REDUCING WASTE BY IMPROVING SHEET METAL EFFICIENCY

Bachelor Thesis

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UNIVERSITY OF TWENTE.

GUNNEBO
For a safer world®

Bachelor thesis Industrial Engineering and Management

Reducing waste by improving sheet metal efficiency

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Remark: Due to confidentiality some confidential information regarding the company, process or products is omitted or replaced with alternative information.

Preface

Dear reader,

You are about to read my bachelor thesis “Reducing waste by improving sheet metal efficiency”. This research is done at Gunnebo Doetinchem BV. The aim of this research is to find a solution for reducing the metal waste in the Gunnebo factory.

First of all, I want to thank Gunnebo Doetinchem for giving me this opportunity and allow me to be at the company, especially in the difficult times of a Covid-19 pandemic. I really enjoyed being at the company and it really helped in raising the quality of my thesis. I gained a lot of new insights, have learned a lot about working in a company and putting the knowledge I gained over the years into practice.

In particular I want to thank my external supervisor Renze Eringfeld from Gunnebo. He helped me well when I had questions, provided my research from good feedback and helped me to gain new insights during the research. I also want to thank the preparation and preliminary work department for the good explanation of the process, the nice input they had in this research and the help they provide me in the evaluation process. A special thanks goes to the QHSE department. During my research this was the department I worked on. I want to thank the QHSE department for creating a nice work-environment for me, making me feel at home and their interest and help in my research. Furthermore, I would like to thank all other employees at Gunnebo for making me feel at home and their help in giving answers to my questions.

Another big thanks go to my internal supervisor Devrim Yazan. I would thank him for his interest in my project, his guidance in my research, the well provided feedback he gave me and the appreciative meetings we had. I also want to thank Eduardo Lalla-Ruiz for his interest in my research and for being my second supervisor.

Finally, I would like to thank my friends and family for their support during my bachelor thesis. Especially I want to thank my buddies Leon Kingma and Sander Phijffer for their feedback on my work and their support during my thesis.

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Management Summary

Problem Identification

The aim of this research is to solve the action problem of Gunnebo Doetinchem. Gunnebo Doetinchem encounters the problem of a high metal waste rate. Last year the company bought 3600 tons of metal. Of the 3600 ton of metal, 1044 ton is waste. This is a percentage of 29%. The aim is to reduce the waste rate of metal with 5%. Looking more closely to the problem of the high metal waste rate we found out this problem is caused by the core problem of having difficulties with sheet metal efficiency improvements. To solve this problem an answer to the research question: “What are the causes of having difficulties with sheet metal efficiency improvements and which solution(s) can remedy these causes?” is given.

Method

This research is conducted following the principles of the MPSM approach (Heerkens & van Winden, 2017). The following steps are taken towards solving the problem:

- Defining the problem
- Formulating the problem-solving approach
- Analyzing the problem
- Formulating (alternative) solutions
- Implementing a solution
- Evaluate solution

Furthermore, the following tools and methodologies are used throughout the research: Root cause analysis, Waste hierarchy, Plan Do Check Act-Cycle (PDCA-Cycle) and Gemba.

Cause identification

The root cause of the problem is identified with the help of a data gathering experiment and categorization research. In the data gathering experiment the waste types distribution is investigated, which gave the following results shown in table I.

Waste type	Weight (ton)	% in total waste
A Punching skeleton	69,7	55,1%
B Punching waste small	48,2	38,1%
C Bending errors	2,1	1,7%
D Punching errors/ Overproduction	2,4	1,9%
E Scrap	4	3,2%
Total	126,4	= 100%

Table I: Waste type distribution

The categorization research identified the most wasteful product types. The products that are expected to produce the most waste in the production are the following products:

1. 95470
2. 97152
3. 96765
4. 95036
5. 902103
6. 95478

7. 95056
8. 901663
9. 97078
10. 901520
11. 90120

Based on these outcomes, interviews and observations we concluded that the root cause of the sheet metal efficiency problem is that the ***sheet sizes are not optimal adapted to the fixed product sizes***.

Solution

To remedy the root cause of sheet sizes are not optimal adapted to the fixed product sizes the following possible solutions are provided.

- ***Adapt sheet size:*** Although the company already purchases sheets that differ from the standard sizes it could be purchasing more sizes, which make the products fits the sheet better.
- ***Standardization:*** A standardization of punching per product part could increase product efficiencies.
- ***Dynamic nesting:*** Dynamic nesting makes a job list based on part geometries. Parts are punched based on efficiency without keeping product order in mind.
- ***Outsourcing:*** Outsourcing punching work could be beneficial when the costs are lower than the waste savings.
- ***Industrial symbiosis:*** Deliver waste and/or byproducts to waste taker in exchange for money/other goods or services.

After query and evaluation of the advantages and disadvantages of the possible solutions, the solution of adapting the sheet sizes is chosen to be implemented. This solution's Key performance indicators (KPIs) scores for the 11 most waste producing products are.

- Metal Efficiency (average of new efficiencies) = 78,58%
- Metal waste savings (annual) = 38432,44 Kg
- Cost savings (annual) = € 30.689,85

Final conclusion and recommendations

The research question answered in this research is "What are the causes of having difficulties with sheet metal efficiency improvements and which solution(s) can remedy these causes?". The causes of having difficulties with sheet metal efficiency improvements lie in the field of nesting. Due to the fixed sizes of the products and the limitations in sheet sizes, the parts are not complementary to the sheet material. The solution that is proved to remedy the causes of the metal efficiency problem is the solution of adapting the sheet size. This solution resulted in a total metal waste reduction of 1,1%.

Lastly, the following recommendations are made.

- Adapt the sheet sizes for the following safes: 95470, 97152, 95036, 902103, 95478, 95056 and 97078
- Investigate other solutions on KPIs
- Identify most wasteful products each year to update product selection.
- Investigate which products out of scope also could benefit from the "new" sheet sizes.
- Keep sheet size and efficiency in mind in when designing new products.
- Create more waste awareness within the company

Glossary

Action problem: A situation where the reality (current situation) deviates from the norm (desired) situation.

Core problem: Problem without further known causes which mainly causes action problems

Coil: A coil is steel on a roller, from this flat sheet material is produced

Knowledge problem: Missing information that is needed.

Managerial problem-solving method (MPSM): A systematic approach for solving managerial problems, consist of 7 steps.

Preparation department: This department plans and controls the processing of sheet material in usable assembly parts. In Dutch called “werkvoorbereiding”.

Preliminary work department: This department produces usable assembly parts from sheet material. In Dutch called “voorwerk”

KPIs: Key performance indicators, KPIs are used to be measured and monitored and are used to steer business strategies.

Lean: Is a worldwide known methodology for reducing waste in manufacturing processes.

Nesting: The process of placing parts in metal sheet material that needed to be punched out.

Flowchart: Visualization tool for a process, with activities and sequence flows.

Business process model (BPM): Visualization tool for a process which include data.

Power-interest matrix: Matrix which visualize stakeholders’ interest and power in a project.

Punching: Process where holes are punched in metal sheet material and metal parts are punched/cut out.

Root cause: Cause of a problem with no further causes after investigation of all causes.

Table of Contents

Reader's Guide

This Reader's guide gives a short introduction of every chapter in this report.

Chapter 1: Introduction
In chapter one an introduction of the company will be given. Furthermore, the action problem of a high metal waste rate is given with its' norm and reality. The action problem and the possible core problems are displayed in a problem cluster. Based on the problem cluster a final core problem will be chosen. Finally, the plan of approach and the research design are going to be discussed in this chapter.

Chapter 2: Theoretical Perspective
In the chapter of the theoretical perspective some tools and methodologies that could be used in finding a solution to the problem are presented. The tools are selected based on a systematic literature review. These tools are going to be used further in this research for identifying causes, formulating solutions and for testing and evaluating solutions.

Chapter 3: Context Analysis
The context analysis maps the current situation. The process of the whole production is provided in a flowchart and the process of the preparation and preliminary work department is provided by a business process model. Some current limitations and challenges that could pop up during the research are also mentioned in this chapter.

Chapter 4: Cause Analysis
In this chapter the waste types data collection and the categorizing research are presented with their results. After this we determine the root cause(s) of the metal efficiency difficulties based on the waste types and product categorization researches with a fishbone diagram.

Chapter 5: Solution Method
The solution method discusses possible solutions which can be used to solve the core problem and so the action problem. In this chapter also the mentioned solutions are going to be evaluated based on weighted score criteria. After this first evaluation one final solution will be evaluated on the following Key Performance Indicators (KPIs): Metal Efficiency (%), Metal Waste Savings (Kg) and Costs Savings (€) and conclusions will be drawn.

Chapter 6: Conclusion and Recommendations
In this section the main research question is going to be answered, the final conclusion is made and the recommendations for the company are presented. Also, directions for further research, the theoretical and practical relevance of the research and the limitations of this research are presented.

Appendix
The appendix shows extra information regarding the research.

1 Introduction

This section gives an introduction of the company, the problem identification and method. The problem identification consists of the action problem, core problem and difference between norm and reality. In the method the problem-solving approach based on the Managerial Problem-Solving Method, abbreviated called MPSM (Heerkens & van Winden, 2017) is showed. Finally, the research design with its Key Performance Indicators (KPIs), restrictions, deliverables and limitations is presented. The aim of this research is to come up with a solution for the action problem that Gunnebo Doetinchem encounters. Gunnebo Doetinchem wants to be a sustainable and cost-wisely company, therefore the company has a lean focus. Because of this focus they want to find a sustainable and cost-efficient solution for their action problem.

1.1 Company Introduction

Gunnebo is a world leader in products, services and solutions for security focused on money management, safes, entrance security and electronic security for banks, shops, (public) transport, public- and commercial buildings and industrial and high-risk locations. The Gunnebo Security Group has sale-offices in more than 25 countries in Europe, the Middle East, Africa, Asia and America, as well as sales partners in more than 100 other markets. The annual turnover is approximately 600 million Euros and the Gunnebo group has 4,200 employees. Extensive knowledge and expertise in combination with high quality, modern design and reliability makes Gunnebo one of the leading suppliers in their industry. The group's mission is to create a safer world for its customers, business partners, employees and society as a whole. An important aspect here is sustainability. The company wants to manage their waste to reduce its waste impact. Gunnebo is a sheet metal processing company and mainly work with steel. About 250 employees work in Doetinchem.

1.2 Problem Identification

Action Problem

The process of safe production at Gunnebo Doetinchem starts in the preliminary work department. Here metal sheets are punched and bent to be later on welded together in the welding department. Gunnebo Doetinchem works following the principles of lean management. This means that the aim of Gunnebo is eliminating all waste in the production process and to be as cost-efficient as possible. Despite this aim Gunnebo still has the action problem of a high metal waste rate. The metal waste is an unwanted effect of punching, wrong bending, errors and scrap waste.

Norm and Reality

Last year the company bought 3600 tons of metal. Of these 3600 tons of metal 1044 ton is waste, which is a percentage of 29%. The aim is to reduce the metal waste with 5%, this means that the norm is a waste percentage of 24%. This means the new norm of metal waste is 864 ton annual and so a waste reduction of 180 ton.

Core Problem

To search for the core problem of the action problem of a high metal waste rate a problem cluster is made (Figure 1). Looked at the figure, the action problem is highlighted in green, possible core problems are highlighted in yellow and the core problem is highlighted in red.

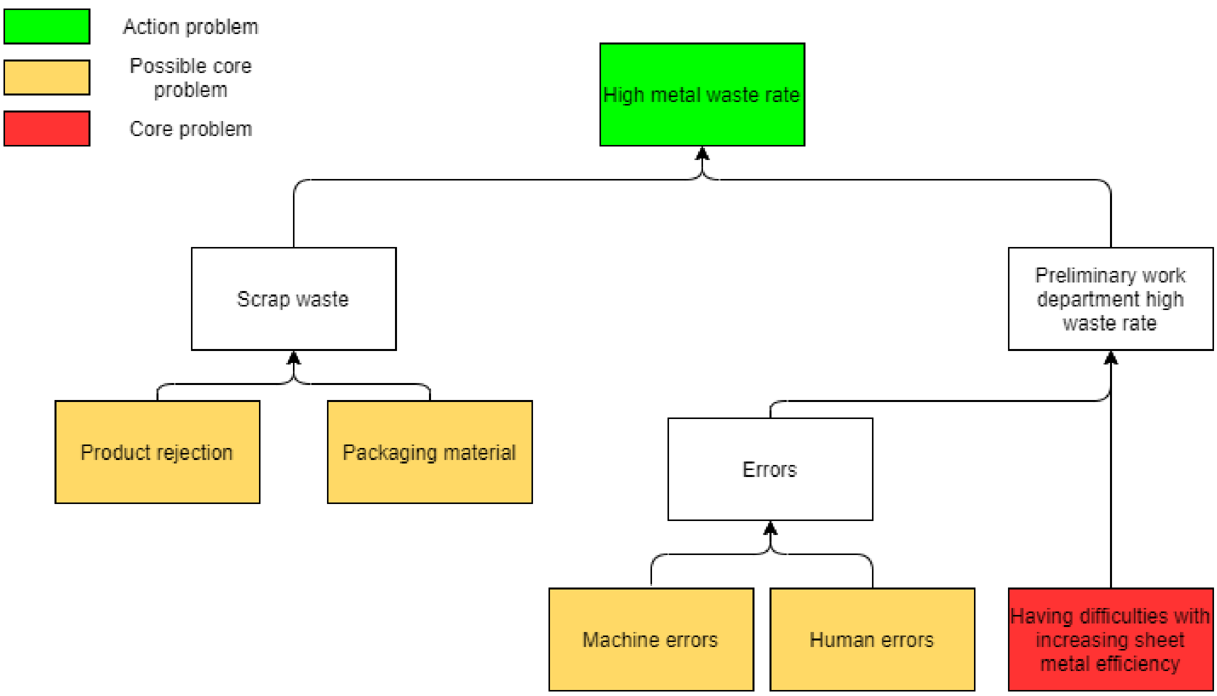

Figure 1: Problem cluster of the action problem "High metal waste rate"

The high metal waste rate in the factory is a result of two types of metal waste:

- Preliminary work department: The preliminary work department is the department which processes metal sheets to metal parts for the safe production. A part of the waste produced here is due to errors. Errors consists of two type of errors, machine errors and human errors. Machine errors are punching errors for example, a metal sheet is folded in the machine. This sheet is not usable after this error and is thrown away. Human errors are bending errors. Most of the bending is done by the employees of the preliminary work department, sometimes a part is bent too far and is not usable for production anymore. The other problem which occurs in the preliminary work department is the problem of having difficulties with increasing sheet metal efficiency. Sheet metal efficiency in this case is described as how efficient raw material (sheet metal) is used, this is the core problem.
- Scrap: This waste is from every other department in the factory. The scrap waste consists of rejected products and packaging material which is thrown away.

The problem of having difficulties with increasing sheet metal efficiency is chosen as core problem, because for this problem no further causes are known jet. In comparison with the other possible core problems of errors, product rejection and packaging material, a solution regarding the improvement of metal efficiency is the one with the highest potential. Product rejection and errors occur not on a daily basis and packaging material is in comparison with the other problems less influencing the total amount of waste. Also, it is almost impossible to eliminate all errors and product rejection. Therefore, there is chosen for the core problem of having difficulties with increasing sheet metal efficiency.

1.3 Method

1.3.1 Methodology Framework

This research is conducted based on the principles of the managerial problem-solving method (Heerkens & van Winden, 2017). The managerial problem-solving method (MPSM) consists of seven phases.

