Analysing the production waste at a printing company

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Management summary

Problem

The company at which this research is completed is Eshuis. It is a printing company that among other labels produces shrink sleeves. These are a specific type of product label. The problem at Eshuis is the excessive production waste generated during the manufacturing of shrink sleeves. This waste can be categorized as avoidable and unavoidable. In 2021 and 2022, the total production waste has increased significantly. Eshuis identified that a huge portion of this waste is avoidable. The goal for the future is to reduce the amount of avoidable production waste. Multiple factors contribute to the high volume of unused shrink sleeves and plastic, leading to this problem.

Analysis

To analyse the waste produced at the production line, observation data is used to get insight of the various waste types and their corresponding quantities. Because the corresponding machine in the first stage of the production line is being replaced soon, this study focuses on the post-processing stages of the production process.

The post-processing stages consist of three stages and at each stage the avoidable waste types are determined to narrow down the focus of this research to only avoidable waste. Waste is avoidable if it does not add any direct value to the customer's perspective and it does not serve any purpose within the production process. Direct value in this case is the benefit the customer derives from the product such as customized dimensions of the shrink sleeves that align with the bottle it is intended for. The stages include gluing and cutting, sleeving, and inspection. The gluing and cutting stage and the sleeving stage correspond both to one machine, while the inspection stage includes three similar machines named N39, N37, and N16. In Table 1 the list of avoidable waste types is given per stage. The average amount of waste in meters is also given per type of avoidable waste. This number depends on the number of rolls coming in and going out of a stage. For example, an input roll can have various sizes from 2000 meters until 10,000 meters. However, the waste stays the same per input roll. This also true for the output roll and end roll.

Table 1. Overview of the types of avoidable waste in the production process

Stage (machine)	Type of avoidable waste	Average amount of waste (in meters)
Gluing and cutting	Transport waste	7.88 per input roll
	Unwinding waste	2.24 per output roll
	Sample waste	0.85344 per output roll
	Machine waste	23.23 per order
Sleeving	Sample waste	0.5334 per output roll
	Machine waste	15.68 per order
Inspection (N39, N37, N16)	Counting waste	20.80 per end roll
	Unwinding waste	9.90 per end roll
	Sample waste	1.0668 per end roll
	Machine waste	2.81 per end roll

To analyse the current production process further, a dashboard is created through Visual Basic for Applications (VBA) that simulates the current production process. Through this dashboard, simulations can be executed to analyse waste values throughout the production process. The total waste distribution in the post-processing stages, resulting from observations and the dashboard, is given in Figure 1.

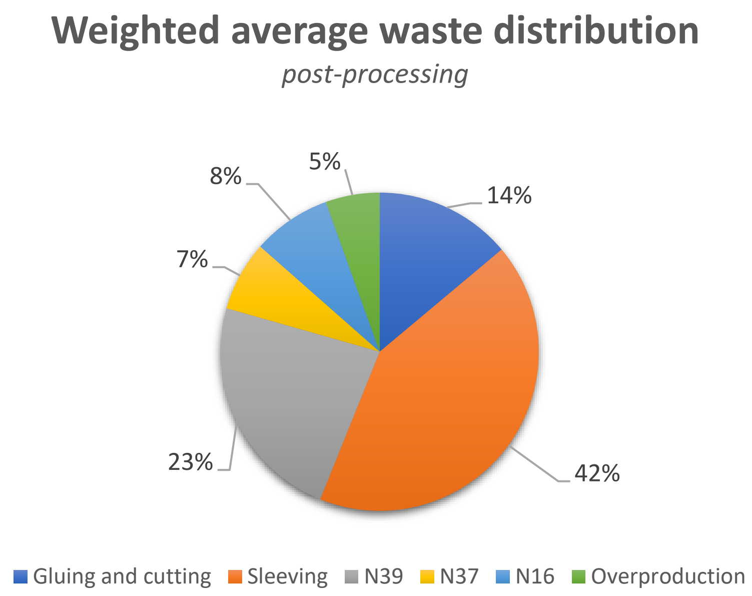

Figure 1. Average waste distribution in the post-processing stages

In Figure 1 the produced waste at the N39 stands out. By taking a closer look at the observation data from the N39 we see the regular waste distribution given in Figure 2.

