53</strong></td>
<td><strong>00:53</strong></td>
</tr>
</tbody>
</table>