1. Defining the problem: The first phase of the MPSM is defining the problem. Here the problems of the company are put in a problem cluster and out of this problem cluster comes the action problem and the core problem. Also, problems are expressed in terms of a norm and reality, the current situation and the situation that is desired in numbers.
2. Formulating the approach: Here the plan of approach is made with D3. D3 stands for Do, Discover and Decide. Do refers to all activities that need to be performed. Discover is everything that needs to be known or understand. Decide is about selecting options, it refers to what to focus on and what to leave out.
3. Analyzing the problem: The problem is in this phase re-examined again and the missing details of knowledge problems are filled in. The cause of the problem is examined.
4. Formulating (alternative) solutions: Solutions for solving the problem are described.
5. Choosing a solution: Solution for implementation is chosen.
6. Implementing the solution: The solution is implemented following an implementation plan.
7. Evaluating the solution: The last step of the MPSM is to evaluate if the proposed solution is proper and if all previous steps of the MPSM are taken correctly.

The MPSM distinguishes 2 different problems, action problems and knowledge problems. An action problem is any situation where reality deviates from the norm. A knowledge problem has to do with missing information. Everything that is not known or understood is a knowledge problem. For action problems the MPSM mentioned above is used. During the MPSM often knowledge problems pop up. When knowledge problems pop up the researcher has to move to the research cycle (Heerkens & van Winden, 2017). The research cycle consists of 8 steps:

1. Formulating research goal: Step one is giving the reason for solving the knowledge problem.
2. Formulating the problem statement: The problem statement can be seen as the main research question. It is recommended to formulate the problem statement as a question.
3. Formulating the research questions: Based on the research question the problem statement must be answered.
4. Formulating the research design: In the research design the types of research that are conducted are described.
5. Performing the operationalization: The research described in the research design is executed.
6. Performing the measurements: The outcomes of the research must be recorded.
7. Processing the data: Analyze the data well, so that logical conclusions can be derived from the data.
8. Drawing conclusions: Give answer on the problem statement by answering the sub questions with data analysis.

The framework of the MPSM is chosen, since it is a systematic approach with a clear description of the different phases. Because of the complexity of the problem, it is also useful to have a flexible approach like the MPSM, where it is possible to jump out for knowledge questions and go easy back to filling in details at previous phases.

1.3.2 Problem Solving Approach

The draft of the problem-solving approach is made following the principle of D3 (Heerkens & van Winden, 2017). D3 consist of do, discover, decide. Do describes the steps that have to be taken to solve the problem, discover describes what is needed to know to solve the problem and decide specifies the focus of the research.

Do: The steps that must be taken to solve the problem of the high metal waste rate are: Map current situation → identify wastes→ look for causes of waste → formulate solutions to remedy causes. → choosing a solution → implement/test solution(s) → evaluate solution(s). First the current situation is mapped, with mapping the current situation we investigate how the total process of production, the preparation and preliminary work department runs. Then the types of waste are going to be identified. After that the causes of these types of waste must be found. Based on these causes solutions for remedying these causes are going to formulated. From all (alternative) solutions one solution for implementation must be chosen. This solution is going to be further tested and evaluated. based on the evaluations, recommendations are made.

Discover: To take all the steps that are mentioned at the do stage, information is needed. Not all information is provided yet, therefore this has to be discovered with research. The following research types will be conducted: qualitative research, systematic literature review, quantitative research, categorizing research and explanatory research.

Decide: The main focus in this research is on the preliminary work and preparation department. These departments have the biggest influence on the metal waste and so it would make the research unnecessary broad to also include other (production) departments when there is no need for, for example the welding department.

1.3.3 Research Design

The goal of this research is to answer the main research question: ***"What are the causes of having difficulties with sheet metal efficiency improvements and which solution(s) can remedy these causes?"***

The main research question will be answered by answering the following sub questions.

1. *What is the current way of working?*

   To search for possible causes of the metal efficiency problem, it is necessary to get an insight in the current way of working. To solve this knowledge problem qualitative descriptive research is done in the form of a context analysis. For mapping the current way of working we make a flowchart, business process model and stakeholder analysis. The flowchart represents the whole production of a safe, where the business process model is more focused on the preliminary work and preparation department. The stakeholder analysis gives an indication of the different departments and their influence and interest in this research. These models are based on observations and interviews.

2. *Which tools can be used for solving the problem of metal efficiency difficulties?*

   For a better understanding of how to reduce waste, it is also useful to look which tools could be applied in this research to identify waste, reduce waste and evaluating solutions. To get insight in what tools and frameworks could help a systematic literature review is conducted. Based on the founded literature the answer on this question is given.

3. *Which types of metal waste are there and how high is their share in the total waste?*

   The 29% waste percentage is of all metal waste. Of this waste there is also waste what is as good as insurmountable, like all metal which is wasted by punching out small holes or scrap metal from other departments in the factory. Therefore, this research must give more information about what metal waste types there are and their share in the total percentage. For answering this question quantitative research is done. An experiment for data gathering is going to be set up. For six weeks employees of the preliminary work department are going to separate the waste in five containers: skeleton waste, punching waste, punching error waste/overproduction, bending errors and scrap metal waste all get their own container. An agreement with the waste processor is going to be made to weight the waste per container over this time. Based on these results the share of the waste types regarding the total amount of waste could be calculated and an insight in the waste distribution is given.

4. *What is the difference in waste/efficiency per product category?*

   At Gunnebo a lot of different products are produced. The big variety in products and relatively short time span of the research make it more difficult to come up with a specific solution per product type. Therefore, it is necessary to narrow the focus of the research to the products with the most potential of improving the efficiency. For the investigation of the product categories a categorization research is conducted with the help of a pareto analysis. The categorization is based on the products expected waste which follows from the product efficiency and the product demand. Most of the metal efficiency per product is known within Gunnebo. Also, there is a forecast and production schedule which indicates which products will be highly produced this year.

5. *What are the root causes of the efficiency problem?*

   Based on the data gathering experiment, product categorization and observations, there will be looked further into the causes of the waste types and/or products with the highest share in the total amount of waste. Therefore, explanatory research will be conducted and causes of the metal efficiency problem will be identified with a fishbone diagram.

6. *What are possible solutions for increasing the sheet metal efficiency and so waste reduction?*

   Based on the answers of all previous questions a list with possible solutions will be made. After this list is made, explanatory research will be conducted to weight the pros and cons of the solutions and which solutions are the best to implement with the determined KPIs.

Key Performance Indicators

The KPIs that are going to be used in this research are Metal Efficiency (%), Metal Waste Savings (Kg) and Cost Savings (€).

Restrictions

The following restrictions are taken into account: the solution must lead to demonstrable improvement of the metal efficiency and the solution must not lead to extreme longer process times, since that is against the principles of the company’s lean methods. Also, the solution must be cost-beneficial.

Deliverables

The deliverables of this research are: Context analysis, Product categorization, Data analysis of waste types, Systematic literature review, Recommendation and a Cost benefit analysis

Limitations

The biggest limitation of this research design are time issues. Due to the limited time, the sampling of the waste types can only be conducted for about six weeks. Therefore, when outliers in the sample occur there should be well considered if these outliers are going to be used in the data gathering, since the sample size is probably not that big when this experiment is conducted for over six weeks. Therefore, the sample will be compared to historical data. Another limitation of this research is that the product categorization is based on the forecast and the production schedule from January till April. Although the forecast and production schedule give a good indication in which products are produced it is still a representation of a respectively short time span.

1.4 Summary

Despite the company's lean methods Gunnebo still has the action problem of a high metal waste rate. Last year 29% of all purchased metal was reported as waste, the aim is to reduce this to 24%. This action problem is going to be solved following the principles of the MPSM approach (Heerkens & van Winden, 2017). The action problem of a high metal waste rate is caused mainly by the core problem of having difficulties with increasing sheet metal efficiency within the preliminary work department. Metal efficiency is here described as, "the rate of sheet metal material that is not thrown away, but used in the product or for other purposes". This core problem is solved by answering the main question of this research: "What are the causes of having difficulties with sheet metal efficiency improvements and which solution can remedy these causes?". To find an answer on this question the following steps are taken: map current situation → identify wastes→ look for causes of waste → formulate solutions to remedy causes. → choosing a solution → implement/test solutions → evaluate solutions. With these steps a solution which is applicable and cost beneficial must be provided. The KPIs that are going to be used in this research are Metal Efficiency (%), Metal Waste Savings (Kg) and Cost Savings (€). The biggest limitation of this research is time, because of time measurements can only be done for a limited time, which influence the validity of the measurements in a negative way. Also, the scope of the research has to be narrowed down due to the time limitations.

2 Context Analysis

In this section the following research question will be answered: "What is the current way of working?" The process is going to be visualized with a flowchart and a business process model. Also, we investigate which departments are influenced by this research and how. Furthermore, some challenges that could influence the research are mentioned.

2.1 The Process

2.1.1 Safe Production Process

To gain more insight in the whole process of the safe production a flowchart is made (Figure 2). The beginning of the process is highlighted in green and the end of the process is highlighted in red.

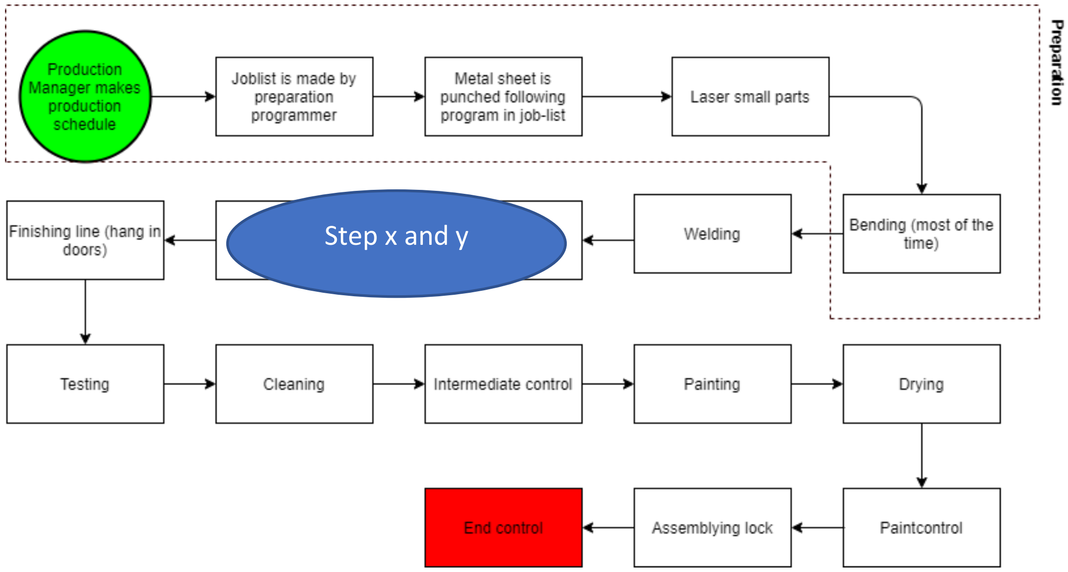

Figure 2: Flowchart of the production of a safe

The production process starts with the production manager who makes the production schedule based on demand. After that the production schedule is shared with the preparation department. The job lists of the punching machines are made. A job list consists of all software programs per safe that have to be ran to complete the desired production batches. The software for these programs is pre-programmed. When the job list is ready the punching machine starts punching following the given batch size and settings in the job list. For the production of safes also some small parts need to be lasered out. For this some rest metal of the punching process is used. Most parts in the preliminary work department need bending. This is the ending of the preparation process. The separate parts are going to be welded together in the welding department, where after that step X and Y take place. Sequent the doors are hanged in and the temporary safe is tested. After that the safe is cleaned and is controlled again. For finishing, the safe is painted. After painting, the products' paint is being controlled and the lock can be assembled. When the safe is judged right in the end control it is ready for departure.

2.1.2 Preparation Process

Looked at the problem of having difficulties with increasing sheet metal efficiency this problem occurs mainly in the preparation sector (see dotted department flowchart). To zoom in more at the preparation department also a business process model (BPM) following the principles of Weske (2007) is made (Figure 3). A business process model represents just like a flowchart a process. Nevertheless, a BPM has more eye for data input and output. A BPM is more detailed than a flowchart and groups the process in different pools and lanes. Pools are different sections and are connected by message flows. Lanes are different roles, but within the same section. For example, the preparation department and preliminary work department have different roles, but work in the same section, preliminary work.

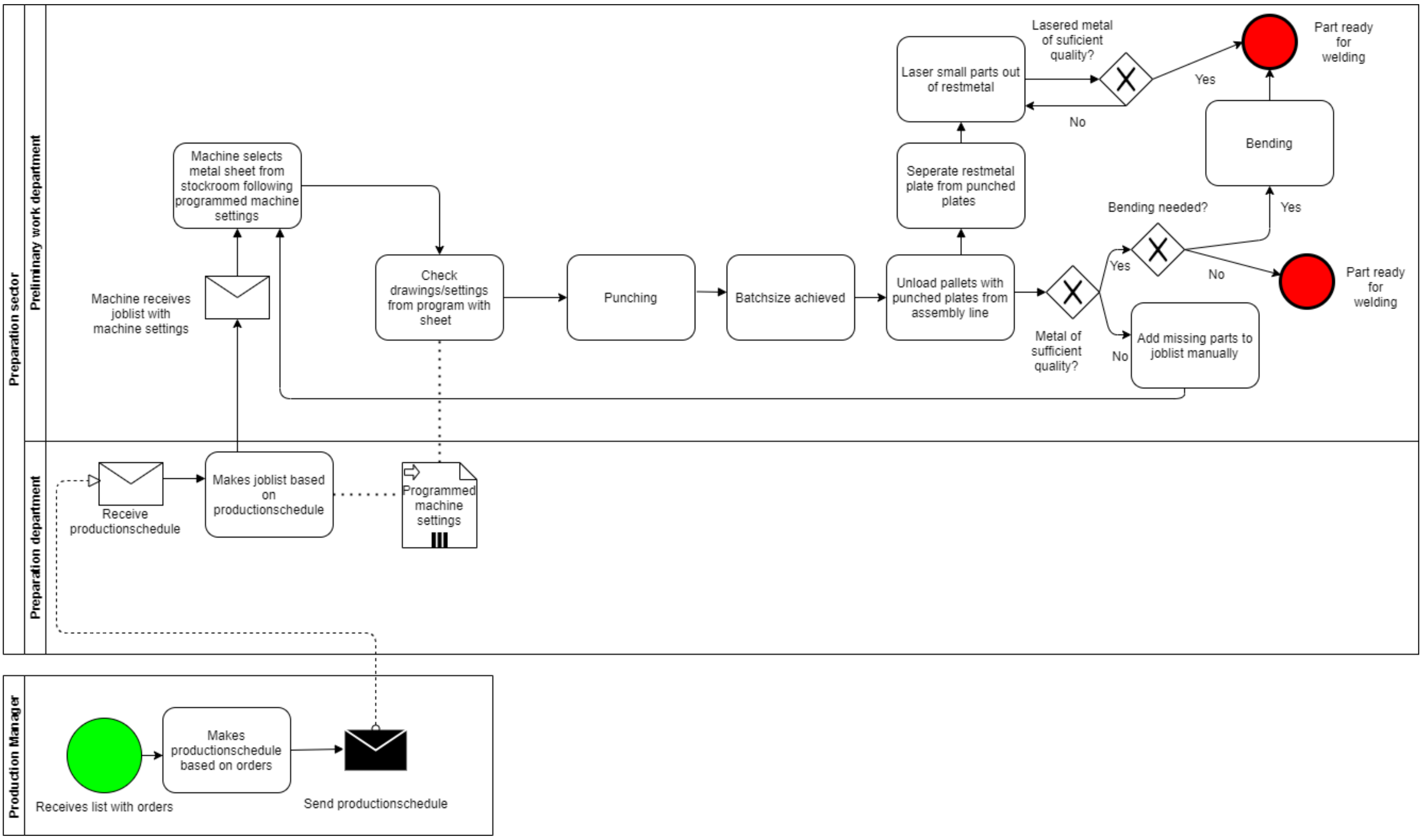

Figure 3: Business Process Model of Preparation and Preliminary work department

The process of preparation starts with the production manager who receives the list with orders, based on these orders the production manager sets up a production schedule. In this production schedule it is determined how many safes and which types have to be produced.