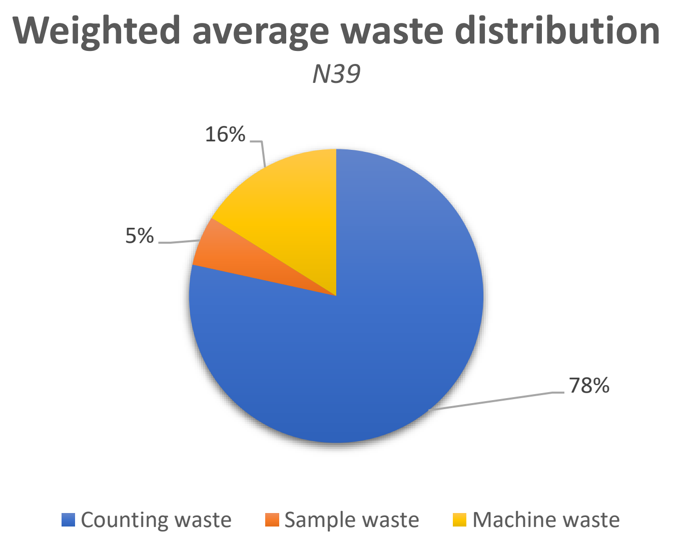

Figure 2. Average waste distribution at the N39.

The waste types that are avoidable and unnecessary for the production process are the following:

- Counting waste at the N39
- Unwinding waste at the inspection stage
- Machine waste at the N39 and N16
- Transport waste
- Overproduction

Solutions

The unwinding waste and machine waste result from long existing work methods by operators. To remove this waste new work methods must be implemented. The transport waste can be solved by protecting the production rolls during their transport in plastic covers such that contact with other surfaces do not result in damages on the production roll. The counting waste is a caused by an inspection machine that is not counting the meters accurately. This can be solved through calibrating the machine. Overproduction originates from the first stage where the number of meters are determined based on an educated guess. An algorithm that calculates the number of meters and the average regular waste produced at each stage is used to prevent any overproduction in the future. To see the impact of the solutions in terms of waste, a dashboard is created to simulate the production waste when different values are inserted for the average amount of waste.

The expected average reduction in total waste in the post-processing stages is calculated using this dashboard. This dashboard first simulates the current production process in terms of production roll sizes and waste by mimicking work methods used by operators. These work methods vary from the sizes operators will produce for a given order size to the average waste operators produce during every stage. The current production process determines the number of shrink sleeves to produce for an order at the first stage. This number includes the order size and an educated guess on the future waste produced. Then the dashboard again calculates the number of shrink sleeves to produce, only now it calculates what Eshuis needs to fill the order at its maximum at the last stage while accounting for the regular average waste produced at the last stage. After that, it is known how much the second-last stage should produce to meet the last stage's needs. The dashboard again calculates how much to produce and calculates the corresponding average regular waste. This is an iterative algorithm that can show the difference between current production waste and production waste without overproduction. Because the regular waste values given in Table 1 can be changed by the dashboard user, the algorithm can be used to show differences in production waste when waste types are reduced. In Table 2, the expected average reduction in total waste is given if the recommended solutions are correctly implemented.

Table 2. Solutions for the avoidable waste types that should be reduced.

Waste type	Where	Action	Expected average reduction in total waste
Transport waste	Gluing and cutting	Protecting surface with covers	3.34%
Overproduction	All stages	Using new algorithm to determine production roll sizes	3.48%
Machine waste	Inspection stage: N37 & N16	New work instruction	5.93%
Unwinding waste	Inspection stage	New work instruction	9.06%
Counting waste	Inspection stage: N39	Calibrate inspection machine N39	25.96%

Recommendations

I advise to Eshuis to implement the solutions that have the most impact on total waste. These solutions include the new work instructions at the inspection stage which are simple adjustments to the current work environment but can already effectively reduce the total production waste. The transport waste can also easily be avoided by protecting the surface of production rolls during internal transports. The counting waste is one of the biggest contributors to total waste and is also easily resolved by calibrating the new machine or adjusting the machine settings. The dashboard is a tool that I recommend using to determine how the average regular waste impacts the total production waste. If regular observations are made, possible average waste value changes can be noticed and implemented in the dashboard to evaluate a new waste distribution in the post-processing stages. Furthermore, the dashboard calculates a number of meters printed at the first stage such that the order is filled and the average regular waste is accounted for. This feature is also recommend to be used for all order sizes.

Preface

Dear reader,

This thesis is written to obtain my Bachelor's degree in Industrial Engineering and Management at the University of Twente. In the process of crafting this thesis, I have had the opportunity to get to know more about the production of packaging labels at the printing company Eshuis.

It is essential to acknowledge that this thesis would not have been possible without the help and guidance of the people at Eshuis. Their willingness to contribute their time, expertise, and resources has been instrumental in the completion of this research. I have been given almost unlimited freedom in my pursuit of researching the waste at their company. Special thanks go out to production manager Arjen Pijkeren and process engineer Jelle Overbeek, who both helped enormously during my research.

Moreover, I would like to thank my supervisor Fabian Akkerman from the University of Twente, who assisted me greatly during the process of researching and writing in this thesis.

Lastly, I would like to thank my family and friends for all their support and interest in my research.