The programmers of the preparation department receive this production schedule and make the job list for the punching machine based on this production schedule. In the job list the programmers select the order of program jobs which are needed to fulfill the production planning of that day. When the job list is set in the punching machine, the machine starts selecting the right metal sheet from the automated stockroom and starts punching it. When a batch size of a product is achieved the punched sheets have to be unloaded from the assembly line.

Rest metal sheets are punched as well, these plates are going to the laser machine for producing smaller parts. For both the lasering and the punching process there is a final check if the quality of the metal is sufficient. After this most parts go to the bending machines where the parts are bent. After a final bending quality check the parts are ready to go to the welding department.

When a part is not of sufficient quality the part has to be produced again. When the part has to be punched again the preliminary work department must manually add the specific job to the job list again.

2.2 Stakeholder Analysis

For a good understanding of which actors are important in this research and for investigating the social impact of this research a stakeholder analysis is made. The stakeholders are going to be described following their influence, the impact of the research and their interest. We categorize the stakeholders at micro (users that are confronted often with the problem or have big influence in the decision making), meso (others that are affected within the organization) and macro (others that are affected outside the organization) level. After that we make a stakeholder power-interest matrix (Figure 4).

Preparation department (micro): The preparation department is the most important stakeholder in this research. The preparation department are the programmers of the punching machines and the production controllers of the preliminary work department. Also, the production manager is considered as a member of the preparation department in this stakeholder analysis. The preparation department has a lot of expertise and influence in the production and punching process. Their interest is to increase the sheet efficiency as much as possible, without extremely longer process times and costs. This department should be managed closely. Their input in the project can give good information and this is also the group with the biggest benefit of improved sheet metal efficiency.

Preliminary work department leaders (micro): The preliminary work department leaders are the front men in the preliminary work production part. They are the team leaders in the production and ensure that the punching, lasering and bending process run well. This stakeholder has a good knowledge of the way of working at the preliminary work department. They also have a good knowledge of the working of machines. Therefore, they could be a useful source of information. The preliminary work department leaders would have a benefit by an improved sheet metal efficiency. They could be a key factor in informing and maintaining contact with the rest of the preliminary work department about changes and the direction of the project. Therefore, this is also a real important stakeholder.

Preliminary work department employee's (micro): The preliminary work department employees have to be informed about changes in machine settings or working principles, since also the production employees work all day with the punching machines and laser cutters. It is also important to include as much as many people in the organization as possible to get a good insight into everyone's wishes. The biggest interest for the preliminary work is to do their job as safely as possible. Therefore, their demands and wishes regarding safety should be well considered in the project, since they are the ones who have to deal with the possible solutions. This group should be informed on a regular basis when big changes in the project or changes on the work floor occur. As previously mentioned, the preliminary work department leaders could play a key role in this.

First line managers (micro): The first line managers have the responsibility of the whole process. Therefore, they are responsible for the preparation process as well as the welding, drying, painting and finishing process. A change in the preparation process could also affect the rest of the production process. Therefore, the first line managers are an important stakeholder in this research and they should be informed on a regular basis on which steps are taken. The biggest interest of the first line managers is that the overall process runs as smooth as possible. Their interest must be taken into account, because the outcome of the research must benefit in the end the whole company.

Purchasing Department (meso): The purchasing department is responsible for the purchasing of sheet metal for the production of safes. The purchasing department can have valuable information about prices and which options of sheet metal are available. Also, the purchasing department should be informed about changes in the way of sheet metal processing, since this could affect the demand of sheet metal. The biggest interest of the purchasing department is to buy in sheet metal for the lowest price possible, because this can help the purchasing department in achieving the targets that are set by headquarters. An improved efficiency and so reduced steel purchasing costs help to achieve this.

Other employees (meso): Other employees must be informed when changes in the preparation department also changes their way of working. Employees for which this could be the case are for example, other production employees like welders and painters. The interest of these employees could differ from each other, but most of the time the interest of these employees would be to do their job as safely and fast as possible.

Customers (macro): Another way of production could lead to different quality levels. The interest for customers is to deliver the product with good quality and on time. When products are produced differently than before it could be an option to inform customers, to improve transparency. The interest of the customer is respected through all operations of the company, this is necessary for a good customer relation. Therefore, the outcome of the research must maintain good product quality and proper product delivery.

Society (macro): Also, society is a stakeholder in this project. When a solution for improving the sheet metal efficiency could be found, also the company becomes (a bit) more sustainable. This is in alignment with the interest of society in this case of having more sustainable companies. Despite that society has not that many influences and interest in the decision-making of this process, keeping the interest of sustainability in mind could lead to a reputation gain.

To map the stakeholders better they are categorized in a power-interest matrix. Based on their interest they could be placed in four “boxes”: Keep satisfied, Manage closely, Keep informed and Monitor (Every, 2020).

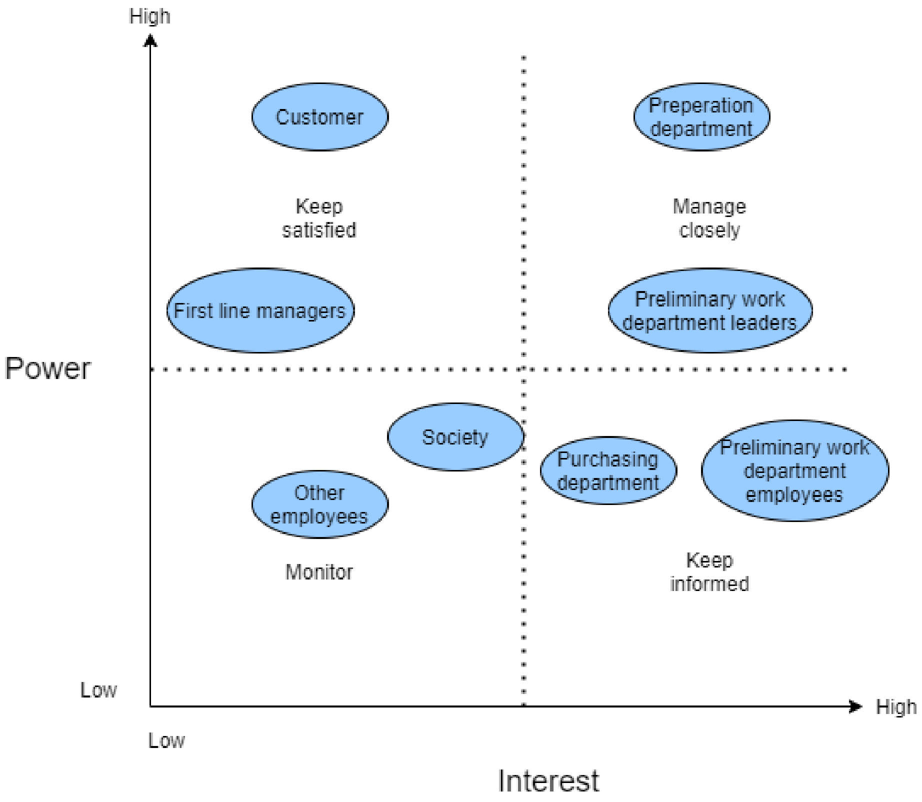

Figure 4: Power-interest matrix of stakeholders

2.3 Challenges

During this research there are some challenges which could pop up when trying to solve the problem. These challenges have to be taken into account during the research and when formulating solutions.

- ***Safety:*** The first challenge is safety. At Gunnebo safety is the most important factor. Therefore, safety must always be taken into account in the solution formulating process and the research. Solutions which can generate dangerous situations are therefore not applicable.
- ***Machine Settings:*** The second challenge is that the current punching machines have some limitations in settings. The biggest limitations are the minimum sheet sizes and maximum sheet sizes. The minimum sheet size is now 1700*900 (mm). On the other side the maximum sheet size is 3000*1500 (mm). Within these sizes it is possible to differ from the standard sheet sizes, which is already done for some safes. Also, the machine has clamps to hold the sheet on its position. Near the clamps there cannot be punched, since then the punching machine punches the clamps and damages itself. Punching skeletons do not need a certain width, but when the width becomes smaller there is a higher change of errors, therefore new programs always need to be tested. Looked at previous investigated solutions, the preparation department already have increased sheet metal efficiency by punching rest metal parts. These rest metal parts are now used for laser smaller parts. Going further into these rest parts, the parts are punched out in fixed sizes. This is done, because that makes it possible to program the sizes of the rest metal in the laser machine, so that the laser also can keep running

more automatically and the production holds it flow better. Most programs do not have a rest metal part.

- ***Product Requirements:*** The third challenge in formulating solutions are the large amount of different product types. At Gunnebo there are a lot of different types of safes all these products have their own fixed design, because the products need to fulfill the safety requirements. Therefore, no changes can be made in the design of the products.

2.4 Summary

In this section we gave answer on the question: "What is the current way of working?". To answer this question, we made a flow chart, business process model, stakeholder analysis and investigated the challenges that could pop up during this research. Following the flowchart, we see that the beginning of the process starts with the preparation process which consist of: making a production schedule, making a job list for the punching machine, lasering smaller parts and bending. When zooming in on the preparation process we see that the production manager is connected with message flows to the preparation and preliminary work department. Information that is exchanged is about product types and quantities.
Based on the stakeholder analysis, the most important stakeholders that need to be managed closely in this research are the preparation department and the preliminary work department leaders. The challenges that (could) occur during this research and the formulation of solutions are safety requirements, limitations in machine settings and fixed product requirements.

3 Theoretical Perspective

In this section the theoretical framework of this research is going to be discussed and there will be given an answer to the question 2. “Which tools can be used for solving the problem of metal efficiency difficulties?”. To find an answer on this question a systematic literature research is conducted. Tools are discussed which can be used in solving the waste and efficiency problem. Also, tools for the implementation of a solution are discussed.

Most of the selected tools in this literature review are tools who derive from lean manufactory. Lean provides a methodology for eliminating waste and improving organizations. This methodology is known for the wide array of tools and techniques (Bashin, 2016, pp.92-101).

3.1 Analyzing Tools

For the identification and analyzation of the waste and causes of the sheet metal efficiency problem the following tools are going to be used: root cause analysis, fishbone diagram, Pareto analysis and Gemba (see section 3.3).

3.1.1 Root Cause Analysis

For the investigation of causes the root cause analysis can be used. Root cause analysis is used in manufacturing for identifying causal factors that cause errors or quality deviations in products. A root cause is the most primary reason for errors and/or quality deviations. Often a problem is solved in the short term by resolving only a symptom, but it will later reoccur because the real root cause is still there. This is the most challenging issue of the root cause analysis, the distinguishing between what is a symptom and what is the real root cause (Lokrantz et al., 2018). Gangidi (2019) discusses a popular tool that is used in root cause analysis, the 5 Whys method. The principle of the 5 Whys method is repeating why five times, and so discover the nature of the problem and a fitting solution. The tool has seen widespread use beyond Toyota, and it is now used within Kaizen, Lean manufacturing and Six Sigma.

3.1.2 Fishbone Diagram

Cause–effect diagrams are an effective method of helping to search for the root causes of problems. The diagram identifies the root cause by asking what, when, where, how and why questions (Slack et al. 2013). Cybenko et al. (2018, p.35) describe a Fishbone diagram as a diagram where all possible contributing factors or sub-causes to a problem are investigated and sorted under different categories. The arrows in the fishbone diagram represent causal relationships between the (sub)causes and the problem. Fishbone diagrams have some advantages. Fishbone diagrams are easy to adapt, since they are also based on discussions during brainstorming sessions, fishbone diagrams encourage data collection, because it also shows where knowledge is lacking and fishbone diagrams helps staying focused on the content of the problem during brainstorm sessions (Cybenko et al., 2018, p.35). A fishbone diagram is often categorized in six sections: equipment, process, people, materials, environment and management (Figure 5).

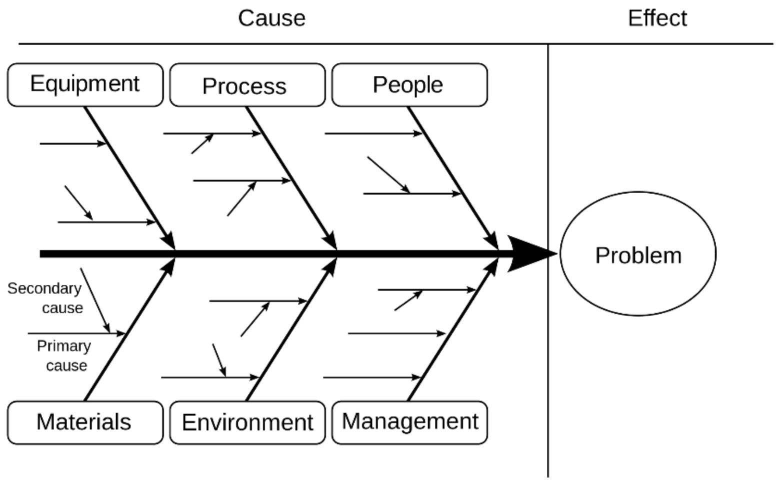

Figure 5: Fishbone diagram (Wikipedia.org)

3.1.3 Pareto Analysis

Another popular tool for the identification of causes that we are going to discuss is a Pareto analysis. The Pareto analysis could be useful in narrowing the scope of the research. According to Slack et al. (2013) the main purpose of a Pareto diagram is to make a distinction between issues. A Pareto analysis arranges types of problem or causes of a problem into their importance (usually measured by frequency of occurrence). This can be used to highlight areas where further decision making will be useful. The Pareto analysis is based on the statements that: 80% of the losses is caused by only 20% of the possible causes, the core of the product requires 80% of the production costs, but only impact the customer with 20% and 20% of a company's products provides 80% of the company's profit (Matiskova, 2015). After a pareto analysis there should come out key factors that are "vital" for solving the problem. The other factors are "non-significant", in the solution process and therefore it is not necessary to deal with them. Of course, it is possible that after mastering the vital problems non-significant problems can be solved (Matiskova, 2015). For making a pareto chart the following steps need to be followed. (Jayswal et al., 2011):

- Prepare a table which shows all causes with their impacts in percentage.
- The table is sorted by order of percentage.
- A third column is added to show cumulative percentage.
- A line chart is prepared. The causes are on x-axis and their cumulative percentage values are on y-axis.
- On the same chart a bar chart is added by causes on x-axis and percent impacts on y-axis.
- A horizontal line is drawn at 80%. At the intersection of the 80% line with curve, a vertical line is added.

The point of intersection of the vertical line and x-axis separates the major causes to the left side and minor causes to the right side (when applying 20/80 rule).

3.2 Solution Tools

Now we have gained more insight in approaches and tools for finding the cause of the metal efficiency problem, there will be discussed some possible solutions for the metal efficiency problem.

3.2.1 Waste Hierarchy

Waste hierarchy has as function to prioritize the most environment-friendly processing methods. The core of waste hierarchy is the ladder of Lansink (Figure 6), this ladder categorized processing methods based on their effect on the environment. The 5 categories are: prevention, re-use, recycle, energy recovery and landfill (Lansink, 2018). Where prevention is the most environment-friendly processing method and landfill is the least environment-friendly processing method. The categories are described as follows.

Prevention: With prevention the waste is eliminated or less waste is produced by changing the process or waste prevention solutions. An example of one of these solutions is industrial symbiosis. Industrial symbiosis involves several companies in physical trades of byproducts. Companies are defined as waste producer or waste user. With industrial symbiosis an agreement between the companies is made where the byproducts/waste of the waste producer is delivered to the waste user who uses these byproducts/waste to produce new products. (Fraccascia et al., 2020). Industrial symbiosis leads to less unused byproducts and so to less waste, therefore it creates environmental benefits. Also, industrial symbiosis can have positive economic effects, such as lower waste disposal costs for the waste producer, revenues from exchanging waste for the waste producer and lower purchasing costs for the waste user (Fraccascia et al., 2020).

Re-use: By reusing materials, you also reduce the amount of waste. Waste which is still usable is used for other purposes. Remanufacturing is a good example of this. In Gunnebo some rest metal sheets are used for lasering, this is also an example of re-using.

Recycle: Most waste streams can be recycled. The most common streams are paper, plastic and metal. Recycling is a long process where waste materials are separated, collected, and processed to manufacture an entirely new (raw material) product. Recycling is preferred alternative when waste can't be prevented or reused.

Energy recovery: Energy recovery is generating energy from waste materials. This is also known as 'waste to energy conversion.' By burning waste, energy can be generated. Most of this energy is in the form of heat and electricity. A downside of energy recovery is that waste materials are burned and so lost forever.

Landfill: A landfill is a site for the disposal of waste materials by burying them in the ground or dump it on a place. This is the least environment-friendly process method, because it generates no "new" material or energy. Furthermore, a landfill is polluting.

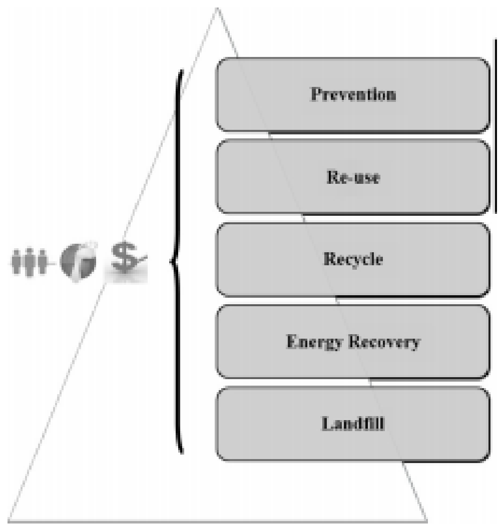

Figure 6: Ladder of Lansink (Keivanpour et al.,2015)

3.2.2 Production Systems

The paper of Miltenburg (2000) distinguish six different production systems: Project, Job shop, Batch Flow, Line flow, Continuous flow and One-piece flow. These production systems are classified in the product-process matrix. The product-process matrix is based on the variety of products and the volume of the products. A project production system fits the best with a high variety and low volume of production, where a continuous flow is focused on one product and high volume. Miltenburg (2000) places the one-piece flow between batch flow and line flow (Figure 7). One-piece flow produces many products in medium volumes, is arranged in cells in which material flow is regular and provides high levels of flexibility. Following Miltenburg (2000) companies should adapt their production system to their flow, product varieties and product volumes.

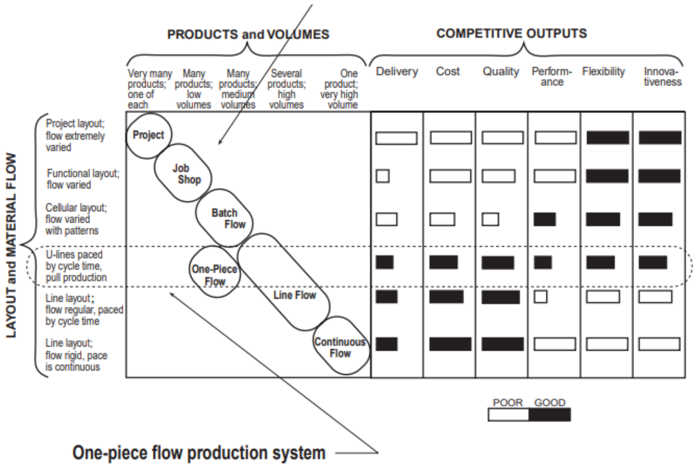

Figure 7: Miltenburg's production systems

3.3 Tools for Solution Testing

For testing and evaluation of solutions the PDCA-Cycle and the principles of Gemba are going to be used

3.3.1 PDCA Cycle

The test of the solution could be done following the principles of the PDCA cycle. PDCA stands for Plan Do Check Act. The PDCA cycle was first used as a tool for controlling the quality of products. However later on the method was also used for the development of improvements in process at organizational level. The PDCA cycle is a continuous improvement approach (Realyvásquez-Vargas et al., 2018). According to Slack et al. (2013) the PDCA phases are defined as follows. The first step of this cycle is the plan phase. This phase involves an examination of the current method. Based on the collected data a plan should be formulated which is intended should improve performance. The next step is the do phase. This is the phase where the plan is operationalized. For example, the solution is tested. Next comes the check stage where the implemented solution is evaluated based on the expected performance improvement. The last phase for the PDCA cycle is the act phase. During this phase the change is consolidated or standardized if it is successful. Otherwise, if the change has not been successful, the lessons learned from the test are adapted. After this there is again the plan phase, where there should be tried to exploit the solution further or adapt the learned lessons in the new improvement plan. The PDCA cycle is a useful tool to use for testing solutions. Therefore, the PDCA cycle will be used in this research for testing and evaluating solutions. .

3.3.2 Gemba

Gemba means the "place of action." A fundamental philosophy of Lean management, Gemba walks denote the action of going to see the actual process, understand the work, ask questions, and learn (Delisle, 2012). Lean improvement often uses the idea of Gemba to make problems visible. Managers should regularly visit the place where the job is done to seek out waste. The concept of Gemba is also used in new service or product development, so that designers get insight in where the service happens or where the product is produced (Slack 2013). Therefore, Gemba could be used in the cause analysis as well as in the solution testing phase. A possible solution must also be accepted by the work floor.

3.4 Summary

In this chapter we gave answer to the question "Which tools can be used for solving the problem of metal efficiency difficulties?" The tools that can be used in solving the problem of sheet metal efficiency difficulties are: root cause analysis, fishbone diagram, pareto analysis, waste hierarchy, production systems, PDCA-cycle and Gemba.

For the identification of waste and their causes several tools could be used. These tools are: root cause analysis, fishbone diagram, pareto analysis and Gemba. Gemba states that to understand a process, enough observations at the place where it "actually happens" must be done (Delisle, 2012). The fishbone diagram and root cause analysis focus on finding the root cause of a problem. A tool often used in the root cause analysis is the five Whys method, this method asks the question why five times to discover the root cause which cause other problems or symptoms (Gangidi, 2019). The pareto analysis distinguishes problems by pointing out "Vital" and "Non-significant" problems. The pareto analysis is based on the 80/20 rule which states that 80% of the losses is caused by only 20% of the possible causes. (Matiskova, 2015)

Waste hierarchy and production systems are two methodologies that support waste reduction. When formulating solutions, the waste hierarchy of Lansink (2018) should be taken into account. The best solution in Lansink's ladder is waste prevention, an example of waste prevention is industrial symbiosis where waste is exchanged to companies who can use the waste (Fraccascia et al., 2020). When this is not possible there should be looked to reusing material and so on till the last step of the ladder, landfill. Miltenburg's (2000) production systems are more focused on the actual production of products and distinguishes product systems in six groups based on product variety product volume and flow.

At last, we discussed tools that are applicable for the implementation and testing of solutions. These tools are the PDCA cycle and Gemba. The PDCA cycle is a continuous improvement approach which can be used for planning and evaluating tests (Realyvásquez-Vargas et al., 2018). Also, in the implementation phase Gemba plays a role. The solution must be accepted by the people who are most affected by the change, in this case the preliminary work department.

4 Cause Analysis

In this chapter the research questions “Which types of metal waste are there and how high is their share in the total waste?”, “What is the difference in waste per product category?” and “What are the causes behind the types of waste and/or the product types with the highest waste contribution?” are answered. This is done by a data gathering experiment regarding the different types of waste, a product categorization based on the products with the highest expected waste and a fishbone diagram.

4.1 Waste Types

The 1044-ton (29%) metal waste of Gunnebo is of all metal waste together. This 1044-ton waste consist of different types of waste. In the problem cluster the waste is already distinguished in two types of waste, scrap waste and waste produced by the preliminary work department. The waste of the preliminary work department can also be divided in different types of waste. These waste types are: punching skeletons, punching waste, punching errors, bending errors and overproduction. Based on these types of waste we distinguished the metal waste types in the factory of Gunnebo in 5 different types (see also Appendix A).

Waste A Punching skeletons: A punching skeleton is left behind after punching the sheet metal. Some punching skeleton is always there, because the clamps of the punching machine must clamp the incoming metal sheet somewhere.

Waste B Punching waste small: This is the waste that is created every time a small hole has to be punched in the metal sheet. This waste is almost insurmountable, because holes have to be punched in the sheets and the waste is so small that it cannot be used further in the process.

Waste C Bending errors*:* When a part is wrong bent it is thrown away. Bending errors are human errors, but occur not that often following the preparation and preliminary work department.

Waste D Punching errors/overproduction*:* When a metal sheet is punched wrong or folded in the machine it is unusable. Also, overproduction is described as a punching error in this case. This is done, due to the fact of space limitations.

Waste E Scrap: scrap in this case is every metal waste produced by other departments than the preliminary work department. Scrap waste is for example rejected or old safes and packaging material. There will be not focused on this waste, because it has nothing to do with the preliminary work department and so nothing with metal efficiency. Although it is necessary to measure the share of scrap in the total metal waste to get an overall view.

To investigate which type of waste has the biggest share in the total amount of waste a data collection experiment is set up. For over six weeks metal waste is separated following these 5 types of waste. An agreement with the waste processor is made for labeling these containers. Based on metal waste per ton a pareto analysis is conducted and the share in the total waste distribution per waste type is indicated.

Assumptions

The following assumptions are made during the measurements:

- Errors: Sometimes when a punching error occurs the error sheet is put between the skeletons by the punching machine, because it is too dangerous for the preliminary work department to separate this waste properly these rarely occurring errors are determined as skeleton waste.
- Overproduction: Overproduction is classified as waste type D punching error, due to space limitations.
- Representativeness: The investigated waste distribution in the given time period is representative for the whole year.
- Outliers: Extreme outliers are filtered out via a boxplot.
- Weeks: The waste processor has some fixed days when they collect the waste. These days are Monday, Wednesday and Friday. Because the separate waste containers for the investigation of the waste types are placed on a Wednesday, there is chosen to determine 1 week from Thursday till Thursday, to prevent double counting disposals.
- The total waste distribution follows from a normal distribution since the second sample size is smaller than 25 (SPSS Tutorials 2015).

4.1.1 Statistical Test

A tool that is often used to see whether two samples differ from each other is a 2 tailed T-test. To verify that the waste distribution of the investigated period is under "normal" conditions and representative for the rest of the year, we state the hypothesis that the mean of the investigated sample is the same as the mean of the sample from previous year. This hypothesis can be tested with the 2 tailed T-test (Glenn, 2021). For this the mean of the investigated sample is compared to the total metal waste per week of last year's sample. The samples must be filtered for outliers, this is done by the creation of a boxplot diagram. (Birkett, 2020).

For calculating the mean in the "normal" situation last year's total metal waste per week is sampled (February 2020-February 2021). The boxplot (Appendix C) shows that there are no (extreme) outliers that need to be filtered out. Also, the six-week sample is investigated for outliers. Appendix C shows that there are no outliers in the six weeks sample as well. Both samples can be founded in Appendix B. When we analyze the waste sample of last year and the waste sample for the investigated period, we obtain the following results (Figure 8).

Group Statistics

	WeekNummer	N	Mean	Std. Deviation	Std. Error Mean
astePerWeekLastYear	Old	53	21114,72	6918,512	950,331
	New	6	21316,67	3674,788	1500,226

Figure 8: Statistical data sample last year and investigated sample

With the output of these samples, we can test whether these 2 samples have a difference in the mean. In other words, in how far is the investigated six-week sample representative for the metal waste distribution per year. This is done with a two-sample t-test with a margin of error of 5%. When the p value of the t test > 0,05 there is statistically significance that we can conclude that the means of the two samples being from the same population is true.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
WastePerWeekLastYear	Equal variances assumed	1,749	,191	-,070	57	,944	-201,950	2884,706	-5978,473	5574,574
	Equal variances not assumed			-,114	9,668	,912	-201,950	1775,896	-4177,383	3773,484

Figure 9: T-test of waste distributions

Looked at the two-sample t-test (Figure 9) we see that the p value of this t test is 0,944 if equal variances are assumed and 0,912 when unequal variances are assumed. This is way higher than the p value of p > 0,05, therefore we can say that the investigated waste sample represents the last year waste sample and is therefore under "normal" conditions.

4.1.2 Results

Now we have verified that the investigated waste sample is representative for the yearly waste distribution, we can determine the waste types distribution. For looking which waste type has the highest share in the total waste distribution we make use of a pareto diagram. In this pareto diagram the weight of the waste types are compared to the total amount of waste in the investigated period. The trend line in the diagram represents the cumulative percentage. The cumulative percentage is the percentage of the summed-up weights divided by the total amount of waste. In the end this percentage is 100%, because then all weights are added up and this is divided by the total amount of waste = 100%. The data we obtained from the six weeks investigation and the corresponding pareto diagram of the waste distribution is presented in table 1 and figure 10.

Waste type	Weight (ton)	% In total waste	Cumulative %
A Punching skeletons	69,7	55,1%	55,1%
B Punching waste small	48,2	38,1%	93,2%
E Scrap	4	3,2%	96,4%
D Punching errors/Overproduction	2,4	1,9%	98,3%
C Bending errors	2,1	1,7%	100%
Total	126,4	= 100%	100%

Table 1: Data waste type distribution experiment

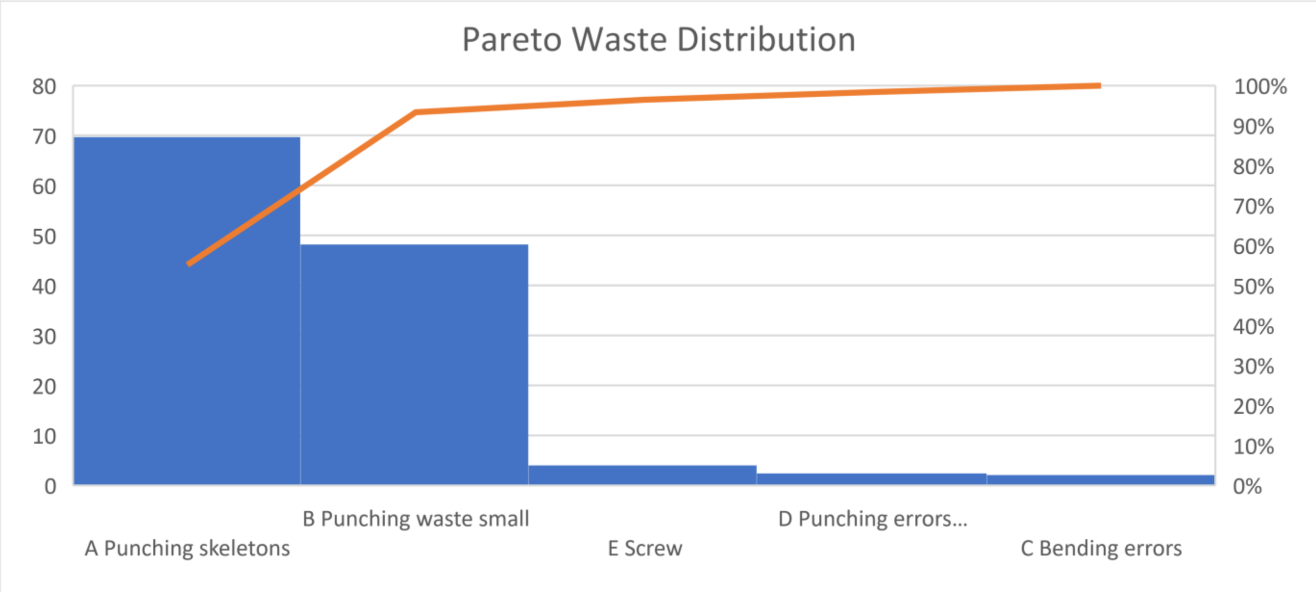

Figure 10: Pareto diagram waste types distribution

4.1.3 Waste distribution conclusion

The experiment shows that almost 60% of the waste produced in the investigated six weeks is waste in the form of punching skeletons. The punching skeleton waste is followed by small punching waste. These two waste types together are responsible for over 90% of the total waste. Out of this we can conclude that other waste types like errors or overproduction play a minor role in the total waste distribution. The waste of punching skeletons and punching waste small is caused due production, therefore the major causes of the metal waste problem lie in the production process itself instead of planning, human errors and waste disposal. Although the punching skeletons and punching waste are responsible for the majority of the total waste, this waste cannot be fully eliminated. A big proportion of this waste is as good as uncompromisingly, since after punching there is always some skeleton and punching waste small. Nevertheless, this pareto diagram also shows that when punching waste could be reduced, this benefits the waste distribution notable.