Bas Arens

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1 Introduction

In this Chapter I introduce the reader to the company and the problem. In Section 1.1, a description of the company is given. In addition, Section 1.2 describes and identifies the problem. In Section 1.3 the problem solving approach is introduced.

1.1 Company description

This research is conducted at Eshuis, which is a printing packaging company located in Dalfsen. Eshuis produces labels and customized packaging material for their customers. These customers are big production companies active in the food and beverage industry as well as individuals who are searching for personalized labels. For this project, I take a closer look at the production line that is dedicated to the labels which are produced for Company X. The labels produced for Company X are used for bottles and are a specific type of product label. The label is heat wrapped around the nutrition bottle by shrinking the label onto the product through the use of water. This type of label is called a shrink sleeve. Company X is using these shrink sleeves to provide their customers with information and an attractive design. At the production line of the shrink sleeves, Eshuis is producing a huge amount of plastic waste in the form of unfinished and unused shrink sleeves. This waste will be the focus of my thesis.

1.2 The problem

This section describes the problem with a problem context in Section 1.2.1. In Section 1.2.2 the problem cluster is defined. From this problem cluster we identify the core problem in Section 1.2.3.

1.2.1 Problem context

The reality at Eshuis B.V. nowadays is that it produces a huge amount of waste at the production process of the shrink sleeves. One part of the waste is avoidable and the other part of it is unavoidable. In 2021, the total production waste was 957,740 kg. In the year 2022, the total production waste increased to an amount of 1,203,027 kg. By Eshuis' calculations, the avoidable waste more than doubled from one year to another. It means that Eshuis could have reduced their waste in 2021 and 2022 with 13.18% and 23.90% respectively. The stacked column chart in Figure 3 visualizes the total waste over the last two years.

Figure 3. Stacked column chart of the total waste in 2021 and 2022

The action problem is therefore formulated as follows:

The avoidable production waste on the production line for Company X at Eshuis B.V. was 23.90% from the total production waste in 2022, while this should be reduced in 2023.

Every reduction of the avoidable production waste in percentage of the total production waste is an improvement. It should be noted that an increase in production of shrink sleeves in the year 2023 respective to the production in 2022 causes the production waste also to be higher. This is why I use a percentage of the avoidable production waste with respect to the total production waste as measure for the action problem.

1.2.2 Problem cluster

The problem that Eshuis is facing is the high amount of production waste at the production line for Company X. This problem is caused by multiple factors leading to a high volume of unused shrink sleeves and plastic. These factors, indicated in the problem cluster shown in Figure 4, produce a high production waste that lead to no added value to the production of shrink sleeves. In this thesis the word "factor" is used to indicate the different causes that lead to the production waste. The high production waste is a problem because it calls for a higher number of raw materials than actually needed for the production of the end product. It makes the production process less efficient and thus costs Eshuis money.