4.2 Product Categorization

To find an answer on the question “What is the difference in waste per product category?” a Pareto analysis of the product types is made, this categorization is based on their yearly expected waste. Within Gunnebo there are a lot of different product types with all their own sheet utilization/ metal efficiency, this varies from around 60% to around 85%. Therefore, also a pareto analysis for investigating which product types have the highest share in the total waste is made. This analysis is based on the demand of the safes and the difference between the gross and net weights (efficiency) of the safes. Two analyses are made, one based on the forecast (Figure 11) and one based on the actual production from January till April (Figure 12). This is done, to see whether the assumption of the forecast is valid. Following the forecast 50 safe types were planned to be produced this year. Looked at the production schedule from January until April there are in reality 72 types of safes produced. To calculate the product efficiency the weight of the raw sheet metals that are needed to produce that safe are weighed, this is the gross weight. When all sheets are processed into parts, all parts of the safe are weighed again and the net weight is determined. Finally, by dividing the net weight by the gross weight the product efficiency can be calculated. Most product efficiencies are already known within the company. In formula product efficiency is defined as follows:

$$Product\ efficiency = \frac{\text{Net weight}}{\text{Gross weight}}.$$

For calculating the expected waste, the products are categorized by (expected metal waste in Kg). The forecast demand or the yearly demand based on the production plan from January till April is multiplied with the difference between the gross weight and net weight. In formula:

$$Expected\ waste\ safetype\ Forecast = \text{Expected safes produced per year following Forecast} * (\text{gross weight} - \text{net weight}).$$

$$Expected\ waste\ safetype\ Production\ Plan = 3 * \text{ Safes produced from January till April } * (\text{gross weight} - \text{net weight})$$

Assumptions

The following assumptions are made for the examination of the product types' waste:

- Seasonal demand: The production plan of January-April does not contain seasonal demand.
- Yearly production= This year's production quantities of the safe types are the January-April quantity times three.
- Inventory is not included in this analysis, so we assume every safe has to be produced following the given quantities.
- Product efficiencies: Given products type' products efficiency is the same for every safe of that type produced.

4.2.1 Results

Based on this expected waste, two pareto charts are made to identify which product types have the biggest share in the total waste. This gave the following results (see also appendix D).

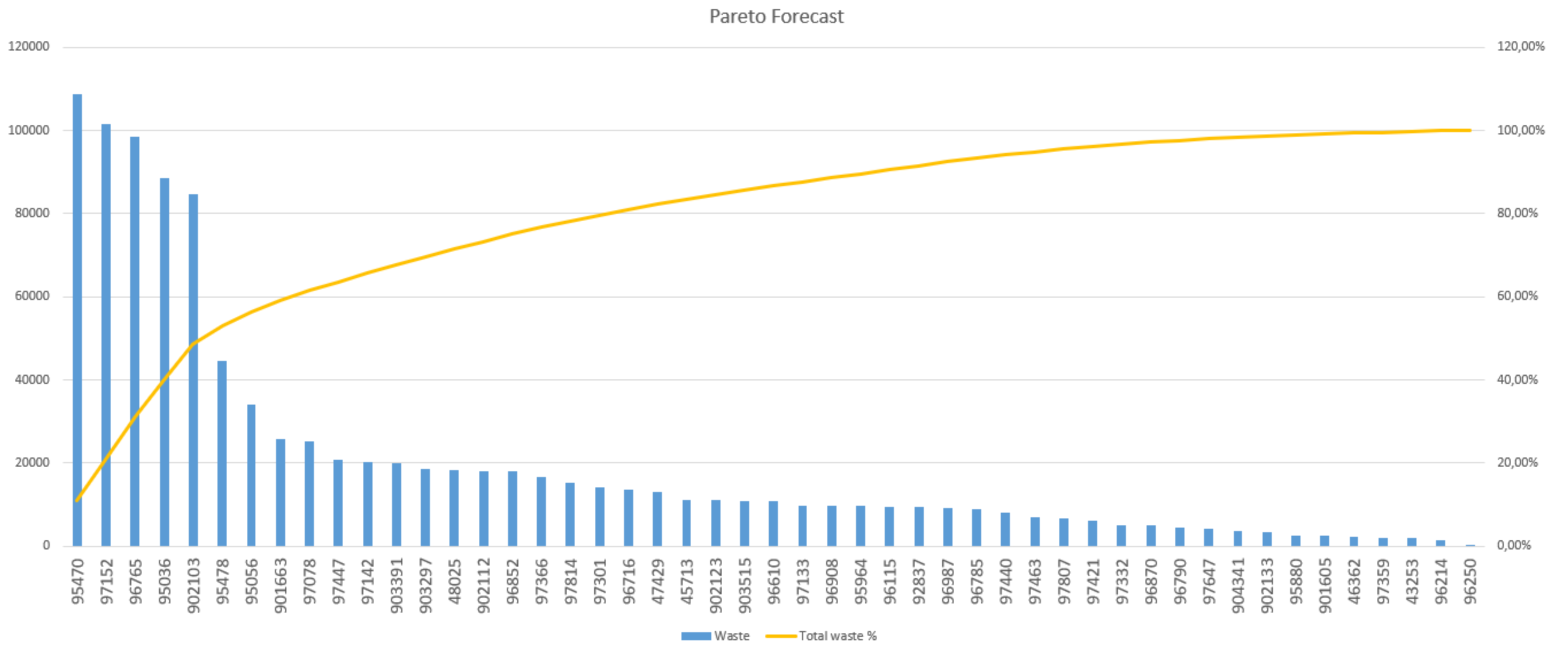

Figure 11: Pareto diagram product types waste based on forecast

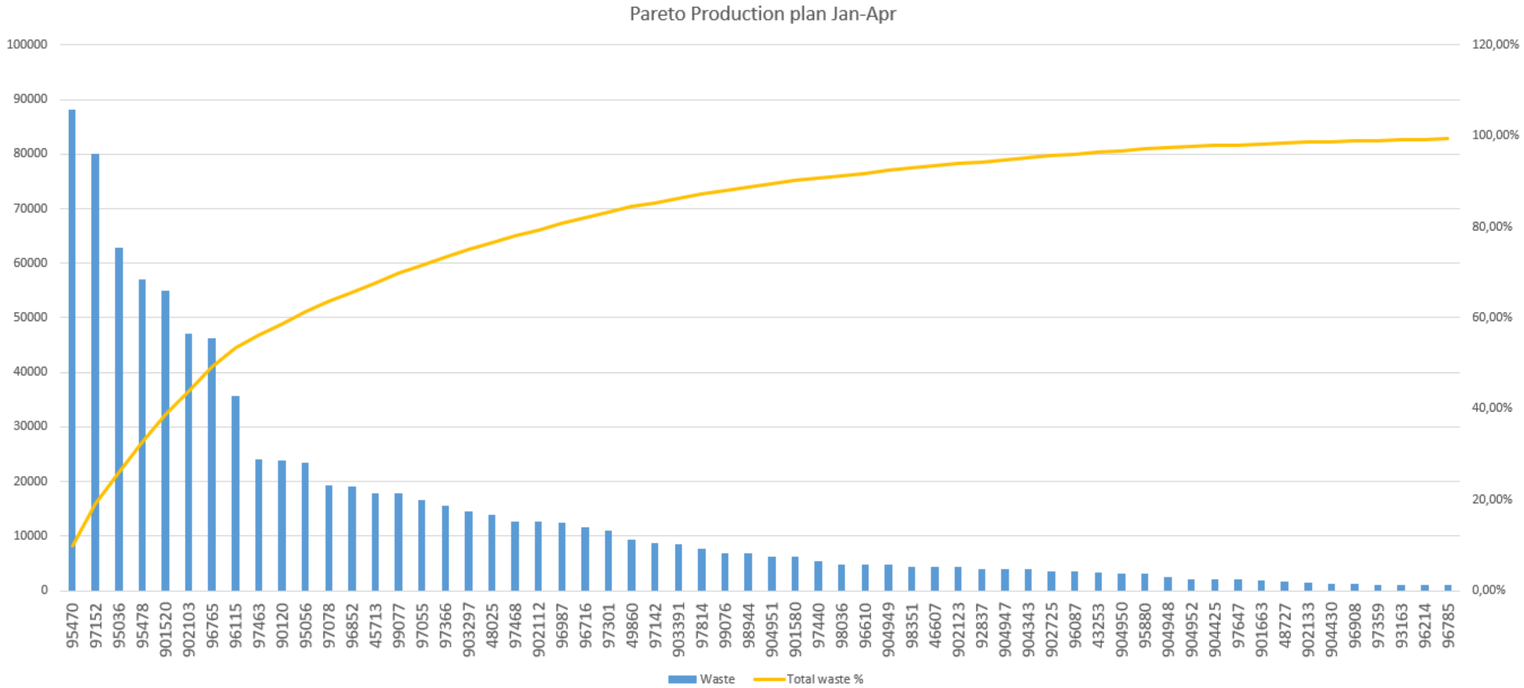

Figure 12: Pareto diagram product types waste based on production plan January until April

Based on the 20/80 pareto rule (Matiskova, 2015) the top 20% of the forecast Pareto and the production schedule Pareto are selected as possible focus. This means that the top 20% of the forecast pareto consist of 50*0,2 = 10 safes and the top 20% of the production plan pareto consist of 72*0,2 ≈ 14 safes.

4.2.2 Conclusion

Looked at the top 20% of the forecast pareto (Figure 11) and the production plan pareto (Figure 12), we see that eight product types are in both top 20%. These safes are selected to focus on. Some extra highly demanded safes are added to the focus after query.

- 901663: The company had a high inventory of this product therefore this product is in the top 20% of the forecast, but not in the production plan top 20%. When the inventory runs out this product will be again highly produced.
- 901520: This product was meant to be produced at another plant abroad, therefore this product type was not included in the forecast. Because of production problems at the other plant the production is changed to Gunnebo Doetinchem, Therefore the product is on the fifth place regarding waste production of the production plan Pareto.
- 90120: This product type is requested by another/new customer and is therefore not included in the forecast. Nevertheless, this product is highly requested.

Based on the pareto diagrams and the query the product types with the highest expected waste this year are:

1. 95470
2. 97152
3. 96765
4. 95036
5. 902103
6. 95478
7. 95056
8. 901663
9. 97078
10. 901520
11. 90120

When we look at the expected share in the total waste of these safes together, we see that it is 61,6% when the demand is expected to be as the forecast predicts (Appendix E). When we look at the actual production plan of January till April, we see that following the production schedule the selected safes have together a share of 57% in the total amount of waste (Appendix E).

4.3 Root Cause(s)

To find the root cause(s) of the core problem of having difficulties with increasing sheet metal efficiency a fishbone diagram is made (Figure 13). The basis of this fishbone diagram is root cause analysis and the five why's method (Gangidi, 2019). The fishbone diagram is divided in 4 primary causes. These are planning, errors, waste disposal and production.

Production

The fishbone diagram shows us that the problem in production has two several causes. High demand is a cause, because of the high demand and high variety of products produced, the metal efficiency is lower than when one product type is produced. The problem of high demand cannot be influenced in such a way it benefits the companies' goals. The other cause of the high waste production of the selected safes is the differences in product efficiencies. Because every product type is different and has different sizes, the nesting of parts is not always optimal. The raw material sheet sizes correspondent not always perfectly with the fixed product sizes. Here we come at the root cause of ***sheet sizes are not optimal adapted to the product***.

Although the company already differentiates from the standard sheet sizes, some safes still have the problem that due to the not perfect adapted sheet on the program, the metal efficiency has lack of improvement.

Planning

The biggest efficiency lost in planning is due overproduction. This overproduction is caused by inventory and batch sizes. The batch sizes are used, because it speeds up the process. Furthermore, inventory is built up, to fulfill high demand within the customers' expected lead time. In the planning segment there is not a root cause, because this small overproduction is needed for customer satisfaction and the lost in efficiency is here too small to focus on.

Waste disposal

Looked at the waste disposal we see that possible root causes in the waste disposal are: packaging and lack of training. Because these causes do not play a role or a minor role in the preliminary work department, these causes are not assigned as root cause(s) of the metal efficiency problem.

Errors

The human errors in the form of bending errors occur mostly due to a lack of training or inattention. The machine errors mostly occur due tool wear. The underlying causes here are lack of training, motivation and maintenance. Since errors barely occur these causes are not assigned as root cause(s) for the sheet metal efficiency problem.

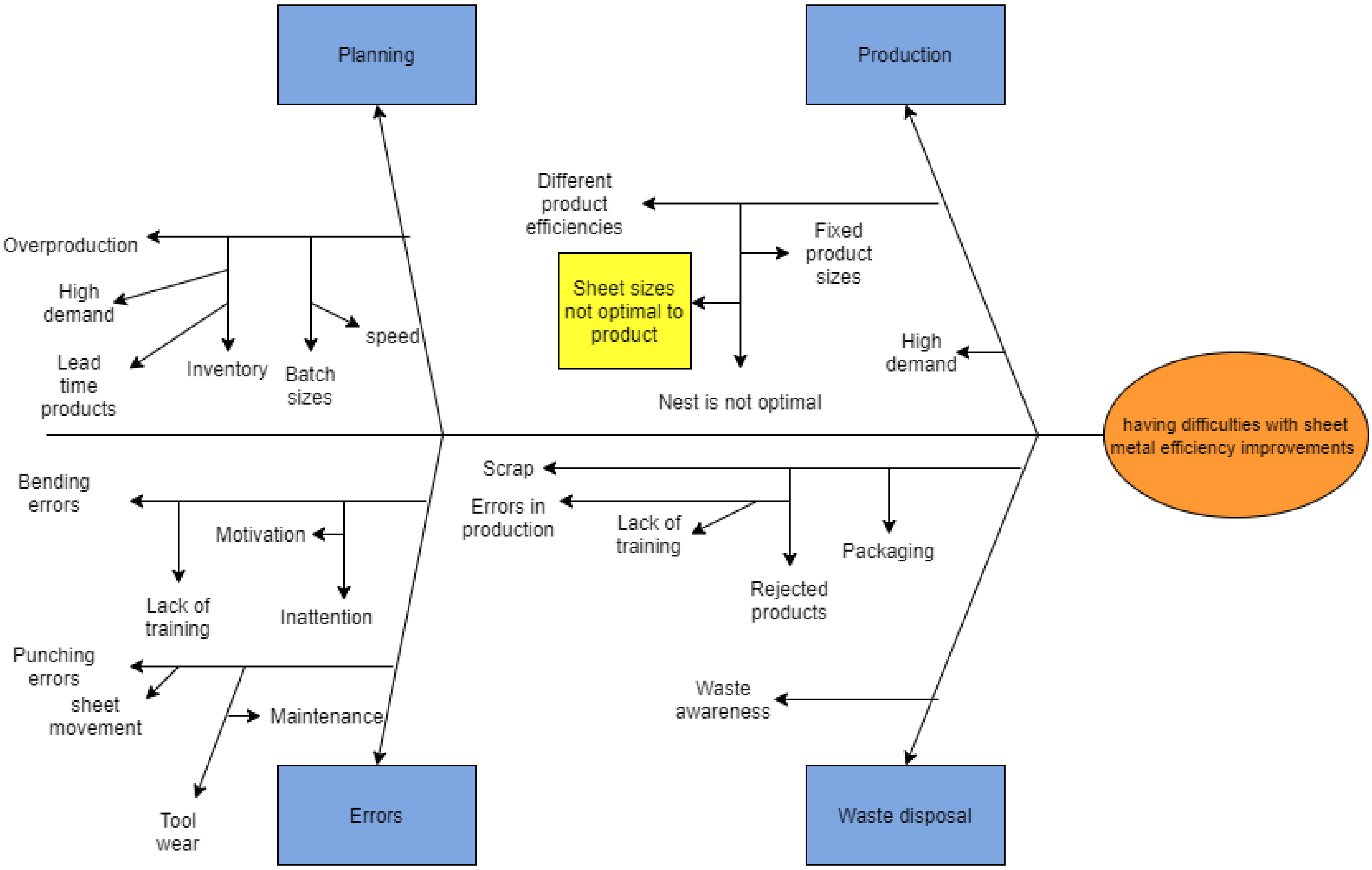

Figure 13: Fishbone diagram of causes and root cause of the core problem

4.4 Summary

In this chapter the research questions “Which types of metal waste are there and how high is their share in the total waste?”, “What is the difference in waste per product category?” and “What are the causes behind the types of waste and/or the product types with the highest waste contribution?” were answered.

We see following the waste type pareto diagram that punching skeletons are the waste type with the highest share in the total amount of waste, followed up by the punching waste small. These two waste types are responsible for over 90% of the total waste in the investigated period of six weeks. Furthermore, the waste types overproduction, punching errors, bending errors and scrap play a much smaller role in the total waste distribution.

We see following the two pareto diagrams of the product types and query that the eleven products which are expected to produce the most waste are products: 95470, 97152, 96765, 95036, 902103, 95478, 95056, 901663, 97078, 901520 and 90120.

Finally, the fishbone diagram shows that the root cause of the problem of having difficulties with increasing sheet metal efficiency is the problem in the production of not having sheet sizes who are optimal adapted to the product. Because of the fixed product sizes and the not optimal sheets sizes, products are more difficult to nest than when the parts and the sheet sizes are more complementary to each other. This results in the end in a lower metal efficiency and so a higher metal waste rate.

5 Solution Method

In this chapter the research question “What are possible solutions for increasing the sheet metal efficiency and so waste reduction?”, “is answered. Possible solutions will be formulated/explained and will be further on evaluated. Looked at the waste ladder of Lansink (2018), the aim is to come up with a solution which prevent or re-uses waste. Solutions which refer to lower levels of the ladder are not possible, since all metal waste from the company is nowadays recycled and so recycling is the lowest level in the company’s waste hierarchy. The solutions are going to be evaluated for the eleven most waste producing products.

5.1 Possible solutions

5.1.1 Adapting sheet size

A way to improve sheet metal efficiency could be to adapt the purchased sheets better to the product-type that is going to be made. This solution supports waste prevention, less raw material is purchased to prevent a higher waste production. The company already purchases metal sheets that differ from the standard sizes of 2000mm*1000mm, 2500mm*1250mm and 3000mm* 1500mm, but when this is done more to expand the numbers of options for nesting, it can increase the metal efficiency per product. Important here is to choose a selected number of products as focus, because it is impossible to adapt the sheet sizes for every product that is produced. The automated stockroom has only limited place for a few different sheet sizes and therefore, too much different metal sheets would cause inventory and storage problems. Because of that the eleven most waste producing products selected in chapter 4.2.1 are selected as possible products for which this solution is applicable. Another important note is that the adapted sheets must have a size that is between the minimum size and maximum size of the machine (1700mm * 1000mm till 3000mm*1500mm).

5.1.2 Standardization

The products that are produced are produced following fixed punching programs. The programs are programmed following one-piece-flow. this means that one product is produced per a certain number of programs. A solution could be to standardized the programs per product part instead of per product and shifting more right in Miltenburg’s production systems (2001). An example of this is instead of punching one product four times, punching four times a top plate of that product and punching eight times a side plate of that product etc. Due to the geometry of some parts, it could be possible that due this the sheet utilization is higher, which means that also the metal efficiency is higher, which could in the end lead to waste prevention. An important condition for this solution is that despite the higher utilization the parts must be stored well and overproduction must be prevented.

5.1.3 Dynamic nesting

Dynamic nesting is the process of not using fixed nesting programs. Instead of fixed programs per product there is punched per part. There is looked into the job list which parts are needed for that day. Then is looked which sheets are available on that day. Based on these two variables there should be find an as optimal as possible nest for nesting as much parts as possible in the lowest amount of sheet material for that day. The biggest difference with standardization here is that standardization is somewhere still product bound (four times the same part of a product), where dynamic nesting is not product bound and nests parts of different products in one sheet.

5.1.4 Outsourcing

Another solution to tackle the metal efficiency problem is the solution of outsourcing the punching process. The company nowadays often encounter the problem of difficult part sizes and so inefficient nesting. When parts of this production are outsourced to another steel company with more capacities the punching waste of this product could be "eliminated" within the company. Big steel processing companies often schedule their orders so that the nests are nearly perfect. The better fitting nest leads to less waste in general and can have economic benefits when the costs of outsourcing are lower than punching the product itself. There should be looked carefully when outsourcing is beneficial, because too much outsourcing can lead to not operating machines which is very costly. Also, the ethical side of outsourcing business must be taken into account.

5.1.5 Industrial symbiosis

The last solution is industrial symbiosis (see section 3.2 Waste Hierarchy). For this solution there should be searched for a partner who wants to be the waste taker in the industrial symbiosis process.

5.2 Solution Evaluation

The solution evaluation will be executed following the PDCA-Cycle (see section 3.3 PDCA-Cycle). The plan phase will be consisting of an evaluation plan. In this plan there will be stated how every solution will be evaluated and based on which questions the evaluation takes place. In the do phase the answers on the questions in the plan phase are given. Also the first evaluation takes place based on the advantages and disadvantages of the solutions. Based on these advantages and disadvantages one solution is chosen to be investigated further. In the check phase the measurements for the chosen solution will take place following the stated KPIs. In the last phase, the act phase conclusions will be drawn.

5.2.1 Plan

The first step in the solutions evaluation process is listing all pros and cons of every solution. This gives the first impression into the effectiveness of the solutions. After this the solutions will be graded following a decision-making process and a solution for further implementation is selected.

This chosen solution will be evaluated on the previous stated KPIs. First the solution will be tested/implemented on the selected safes. After this we measure the KPIs Metal Efficiency (%) and Savings on metal waste. Finally, the cost benefit analysis takes place to calculate the KPI Cost Savings (€) and we investigate whether the solution is cost-beneficial or not. Based on these results we conclude how effective the final solution is.

For the not chosen solutions the plan is slightly differently. Due to a shortage in time, for these solutions we are only going to give answer to the questions in the evaluation plan. Due the lack of time it is not possible to test/implement every solution on this short term. Table 2 shows the (additional) questions that are going to be answered in the evaluation.

Solution	Questions	Departments involved
Adapt sheet size	- How many extra sheet sizes could be added to the stockroom? - How much (millimeters) could the variation in sheet sizes be?	Purchasing, preparation department and machine supplier
Standardization	- How can the punching process be standardized in such a way it increases metal efficiency?	Preparation department
Dynamic nesting	- How should the production be changed when dynamic nesting is used as solution?	Preparation department
Outsourcing	- Which products are applicable for punching outsourcing?	Purchasing
Industrial symbiosis	- Which waste could be used for industrial symbiosis?	Preparation department

Table 2: Evaluation plan

5.2.2 Do

For the do-phase of the solution evaluation first the questions stated in the evaluation plan are answered. After interviewing and obtaining information from different stakeholders the answers to the questions are:

- *How many extra sheet sizes could be added to the stockroom?*

There is not a limit on the number of extra sheet sizes, but due to the company's limited stockroom on the ground not too many extra sheet sizes can be added. Too many sheet sizes will make the situation in the preliminary work department messy and unmanageable.

- *How much (millimeters) could the variation in sheet sizes be?*

Sheets could be varied within the limits of the machine setting. An important note is that purchasing a longer sheet does not make the price per kilogram more expensive, but purchase a wider or thinner sheet makes the price per kilogram more expensive.

- *How can the punching process be standardized in such a way it increases metal efficiency?*

The parts should be produced in complementary batches, For example three top plates and six side plates. This gives the least change of overproduction or a proper part inventory system must be developed.

- *How* should the production be changed when dynamic nesting is used as solution?

Dynamic nesting could increase the metal efficiency, but needs a lot of change in the production process. All separate parts need to be sorted out and placed by the right product. This needs to be done by the preliminary work department employees.

- *Which products are applicable for punching outsourcing?*

Looking at the different product-types we see that the product type 90120 is the one with the lowest metal efficiency of the selected safes. When no other solutions are applicable for this product it could be an option to outsource the punching process of this product when this is cost-beneficial.

- *Which waste could be used for industrial symbiosis?*

Since the company is lasering from rest metal the rest metal inventory builds up. When the factory keeps producing more rest metal sheets than there are used on the laser this can be a problem in the future. This could lead in the future to more metal waste. This could be prevented by using industrial symbiosis for the rest sheets. Since this are rectangular sheets, it is easier to use these sheets for industrial symbiosis instead of punching waste.

In the do phase of the evaluation, we also demonstrate the pros and cons of all solutions. Based on these pros and cons a final solution for investigating in the check phase will be chosen. For this we make use of weighted score criteria (Heerkens & van Winden, 2017). The weighted score criteria that are chosen with the corresponding weights are: Savings potential (2x), Production flow (1,8x) and Ease of implementation (1x) The total score per solution will be formed by the following formula:

$$Number\ of\ pros\ in\ category\ *\ weight\ -\ Numbers\ of\ cons\ in\ category\ *\ weight$$

The advantages and disadvantages of the solutions will be categorized following this weighted score criteria. After interviews in the preparation and in the preliminary work department the following advantages and disadvantages for the solutions are determined.

Adapt sheet size

Advantages:1x Ease of implementation to adapt,1x Production flow, 1x Savings potential
Disadvantages:1x Ease of implementation

The adapting of the metal sheet sizes has quite some advantages. First there is the advantage of savings potential. The adapting of sheet sizes could increase the efficiency of some products significantly and so contribute to metal savings. Also, this solution is easy to implement, because it does not change the process too much. Since the process change not that much the production holds its flow when adapting sheet sizes. Looked at the disadvantages of this solution, we encounter that due to the automated stockroom and inventory limits it is not possible to apply this solution very specific per safe.

Standardization

Advantages:1x Ease of implementation to adapt,1x Production flow, 1x Savings potential
Disadvantages:1x Savings potential

The solution of standardization has the same advantages as the adapting of the sheet size. It can yield a higher product efficiency and so contribute to the metal savings. Furthermore, because the standardization is done per product part the production process does not change too much. The production can hold its' flow and the solution is quite easy to implement. One important downside of standardization is that the changes of overproduction increase, due to the fact that parts are more produced in batches now instead of per product. This could threaten the real savings potential for this solution.

Dynamic nesting

Advantages:1x Savings potential, 1x Ease of implementation
Disadvantages: 1x Production flow

The biggest advantage of dynamic nesting is the savings potential. Due to the fallen limitations of punching per product the dynamic nesting could have a positive effect on the metal efficiency. Although this advantage the solution of dynamic nesting also brings some disadvantages. Instead of punching per product there is here punched by parts. The implementation is feasible, but this solution could lead to a longer production time due extra sorting and it can occur that due to this solution the welding department have to wait longer for all product parts arriving, because a final product part is in a later punching batch.

Outsourcing

Advantages: 1x Savings potential
Disadvantages: 1x Ease of implementation, 1x Production flow

Outsourcing could have the benefit of increasing the metal efficiency for some safes. In fact, outsourcing of punching "eliminates" the punching waste within the Gunnebo factory. However, outsourcing can only be done for a limited selection of products and when deliveries of suppliers are unreliable it can threaten the production flow.

Industrial symbiosis

Advantages: 1x Savings potential
Disadvantages: 1x Ease of implementation

The last solution industrial symbiosis has also the benefit of a relatively high saving potential. The biggest disadvantage of industrial symbiosis is that because of waste fluctuations it is difficult to agree on the amount of material that has to be exchanged.

Looked at the advantages and disadvantages of the solution and the connected weighted score criteria's we obtain the following scores.

Solution	Savings potential (weight 2)	Production flow (weight 1,8)	Ease of implementation (weight 1)	Total score
Adapt sheet size	2	1,8	0	3,8
Standardization	0	1	1	2
Dynamic nesting	2	-1,8	1	1,2
Outsourcing	2	-1,8	-1	-0,8
Industrial symbiosis	2	0	-1	1

Table 3: Results weighted score criteria solutions

In table 3 we see that the adapting of sheet sizes is the solution which scores the best on the weighed score criteria, therefore this solution is the solution which will be investigated further in the check phase. The solution that scores second best is standardization, followed by dynamic nesting and industrial symbiosis on the third and fourth place. The worst scoring solution is outsourcing, due to the not widely applicability and the uncertainty in lead times outsourcing brings.

5.2.3 Check

To check the effect of the solution of sheet size adapting, this solution will be evaluated further on the following KPIs: Metal Efficiency (%), Metal Waste Savings (Kg) and Cost Savings (€). For the adapting of the sheet sizes, we investigated all punching programs of the 11 selected safes and choose a new fitting sheet for the program when it was possible. For most of the programs adapting the sheet size was not possible. Most of the time this was due the fact that the sheet length was already fully optimized or due difficult product geometries. The new sheet sizes that are created after investigation of the punching programs can be found in Table 4, also a more detailed overview of the adapted sheet sizes per product could be found In appendix F.

Sheet length (mm)	Sheet width (mm)	Sheet thickness (mm)
1850	900	3
2400	900	3
1700	1000	3
2300	1250	2
2300	900	3
1800	1000	2

Table 4: New sheet sizes

KPI 1: Metal Efficiency

The first KPI this solution is evaluated on is Metal Efficiency (%). The metal efficiency is the weight of all punched out parts divided by the gross weight of all sheet metal used for the production of the product. When we adapt the sheet sizes following appendix F we get the following new metal efficiencies.

Casco	Old efficiency	Efficiency in new situation	Efficiency gain
94570	79,91%	81,27%	1,36%
97152	73,47%	75,95%	2,48%
96765	80,51%	80,51%	0,00%
95036	78,32%	81,06%	2,74%
902103	73,48%	75,62%	2,14%
95478	82,62%	83,96%	1,34%
95056	79,07%	79,99%	0,92%
901663	80,25%	80,25%	0,00%
97078	75,58%	76,55%	0,70%
901520	82,27%	82,27%	0,00%
90120	66,95%	66,95%	0,00%
Average	77,49%	78,58%	1,09%

Table 5: New metal efficiencies for selected products

We see that the average metal efficiency of the selected products is 77,49% in the old situation and 78,58% when the sheet sizes of the selected safes are adapted. The average efficiency gain is therefore 1,09%.

KPI 2: Metal Waste Savings (Kg)

The second KPI that is used in the evaluation of the sheet size adapting solution is the KPI metal waste savings (Kg). All the gross weights of the new sheets are calculated and the new gross weight is compared with the old gross weight of sheet material to compute the metal waste savings per product type. In Table 6 the waste savings per safe could be found.

Casco	Metal waste savings Jan-Apr (Kg)	Annual expected metal waste savings
94570	2400,252	7200,76
97152	3278,88	9836,64
96765	0,00	0,00
95036	3228,48	9685,44
902103	1680,00	5040,00
95478	1535,76	4607,28
95056	429,84	1289,52
901663	0,00	0,00
97078	257,6	772,8
901520	0,00	0,00
90120	0,00	0,00
Total	12810,81	38432,44

Table 6: Metal waste savings of sheet size adapting

We see that following the product quantities of January till April the sheet size adapting solution resulted in this situation in a metal waste saving of 12810,81 Kg. This leads to 3*12810,81 = 38432,44 Kg expected annual waste savings.