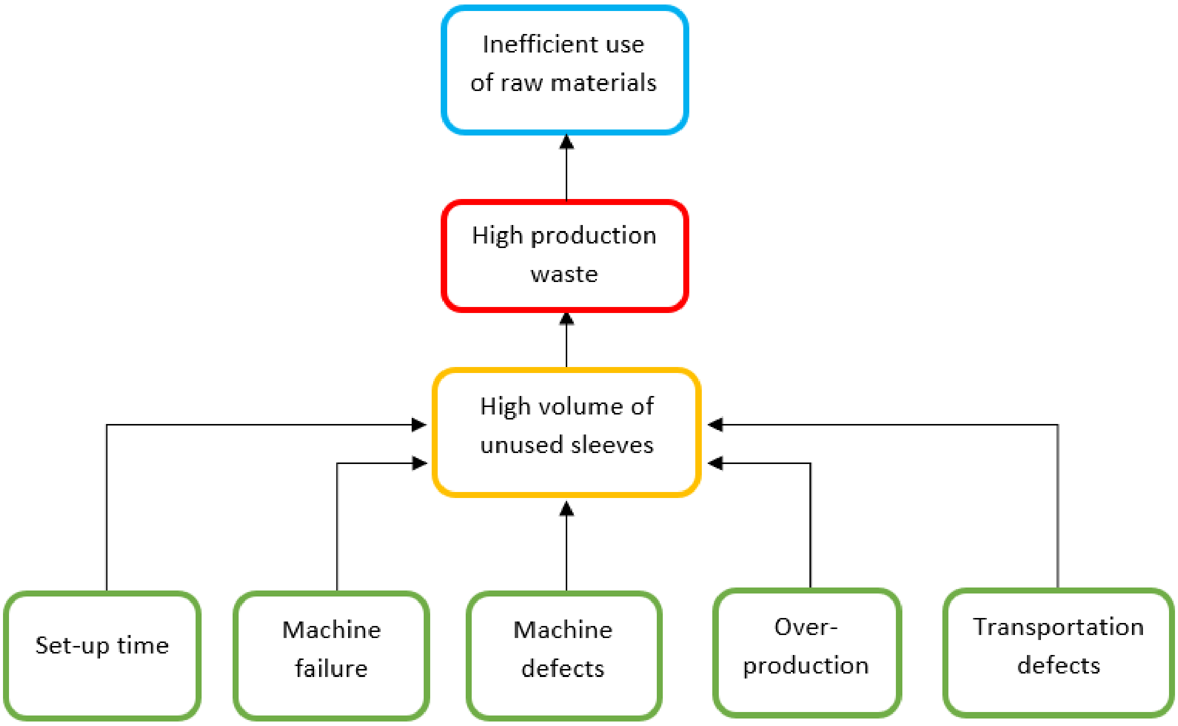

Figure 4. Problem cluster

The factors contributing to the production waste are indicated in the green boxes on the bottom of the problem cluster. These green boxes represent the core factors of the production waste.

The five green boxes in the problem cluster are all leading to a high volume of unused sleeves. The factor "Set-up time" produces waste when a machine in the production line needs to be set-up. The machines need to warm-up and get to the right speed to produce products with the right quality. This warm-up uses raw materials that cannot be processed further, resulting in unused sleeves.

The factor “Machine failure” produces unused sleeves when a machine in the production line fails and needs to be repaired to continue. This leads to waste of the products that are being processed at the time of failure since the machine needs time to achieve the right speed and quality.

The core factor “Machine defects” represents the waste that is produced due to quality failures throughout the production line. These can be technical failures damaging the products which are being produced or inaccurate setting such that the quality is not satisfactory.

“Overproduction” is a factor that occurs when an excessive number of labels are produced for an order. When producing the demanded meters of product, Eshuis has agreed with Company X that it may produce 5% less or 5% more than what is ordered by Company X. The price for Company X will be adjusted to the percentage of over- or underproduction. This is why Eshuis targets to produce 105% to maximise its turnover. This sometimes leads to the production of more than 105% of the order because of poor calculation of the number of meters that should be produced to account for the total waste throughout the production process.

The last factor, “Transportation defects”, occurs when production rolls are transported from the supplier to Eshuis, from one production line to the other, or from Eshuis to the customer. These can lead to damages on the surface of the roll, therefore leading to unused sleeves.

1.2.3 Core problem

The problem cluster in Figure 2 shows that all factors lead to a high production waste. These factors could all be core problems. When more than one potential core problem in the problem cluster remains, the most important one should be solved. In this case, which means that the factor that would reduce the production waste the most when solved, is the core problem.

Since the impacts of the factors on the total production waste are unknown, the following core problem is stated:

The production waste at the production line dedicated to Company X is too high.

The high production waste leads to an inefficient use of raw materials. This is a negative consequence of the core problem, but not the core problem itself.

1.3 Problem Solving Approach

In this section, the problem solving approach is explained. Section 1.3.1 introduces the methodological framework. In Section 1.3.2 the research questions are formulated. In Section 1.3.3, the limitations of the research are listed.

1.3.1 Methodological framework

The methodological framework encompasses all the activities that need to be executed to solve the core problem. The steps I need to perform are visualized in the process flow in Figure 5.

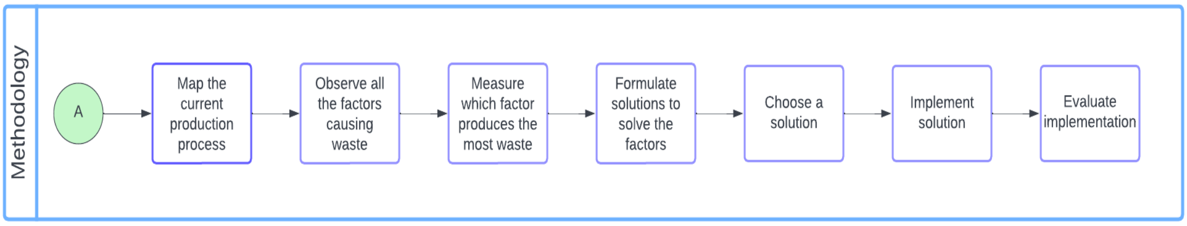

Figure 5. Methodological process flow

The activities are based on the Management Problem Solving Method (Heerkens & van Winden, 2017). In the first activity I gain insight in how exactly the product is being produced from entering the factory until leaving. By observing I then state all the factors that contribute to the total production waste. These factors cannot all be tackled at once; I therefore first figure out which factor can be avoided in the production process and which factor is still necessary. After that I measure the impact each factor has on the total production waste in order to analyse how the total production waste is constructed. Next, I formulate solutions to solve or limit the impact of the factors deemed avoidable or reduceable to decrease the total production waste as much as possible. I choose the solution that works best in this context and implement it. After implementation I can evaluate the new results.

1.3.2 Research questions

Before I can complete all the activities stated above, I first need to discover more about the production waste at the production line of shrink sleeves for Company X. The total production waste is known, but the impact each core factor has on total production waste is not. The core factors, as discussed in Section 1.2.2, cause a high volume of unused sleeves. Therefore, I focus on these factors. Measuring the impact of the core factors on production waste is necessary to find out which core factor produces the most waste. After this is measured, I can focus on targeting one or more factors which effectively reduce the total avoidable production waste.

The following research questions are related to the problem solving approach:

1. *What factors determine waste in the Company X production line?*

The core factors that are already stated in the problem cluster are known to Eshuis, but there may be other factors that are yet to be discovered that could be of major influence on the production waste. That is why this topic needs to be researched.

2. *What are existing methods that identify and analyse waste in production processes?*

Existing methods can help in identifying and analysing the types of waste that are produced in the overall production process at Eshuis.

3. *How do the factors causing waste affect total production waste?*

Measuring the impact of each factor contributing to production waste can help gain insight into the difference of the impact between factors. If a factor is a big contributor to the total production waste, solving for this factor can be more effective than solving for a small contributor of total production waste.

4. *Why do the factors causing waste affect total production waste?*

Understanding why the factors that cause total production waste affect the waste can help in creating the solutions. If a factor contributes to waste but its cause is unknown, it can be an area to focus on to solve for this factor.

1.3.3 Limitations

The limitations that come with this research are the following:

- **Only processing stages are in the scope of research.**
  The key areas of focus are the four stages that together form the production line of all the products for Company X. These four stages each correspond to one machine fulfilling a task in creating the shrink sleeve and based on observations, the production waste at these areas is high. Other areas in the factory, such as the packaging area and the warehouse will not be researched individually because of their low expected impact on total waste.

- **Irregular waste is not measured.**
  In the analysis of the current production process, I focus on a variety of waste streams that will help in achieving the goal of this research, which is reducing the waste in the production process. However, I do not focus on the waste that occurs through irregularity because incidental mistakes and problems will always arise during a production process. Focusing on the waste streams that occur regularly can also reduce the total production waste on a regular basis. Irregular waste streams are for example defects in the product resulting from machine failure or human error. Occasionally a machine experiences technical issues causing waste in terms of time and defected shrink sleeves. These issues will not be part of the research I am conducting because the occurrences of those issues are inconsistent making it difficult to observe the waste produced during that occurrence.

1.4 Research design

For each research question a data collection method and data analysis is specified:

1. *What factors determine waste in the Company X production line?*

In order to determine all the factors contributing to production waste an exploratory research can be designed to observe all causes of production waste. An observational research design can be conducted which should reveal every factor contributing to the regular total production waste and the frequency of how many times this factor occurs. Because the production line consist of four stages, all set in different places, one observation research should be dedicated to one stage. The observation should be at least two hours long and I only observe factors that are causing production waste. This means that I will use event sampling to observe every factor that causes meters of waste on the end roll. When something occurs and the operator indicates that an particular part of the work in progress is not going to be used, I write down the cause of the waste that has been indicated. After observing and writing down all causes in a period of two hours, a good overview can be created of all the factors by using a pareto diagram that visualizes what factors are contributing to the high production waste and what frequency corresponds to it. I can use this data as an input for my third research question where I will be focusing on how much waste each factor is contributing to the overall production waste.

2. *What are existing methods that identify and analyse waste in production processes?*

For this research question I need methods that are already tested and applied in a similar or relevant situation as the situation that Eshuis is in. This can give insight in possible approaches to analyse the waste at the production line. A systematic literature review is executed to help answer this question.

All the steps that are taken to execute this systematic literature review are written in the appendix of this project plan.

3. How do these factors affect production waste?

At the production line a lot of waste is produced and the factors that contribute to the production waste are known when the first research question is completed. With the output of the first research question, I can now execute a second observation research that focuses on the number of occurrences of the causes of production waste. I will measure the impact that each factor has on total production waste. Analysing and figuring out this impact, can lead to areas where the focus should be to reduce total production waste. By observing the production process for a two-hour period, a good approximation can be made about how many times a contributing factor to production waste occurs. This observation should be repeated at least one time to get valid data output. On the end roll that is produced at a production line, colour indicators are used to show what part of the end roll should be used for the machine and what part is waste. I can now relate the contributing factor of production waste to a certain amount of the end roll, thus measuring the impact a factor as on production waste. So, I will observe what factor causes the waste and how much waste is caused by this factor. After this is executed, an approximation can be made to generalise the measurements on a bigger scale. With this data I can identify the biggest waste streams in the production process and focus on the solutions to reduce it.