KPI 3: Cost Savings (€)

The last KPI the sheet size adapting is evaluated on are the cost savings in euros. For this we made a cost-benefit analysis to investigate the costs and savings gained with this solution. For this cost benefit analysis, the sheet prizes of Q2-2021 are used and the last known recycle price. An important note regarding the sheet prices is that the prices are given per ton or Kg and we assumed that the current kg prices do not change over the investigated period. The price per Kg is determined by the width and thickness of the sheet. When the sheet length is changed the price per Kg stays the same, however when the width is increased and/or the thickness is smaller, then the price per Kg increases also. This is due the fact a metal coil with more width or smaller thickness is more expensive for the wholesalers, where the length is simply cutting off the coil. In Table 7 the purchasing savings per safe could be found, also here the expected annual purchasing savings are the purchasing savings of the January-April period times three.

Casco	Products produced Jan-Apr	Total savings Jan-Apr	Expected annual savings
94570	834	€ 3.001,20	€ 9.003,60
97152	759	€ 2.731,31	€ 8.193,93
96765	609	€ 0,00	€ 0,00
95036	472	€ 4.104,76	€ 12.314,28
902103	420	€ 1.706,04	€ 5.118,12

95478	474	€ 1.279,29	€ 3.837,87
95056	199	€ 358,06	€ 1.074,18
901663	23	€ 0,00	€ 0,00
97078	161	€ 434,06	€ 1.302,17
901520	479	€ 0,00	€ 0,00
90120	294	€ 0,00	€ 0,00
Total	4724	€ 13.614,72	€ 40.844,15

Table 7: Purchasing savings of adapting sheet size

The costs that come with adapting the sheet size and so metal waste reduction lie in the field of recycling gain. For all metal that is disposed by the company and processed by the waste processor the company receives money. The nowadays recycling price is 0,26966 €/kg. When we have a waste reduction of 12810,81 Kg in the January-April period, it will lower the recycling funds of the company with 12810,81* 0,26966 = € 3.454,56. Therefore the actual cost savings of adapting sheet sizes is € 13.614,70- € 3.454,56 = € 10.160,14. Which is approximately 3 * € 10.160,14 = € 30.480,42 on annual basis.

This means that when we look on annual basis the three KPI-results are as follows.

- Metal Efficiency (average) = 78,58%
- Metal Waste Savings (annual) = 38432,44 Kg
- Cost Savings (annual) = € 30.480,42

5.2.4 Act

When we look at the KPI-results of the sheet size adapting solution, we see that it helped to raise the metal efficiency of most selected safes, it helped to reduce the metal waste and it is also cost beneficial. However, the sheet size adapting solution is feasible for the selected safes, there are some challenges when implementing this solution. These challenges are all regarding inventory management and purchasing. For good implementation of the solution, it is necessary to manage the inventory well. There is room for the extra sheet sizes in the automated stockroom, nevertheless it is essential to manage the sheet inventory in such a way it does not hinder the work floor. Furthermore, in times of scarcity of resources it could be more challenging to obtain all the preferred sheet sizes.

We also encountered that for most of the punching programs it was not able to raise the metal efficiency by adapting the sheet size. Most of the time sheet size adapting did not work, since that would bring the problem of parts not fitting in the nest of the sheet material. Also, part shapes play a crucial role in the metal efficiency. The parts have a lot of protrusions. These protrusions are for the bending process and make the parts fit each other better during the welding process. These protrusions make it more difficult to nest parts closer to each other, which effects the metal efficiency negatively.

5.3 Summary

In this chapter we have answered the research question “What are possible solutions for increasing the sheet metal efficiency and so waste reduction?”. The 5 solutions that are possible for improving the metal efficiency are:

- Adapting the sheet sizes
- Standardization
- Dynamic nesting
- Outsourcing
- Industrial symbiosis

Based on weighted score criteria, adapting the sheet sizes is chosen as solution for further investigation. For implementing this solution, the following additional sizes are added. 2400 mm * 900 mm, 2300 mm * 900 mm, 1850 mm * 900 mm and 1700 mm * 1000 mm Furthermore, the size 2300 mm * 1250 mm and 1800* 1000 (2 mm thickness) are added.

The creation of these sheet sizes and changing the punching programs according to these sizes resulted in the following KPI results.

January- April period

- Metal Efficiency (average) = 78,58%
- Metal Waste Savings = 12810,81 Kg
- Cost Savings = € 10.160,14

Annual expected KPI values

- Metal Efficiency (average) = 78,58%
- Metal Waste Savings = 38432,44 Kg
- Cost Savings = € 30.480,42

It was not possible to improving all product efficiencies, due to some sheets were already nested in full sheet length or due part shapes. Part shapes play a crucial role in the metal efficiency. Protrusions makes it hard to improve the metal efficiency, due protrusions parts cannot be nested that close together. For the implementation of sheet size adapting some challenges occur. For a good implementation of the solution, it is necessary that the inventory is managed well and the extra sheets does not affect the work floor or purchasing in a negative way. Also obtaining all preferred sheets in times of scarcity is a challenge that comes with this solution. Therefore, there is a tradeoff between the gained metal efficiency and the standardization of the purchase and production process.

6 Conclusion and Recommendations

6.1 Final conclusion

The goal of this research was to solve the high metal waste rate problem of Gunnebo Doetinchem. The aim was to reduce the metal waste percentage with 5%, from 29% to 24%. The steps that are taken during this research are: literature research, mapping the current situation, identify the waste types, identify the most wasteful products, look for root causes of efficiency problem, formulate solutions to remedy low efficiency causes, choosing a solution and evaluate solutions.

Following the data analyses, we concluded that the waste type punching skeletons is the key player in the metal waste distribution, followed by punching waste small. These 2 waste types are together for more than 90% of the waste responsible. Furthermore, we saw that the waste types: punching errors/overproduction, bending errors and scrap play a minor role in the waste distribution. Furthermore, we concluded out of the product efficiencies pareto that the product types: 95470, 97152, 96765, 95036, 902103, 95478, 95056, 901663, 97078, 901520 and 90120 are the products which are expected to produce the most waste. Based on these outcomes we concluded in the fishbone diagram that the root cause of the sheet metal efficiency problem is that the ***sheet sizes are not optimal adapted to the fixed product sizes***.

For remedying the root cause of sheet sizes are not optimal adapted to the fixed product sizes the following possible solutions were provided.

- Adapt sheet size

- Standardization.
- Dynamic nesting
- Outsourcing
- Industrial symbiosis

After evaluation with the help of weighted score criteria and based on the advantages and disadvantages the solution of adapting the sheet sizes was chosen to be implemented and evaluated further. This solution's KPI scores for the 11 most waste producing products are:

- Metal Efficiency (average) = 78,58%
- Metal Waste Savings = 38432,44 Kg
- Cost Savings = € 30.480,42

Based on all the answers on the sub research questions we can give now answer on our main research question "What are the causes of having difficulties with sheet metal efficiency improvements and which solution(s) can remedy these causes?" The causes of having difficulties with sheet metal efficiency improvements lies in the field of nesting. Due to the fixed sizes of the products and the limitations in sheet sizes, the parts are not complementary to the sheet material. The solution that is proved to remedy the causes of the metal efficiency problem is the solution of sheet size adapting. When the selected highly requested products have better fitting sheets this result in an average metal efficiency of 78,58% for the selected safes, an expected metal waste saving of 38432,44 Kg per year and € 30.480,42 expected savings in costs.

To reach the aim of 5% waste reduction the current waste rate must go from 29% to 24%. The company bought 3600 tons of steel where 1044 ton ended up as waste. To reach the goal of 24% and so 5% waste reduction the solution must lead to a waste reduction of 180 ton of waste. The KPI metal waste savings shows us that the sheet size adapting solution resulted in a metal waste reduction of 38432,44 Kg. This is a waste reduction of 38432,44 / 3.600.000 = 1,1%. This means that the aim of 5% waste reduction is not reached. One reason for this is that in this research there is narrowed down a lot, because of time. With every narrowing down some waste falls out of scope which decreases the waste reduction potential. When the "new" sheet sizes are going to be applied more widely to more products where it is applicable, the waste reduction can be increased further.

6.2 Discussion

As previously mentioned, the biggest limitation in this research was the time limit. Because of the limited number of weeks within this research could be conducted the waste type experiment is only a sample for six weeks. Although we verified with the help of statistics that the total waste distribution of this period was representative for the rest of the year it is always questionable if this was really the case. Furthermore, only eleven product types are selected as focus for solution testing. This selection is made based on expected demand. It is therefore questionable if the assumption of most produced products correspondents fully with the reality. The selection is made, because of lack of time. The last threat in validity of this research is that only one solution is worked out with KPIs and that this solution is chosen following the weighted score criteria. This is also done because of the time constraint. When not all solutions are tested following KPIs it is more difficult to conclude which is the best solution. Although the weighted scores are based on interviews in multiple departments the answers the interviewees gave always could contain some elements of bias. The last threat of validation for this research is that the annual KPIs are the expected annual KPIs and are based on the selective period from January till April.

6.3 Theoretical contribution

The theoretical contribution of this research lies in the field of root cause analysis, waste hierarchy and waste prevention. We showed how via root cause analysis the root cause of a problem can be found. We first identified the waste types and product types via a pareto analysis and select the focus following the 80/20 rule (Matiskova, 2015). Following all the data obtained we find the final root cause following the fishbone diagram (Cybenko et al., 2018, p.35). The solution formulating process was mainly based on the ladder of Lansink (Lansink, 2018), where we focus on waste prevention and re-using waste. With the solutions of standardization and industrial symbiosis we showed how the theories of Miltenburg (2000) and Fraccascia (2020) could be used in a waste problem. Finally, this research showed how a research could be conducted following the MPSM approach (Heerkens & van Winden, 2017).

6.4 Practical contribution

The practical contribution of this research lies in the field of cost savings and sustainability. Although the aim of 5% waste reduction is not met the research led in the end to a reducing of the company's the metal waste by 1,1%, which was the action problem that was needed to be solved. With a wider application and additional research, the metal waste could be further reduced. We solved this problem by first solving the core problem of having difficulties with increasing sheet metal efficiency. We provided multiple solutions which could lead to an improved metal efficiency, where the solution which scores the best in the weighted score criteria is chosen for testing. Out of the measurements in the solution evaluation follows that this solution is reducing the metal waste and is costs beneficial. Furthermore, additional recommendations for the company are made with reference to metal waste management and options for further research are mentioned as well.

6.5 Recommendations

Based on the research that is done and the conclusions that are drawn the following list of recommendations is made

- Adapt the sheet sizes for the following safes: 95470, 97152, 95036, 902103, 95478, 95056 and 97078 (see appendix F): When the company would have adapted the sheet sizes of these safes from January till April, it would have saved the company 12810,81 Kg metal waste and € 10.160,14 in this period.

- Investigate other solutions on KPIs: Before making a final decision about which solution will benefit the company the most it is recommended to also investigate the other formulated solutions on the stated KPIs. Since only for adapting sheet sizes the KPIs are calculated it is not clear for now how effective the other solutions could be.

- Annual identification of wasteful product types: When the safes that are currently the most produced or the most wasteful become outdated product types, the adapting of sheet sizes loses its' benefit quickly. Therefore, when the company wants to keep adapting sheet sizes it has to select every year a new focus group for adapting to maintain the benefits of it. When outdated models fall out of selection the programs also have to be changed to the "more standard" programs to keep the sheet inventory manageable and the new most waste producing types have to be selected for adapting the sheet size.

- Investigate for which product types the "new" sheet sizes also could have a positive impact on metal efficiency: When the programs of the selected product types are adapted to the "new" sheet sizes it is also recommended to look at the wider applicability of the “new” sizes. When also other safes could benefit from adapted sheet sizes the total metal efficiency can be further improved.

- Keep sheet sizes and metal efficiency in mind when designing new products: Within the bandwidth of customer wishes and safety requirements the design of products must be designed, so that they can be nested in the most efficient way as possible. An example of this is to design products with smaller protrusions and with a width or length that correspondent well to the standard sheet sizes. Again, the customer and safety requirements must allow this.

- Create waste awareness: When every employee in the company is more aware of how to prevent waste and the importance of waste reduction, employees would put in more effort to contribute to waste reduction solutions. For this it is important to keep monitoring waste streams. Examples of this are employees at the preliminary work department who are bending more carefully when they know waste is monitored or employees of the preparation department looking for continuous improvement of lower efficiency products.

6.6 Further research

Although this research helped in reducing the metal waste by improving the metal efficiency more research can be done regarding metal waste reducing and waste management. Options for further research regarding this field within Gunnebo Doetinchem are:

- The sheet size adapting is in this research is only applied to a selected group of products. More research could be done to whether these sizes are also applicable on other punching programs out of the scope of this research.

- The sheet size adapting solution is the only solution that is evaluated based on KPIs. In further research the other solutions could also be evaluated following the given KPIs. This makes it possible to compare solutions and to see which solution really have the highest potential.

- For the solution of industrial symbiosis, we only investigate which type of waste could be used for industrial symbiosis in the future. Further research could be done to see whether this is beneficial and which possible waste takers there are for this waste.

- The solutions that are provided in this research could also be combined with each other. For example, it is possible to choose sheet size adapting, but also use industrial symbiosis. In further research it could be possible to investigate which solutions go well together and if that benefits the company more than only implementing one solution.

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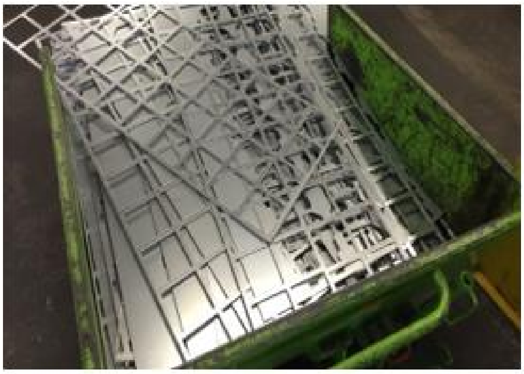
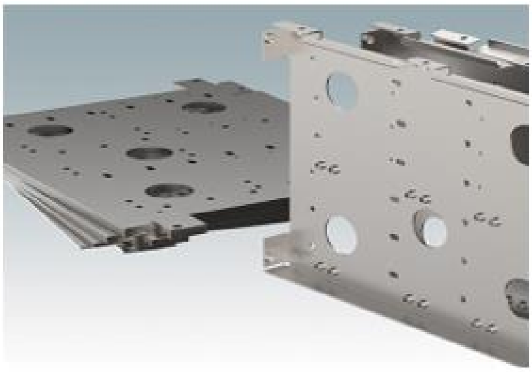
Appendices

Appendix A: Waste types pictures

These pictures are not from the company's factory due to confidentiality.