4. Why do these factors affect production waste?

This sub question can be answered by means of interviews and observational research. The interviews can be executed with the help of people that work alongside the production line dedicated to Company X. These operators know how to work with the machine and also know how the waste is produced. Their perspective on the factors that affect production waste can be valuable. The observational research can be held at the same time as the observational research that is conducted for sub question 1 and 3. However, this research should not become overloaded such that the observer does not have enough time to register all information. If this is the case, two observational research can be executed where one focuses on the relationship between the factors contributing to production waste (sub question 1 and 3) and one on the reason why these factors affect production waste. The data from the interviews and observational research can be used in determining what waste streams should be selected to focus on in order to reduce total production waste. It can yield waste streams that could be easily solvable. After the interviews and the observational research, a choice must be made to solve a waste stream based on the ease of the solution or on the amount of waste it can reduce.

After I have answered the research questions, I have relevant information about the current situation at Eshuis and I can try to focus on reducing the biggest waste stream or reducing a waste stream that yields a straightforward implementable solution.

1.5 Glossary

Before delving into the production process, I define the terms that are used throughout this thesis such that those terms are not misunderstood.

Term	Definition
Production roll	A roll of semi-finished shrink sleeves which is used as an input or output for production machines
End roll	A roll of shrink sleeves which is processed by all machines in the production process
Label	A semi-finished product in the production process that has not been sleeved yet
Shrink sleeve	A 360-degree printed label that can utilize heat in the application process to conform the label to the shape of a nutrition bottle
Roll-to-roll manufacturing	a manufacturing technique where a thin and flat, film-type two-dimensional structures are processed continuously on a flexible moving web that is conveyed at some fixed speed between two or more rotating rollers (Greener et al., 2018).
Substrate	The web made of thin, flexible, and long material that is guided through machines in roll-to-roll processing
Unwind guide	A device used at the entry of a roll-to-roll machine to appropriately fed substrate into the machine at the right location
Rewind guide	A device used at the exit of a roll-to-roll machine that chases the substrate so that the substrate is wound on the roll in the right position
Post-processing	All the production stages following after the offset printing stage

2 Description of the current production process

In this Chapter the current production process will be explained step by step and I elaborate on the techniques used to produce shrink sleeves. This information is necessary in order to understand the origins of production waste.

2.1 Production process

In Figure 6 the production process of shrink sleeves is visualised by means of a flowchart. The production process is divided into eight departments and follows the workflow from the moment an order is received until the product is delivered. The four stages in which processing occurs are highlighted with a blue background.

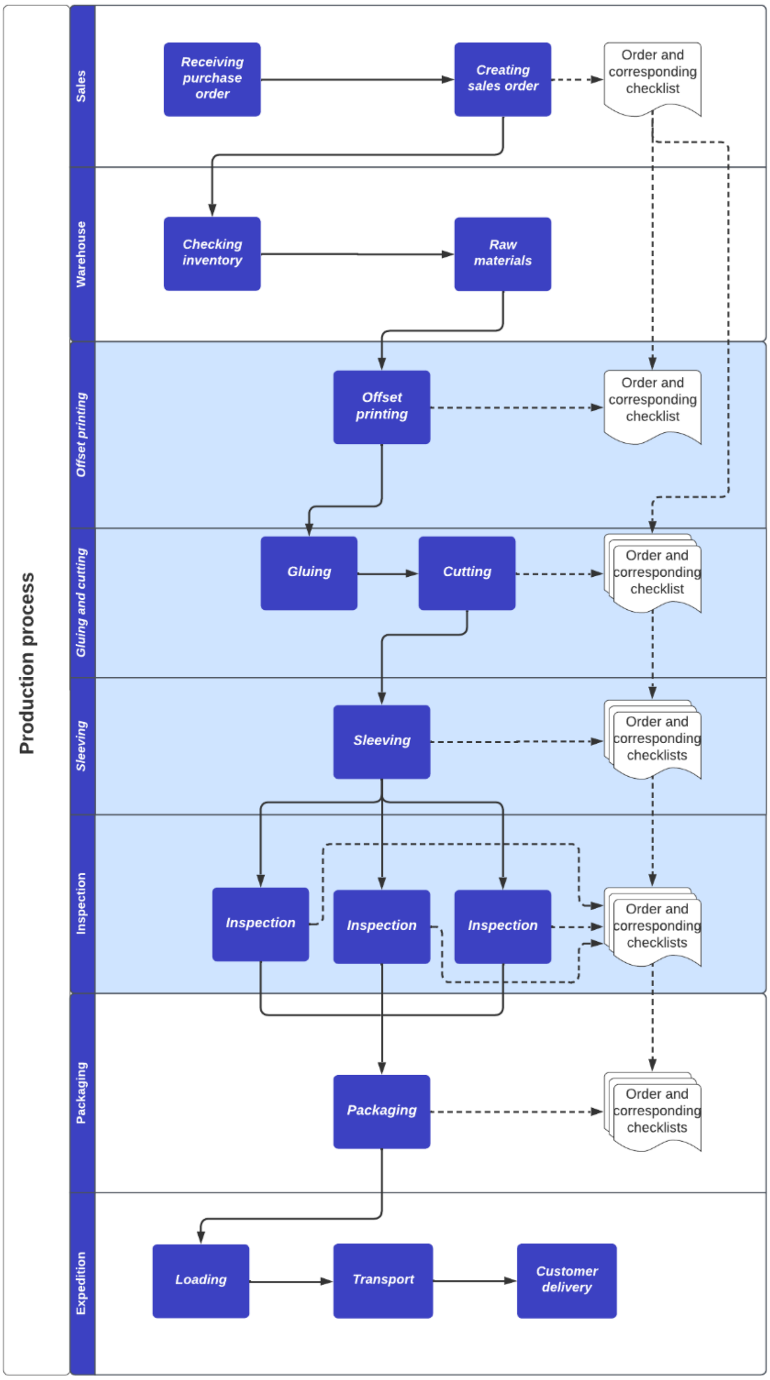

Figure 6. Flowchart of the production process of shrink sleeves

At each processing step in the production process a feature is added or a check is performed. The labels are stored and transported via production rolls which can be used as an input for a machine in the production process. The production rolls consist out of thousands of shrink sleeves. These shrink sleeves are referred to as labels before the process of sleeving and are referred to as sleeves when the process of sleeving is completed. When a production roll has been processed by the last machine, it will be defined as an end roll. This indicates that all the sleeves on that roll have completed the processing of every production machine within the production process.

2.1.1 Offset printing

In the first step of the production process, offset printing is used to print ink on plastic to create the design for the order. The machine used for this process is called the Nilpeter and is shown in Figure 7.

Figure 7. Offset printing machine

One or two operators will work at this station and are responsible for printing the design and producing an number of meters that fills the order. Because waste is produced throughout the production process, the operator generally produces more than Company X is demanding since a percentage of printed meters will be thrown away due to defects, set-up meters, and other types of waste on which I will elaborate in Chapter 4. The operator places a production roll that consists out of plastic substrate at the beginning of the machine as shown in Figure 8.

Figure 8: Plastic production roll attached to the unwind guide

The new substrate is attached to the substrate present in the machine from the last order. The new plastic can now be guided through the machine. This technique is used at every machine throughout the production process. It saves all the troubles of manually guiding material through the machine which takes a great amount of time when it needs to be repeated with every roll that is processed.

When the plastic material is set, offset printing can begin. In offset printing, an image is transferred from an offset plate to a rubber blanket cylinder. As the rubber blanket cylinder is making contact with the offset plate, it simultaneously makes contact with the plastic. The image is now transferred from the offset plate to the plastic through the use of this rubber blanket cylinder. In Figure 9 this technique is visualised using paper as a substrate.

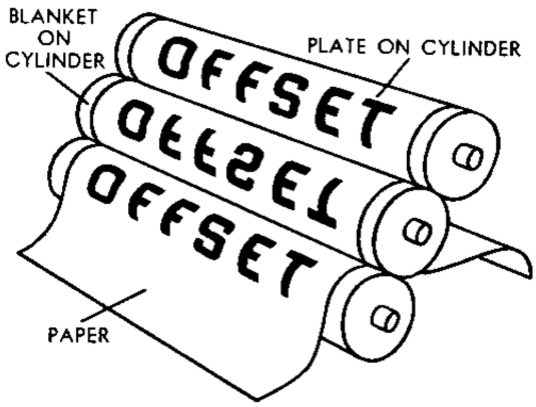

*Figure 9: Offset printing process illustration (*Sonal, n.d.)

This technique is used in combination with the CMYK colour model. The abbreviation CMYK refers to the four ink plates used: cyan, magenta, yellow, and key (black). These are the four ink colours which are used to create every colour necessary for the design of the orders. One printing plate is required for each printing ink colour, which means that there are a total of 4 printing plates, i.e., one for each of the four CMYK colours (Berghaeuser, 2016). The visualisation in Figure 10 shows the general process of offset printing.

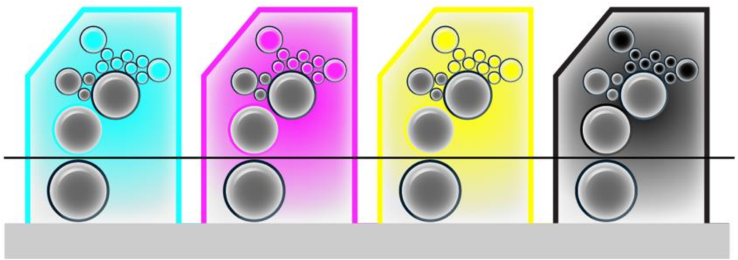

Figure 10: Offset printing press illustration (The Informed Illustrator, 2014)

The labels are 206.50 millimetres in length and 106.68 millimetres in width. The labels are printed in two files on the production roll. This creates a production roll on the rewind guide that in width is slightly wider than the length of two labels. This process uses the most plastic due to the difficulty in skill that the operator must possess to print the right colours.