A Skeletons



D Punching errors

B Punching waste

E Screw

B Bending error

(Google images 2021)

Appendix B: Waste experiment samples

Total metal waste final sample last year

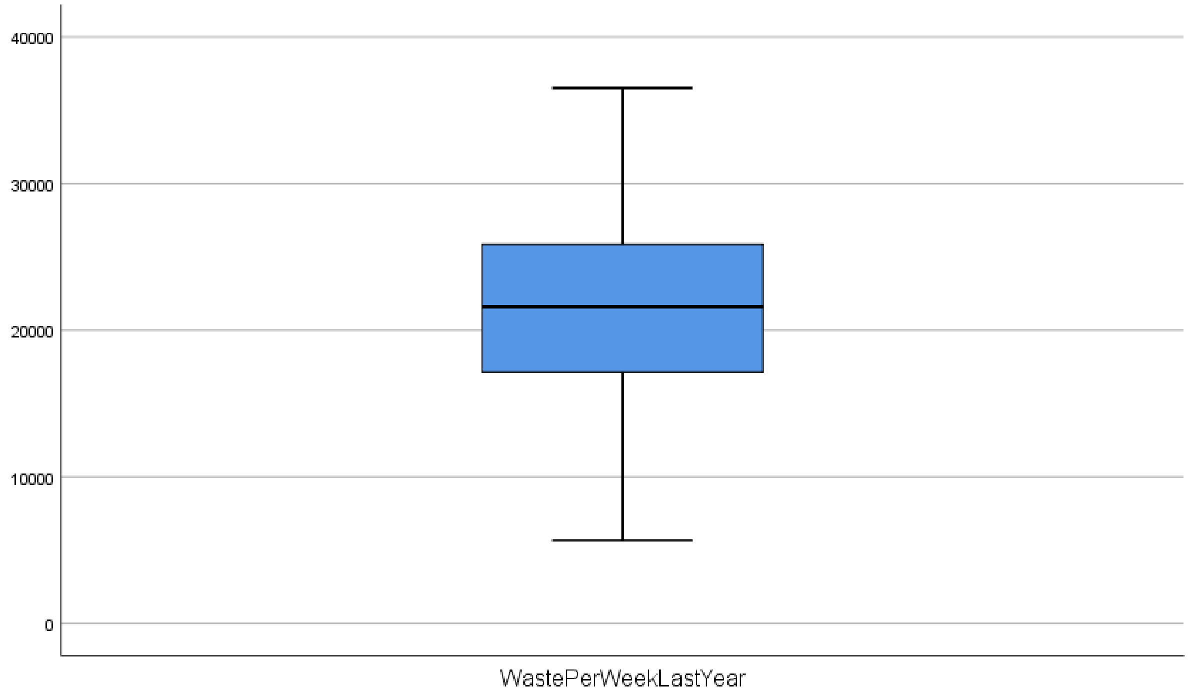
Week	Metal waste (Kg)	Week	Metal waste (Kg)	Week	Metal waste (Kg)
1	21560	**19**	27360	**37**	27800
2	23240	**20**	24460	**38**	17640
3	21500	**21**	25860	**39**	36520
4	31640	**22**	22840	**40**	19360
5	18620	**23**	21600	**41**	30800
6	30500	**24**	20060	**42**	21940
7	22720	**25**	22420	**43**	25920
8	24940	**26**	16800	**44**	21280
9	29560	**27**	14440	**45**	9000
10	16920	**28**	24980	**46**	9280
11	6840	**29**	29580	**47**	11260
12	7100	**30**	16860	**48**	22200
13	32460	**31**	19980	**49**	21220
14	20800	**32**	14380	**50**	25900
15	5660	**33**	20620	**51**	12220
16	26540	**34**	24800	**52**	10380
17	23820	**35**	25960	**53**	22440
18	19360	**36**	17140		

Waste sample investigated period

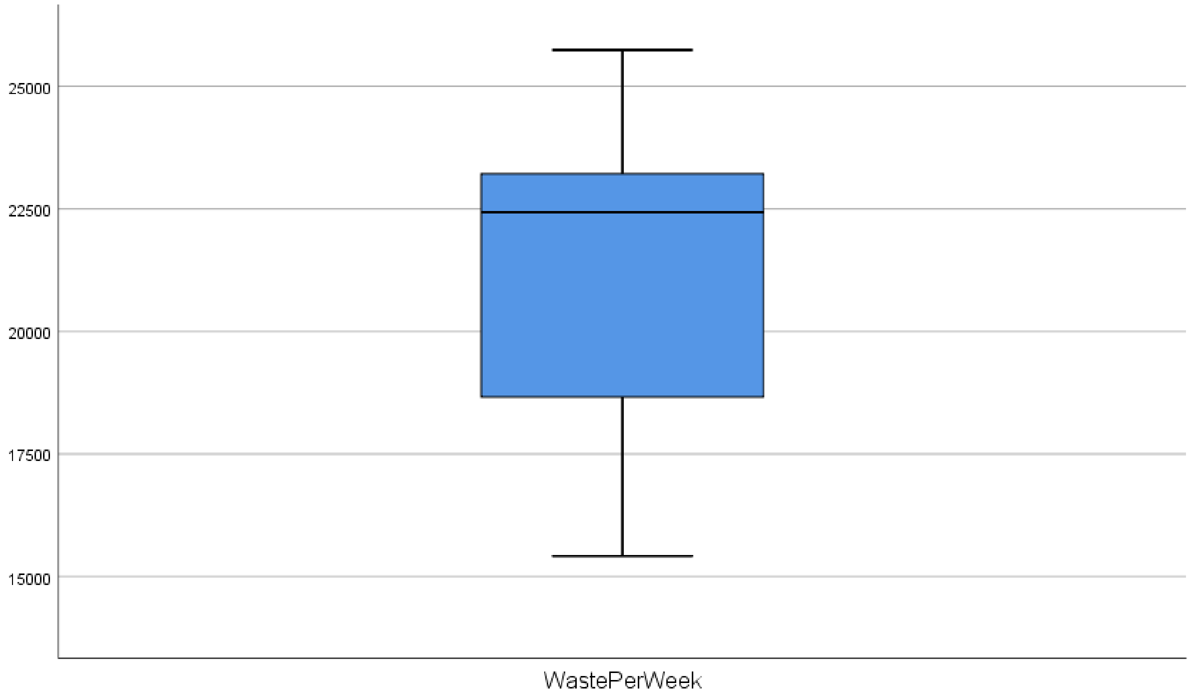
Week	Metal waste (Kg)
1	18660
2	22320
3	15420
4	22540
5	25740
6	23220

Appendix C Boxplots

Boxplot sample last year



Boxplot sample investigated period



Appendix D: Product categorization tables

Forecast

Casco	Annual expected waste (Kg)	Cumulative waste %
95470	108680	10,940%
97152	101552	21,162%
96765	98483	31,075%
95036	88702	40,004%
902103	84714	48,531%
95478	44522	53,013%
95056	33943	56,430%
901663	25864	59,033%
97078	25067	61,556%
97447	20766	63,647%
97142	20173	65,677%
903391	20056	67,696%
903297	18540	69,562%
48025	18414	71,416%
902112	18088	73,237%
96852	17953	75,044%
97366	16617	76,717%
97814	15115	78,238%
97301	14206	79,668%
96716	13571	81,034%
47429	12929	82,335%
45713	11200	83,463%
902123	11182	84,588%
903515	10900	85,686%
96610	10731	86,766%
97133	9675	87,740%
96908	9597	88,706%
95964	9568	89,669%
96115	9389	90,614%
92837	9326	91,553%
96987	9149	92,474%
96785	8870	93,366%
97440	7921	94,164%
97463	6927	94,861%
97807	6753	95,541%
97421	6115	96,156%
97332	5051	96,665%
96870	4954	97,163%
96790	4359	97,602%

97647	4216	98,027%
904341	3478	98,377%
902133	3290	98,708%
95880	2608	98,970%
901605	2496	99,222%
46362	2179	99,441%
97359	1966	99,639%
43253	1918	99,832%
96214	1457	99,979%
96250	168	99,996%
97455	45	100,000%

Production Plan

Casco	**Annual expected Waste (Kg)**	**Cumulative waste %**
95470	88170	9,952%
97152	80150	18,998%
95036	62927	26,101%
95478	57036	32,538%
901520	54893	38,734%
902103	47124	44,053%
96765	46278	49,276%
96115	35594	53,294%
97463	24154	56,020%
90120	23867	58,714%
95056	23426	61,358%
97078	19310	63,538%
96852	19061	65,689%
45713	17920	67,712%
99077	17842	69,725%
97055	16663	71,606%
97366	15519	73,358%
903297	14459	74,990%
48025	13947	76,564%
97468	12593	77,985%
902112	12582	79,405%
96987	12393	80,804%
96716	11607	82,114%
97301	11009	83,357%
49860	9266	84,403%
97142	8679	85,382%
903391	8504	86,342%
97814	7697	87,211%
99076	6854	87,984%

98944	6847	88,757%
904951	6277	89,466%
901580	6268	90,173%
97440	5361	90,778%
98036	4786	91,319%
96610	4776	91,858%
904949	4706	92,389%
98351	4416	92,887%
46607	4409	93,385%
902123	4363	93,877%
92837	4044	94,334%
904947	3976	94,782%
904343	3937	95,227%
902725	3496	95,621%
96087	3452	96,011%
43253	3384	96,393%
904950	3184	96,752%
95880	3091	97,101%
904948	2584	97,393%
904952	2012	97,620%
904425	2003	97,846%
97647	1983	98,070%
901663	1851	98,279%
48727	1738	98,475%
902133	1520	98,646%
904430	1256	98,788%
96908	1212	98,925%
97359	1134	99,053%
93163	1088	99,176%
96214	1033	99,292%
96785	946	99,399%
905465	879	99,498%
92875	831	99,592%
96250	606	99,661%
96790	549	99,723%
905906	510	99,780%
95136	489	99,835%
95019	428	99,884%
95574	374	99,926%
97421	216	99,950%
905905	198	99,973%
92790	129	99,987%
97845	113	100,000%

Appendix E: Selected products share in punching waste

Selected products waste based on forecast		
Casco	Waste (Kg)	share in total punching waste%
95470	108680	10,9%
97152	101552	10,2%
96765	98483	9,9%
95036	88702	8,9%
902103	84714	8,5%
95478	44522	4,5%
95056	33943	3,4%
901663	25864	2,6%
97078	25067	2,5%
901520	0	0,0%
90120	0	0,0%
Total	611528	61,6%

Selected products waste based on Production Plan		
Casco	Waste (Kg)	share in total punching waste%
95470	88170	10,0%
97152	80150	9,0%
95036	62927	7,1%
95478	57036	6,4%
901520	54893	6,2%
902103	47124	5,3%
96765	46278	5,2%
90120	23867	2,7%
95056	23426	2,6%
97078	19310	2,2%
901663	1851	0,2%
Total	505034	57,0%

Appendix F: Sheet size changes per product type

	No sheet size adaption			Sheet size adaption		
	Length	Width	Thickness	Length	Width	Thickness
Casco 95470	2500	900	3	2400	900	3
	2500	900	3	2400	900	3
Casco 97152	2500	900	3	2300	900	3
Casco 95036	2000	900	3	1850	900	3
	2000	1000	3	1700	1000	3
Casco 902103	2500	1250	2	2300	1250	2
Casco 95478	2000	900	3	1850	900	3
Casco 95056	2500	900	3	2400	900	3
Casco 97078	2000	1000	2	1800	1000	2

Appendix G: Reflection

Research Methods

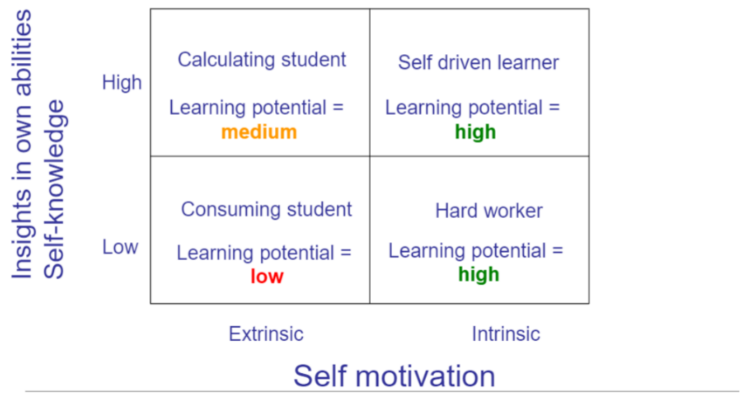
During the preparation and execution of this bachelor assignment I learned a lot of things in all kinds of areas. I learned how to set up a research design properly, how to execute a systematic literature review and how to guarantee validity in the research design. I also encounter how important the support of methodologies and theories in a research could be. In the beginning I wanted to quick formulating solutions without identifying the root cause. I was a bit impatient and wanted to take too big steps at a time. Therefore, I had some struggles in finding structure in the beginning. After some good advices of my supervisors, I became more patient and over time I finished my research design, which gave me more structure in the continuation of my project. Also, the methodologies and theories that I found with the help of the systematic literature review helped me in steering my project in a good direction. During the mapping of the current situation, I gained a lot of input from employees of the company and observations. This helped me a lot with better understanding the problem. When identifying the causes, I learned how to analyze causes with the help of data collection. One of the most difficult things in the project was in my opinion the solution formulation. This required some creativity and because of the challenges and limitations in the factory not every solution is feasible. The solutions were needed to be well considered, because the testing possibilities were limited, due to time.

Professional responsibility

This research is conducted within a company, which also involves some professional responsibility. Looked at my professional responsibility I took my role within the company serious. My goal was to propose an overall accepted and cost beneficial solution to the company. Through the whole project I strived to provide a solution with the highest benefit of the company. Also, I must guarantee the safety of the other employees within my research and stick to the safety rules within the company. Furthermore, I must show active responsibility towards other employees and I must always be possible to justify my actions. Looked at my active responsibility there was one point where I could take more active responsibility. For the waste types experiment the agreement with the waste processor was made. After a while the waste processor informed about the fact that additional information must be delivered every time a container was picked up. The pickup for the desired container(s) should be registered in a portal. This should be done for in case no historical data was known by the waste processor. In this case I could take more responsibility in registering the containers. In the end we were able to manage this unexpected event well, but I could be more proactive in asking about the data to prevent worries about the data collection.

Self-driven-learner (SDL)

Following the introduction lecture of M11 a self-driven learner is motivated to take responsibility for his/her work, manages the work well and is able to monitor himself/herself. When reflecting on my development as a self-driven-learner I noticed that my intrinsic motivation has grown over this period. I adapted a more growth-mindset, by looking at this project as an opportunity to learn about making theory work in practice and working like an engineer, instead of doing this project only to graduate or obtain a high grade. Before my bachelor-project I only put extra energy in something when this benefits me in the form of a grade for example. When doing this bachelor-thesis I also want to make my report as good as possible, but I noticed that it is not just for receiving a high(er) grade, even so I wanted providing a solution with the highest benefit. To come to this solution, I know my own expertise's and called for help of my supervisors or other employees of the company when I needed additional information or expertise. Looking at the aspect of self-monitoring, I managed to stick somehow to my week planning, for the preparation phase of the project I did not manage to stick to my planning. This means I am now more able to manage my own project work. The last aspect of a SDL is self-monitoring. Looking at my self-monitoring for reflection I made use of buddies, teachers and supervisors. I took their feedback serious and improved my report a lot with the help of this feedback. There is one point of improvement regarding self-monitoring, I failed to keep a proper log. Although I reported my findings on paper and in the report, I could register findings more systematically. This makes it easier to monitor yourself. Looked at my development towards a SDL, although the points of improvements that are mentioned before, I became from a calculating student a more self-driven-learner, due to my improved intrinsic motivation.



Self-driven-learner matrix

Conclusion

Looked at my own work, I learned a lot from this project. I learned how to bring theory into practice and how to set up and execute a research design. I also learned how to adapt a more growth mindset. I really liked it to work for a company and see whether my actions could lead to the improvement of the metal efficiency. I also liked working in an organization very much. Since this project was done within an organization and needed to be managed mainly by myself, it needs a lot more responsibility from me. In previous group projects I also felt responsible for the work, but now when working for a company and being my own project manager, I felt more responsible. Another thing is that beside a good grade I also felt responsible for providing a beneficial solution for the company. Despite it asks more responsibility, I was able to manage it and I somehow liked the responsibility the company gave me. Although I learned a lot, there are still some points of improvement. I could improve my pro-activeness, planning and the use of a logbook. Looking at my pro-activeness I was pro-active during this project, but sometimes I could ask things earlier to make it easier for myself. I do not want to bother other people while they are working too quick and try to solve things by myself, so therefore I am sometimes a bit timid and try to solve issues (too) long all by myself. Looking at my planning I still could divide activities more, so that it is easier to stick to my planning. With a better planning the change of unexpected time delay could be prevented. Looking at my self-monitoring I could document data and information better. I document my interviews and evaluating meetings, but this could be done sometimes in more detail. I noticed that sometimes some things that for example were discussed on Friday I forgot on Monday. A better documentation of information could prevent this. So, despite my growth towards a more self-driven learner there is still room for improvement.