2.1.2 Gluing and cutting

The second step in the production process is adding glue strips to labels and cutting the plastic roll into two single files. The input is one roll on which the design from the order is printed and the roll consists out of two files together. The output is two single file rolls with added glue strips. The machine which is used for this process is depicted in Figure 11.

Figure 11: Gluing and cutting machine

The path of the substrate processed by the gluing and cutting is visualised in Figure 12. This shows all the parts out of which the gluing and cutting machine consists of and the process from unwinding the output of offset printing until creating two single file production rolls.

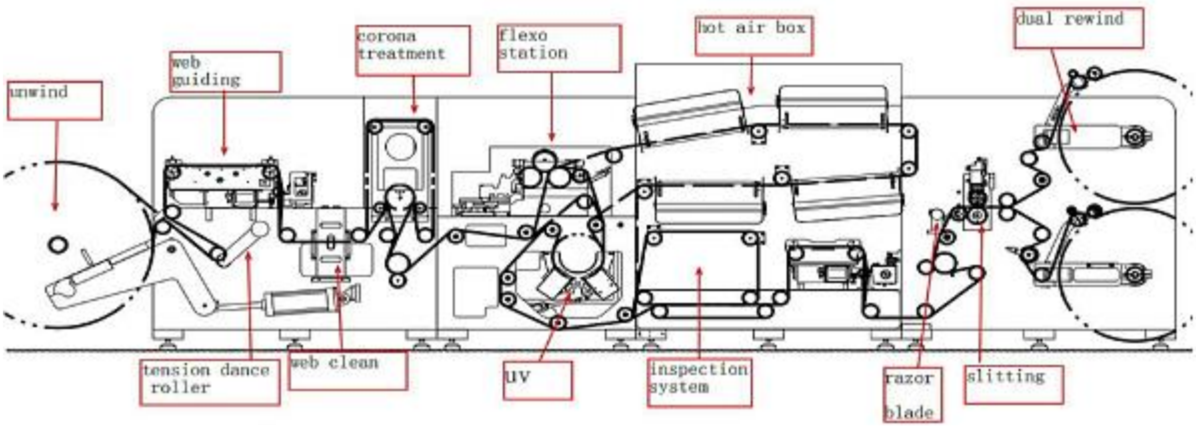

Figure 12: Path of the gluing and cutting machine from the unwinder until the dual rewinder.

When the operator attaches the production roll from offset printing to the unwind guide and the roll is guided through the machine, the process can be executed on full speed. The roll passes through a corona treater which is a device that modifies the surface of the roll with a high frequency electrical discharge at close range. This breaks up the long molecular chains in the surface of the film and oxidises it (Coombes, n.d.). The result of this is that the film of labels is better suited to adhere glue strips to its surface. The glue strips are now added to the surface of the film and after this it is key to dry the glue strips. After drying the glue strips, the double file substrate is cut into two single files. This results in two single file production rolls, shown in Figure 10 on the right side at the dual rewind guide of the gluing and cutting machine.

The number of meters of product that can be used as output are determined upfront. These quantities are set such that the consecutive machine in the production line can create quantities that are desired for the last stage in production process. Company X demands end rolls that each contain 16.000 shrink sleeves. These 16,000 shrink sleeves are equal to 1706,88 meters. That is why the length of production rolls created on the gluing and cutting machine have a minimum of 1780 meters in order to account for the possible production waste on the consecutive processing machines. The operators will in general create production rolls of 6880 meter. With this length, it is possible to create four production rolls of approximately 1715 meters each on the next machine out of one input production roll of the gluing and cutting machine. The maximum number of meters that can be produced is 8600 meters. Why this amount is relevant will be discussed in Section 2.1.3.

2.1.3 Sleeving

The third stage in producing the shrink sleeves is sleeving the labels such that the two edges of one file are attached to each other, creating a sleeve that could fit around a bottle. This process is handled by one or two operators, using the K5 COMPACT as visualized in Figure 13.

Figure 13: Shrink sleeve converting seam machine

carrier and attached to the unwind guide of the sleeving machine. When the machine is nearly finished with processing a production roll of the same order, a new production roll can be rotated in the machine without stopping the process of sleeving. When the nearly finished production roll is unwound almost completely, the operator presses a button which causes the machine to cut the substrate of the current production roll being processed and rotate the new production into the

machine while the current production roll will rotate out of the machine. The new substrate is attached to the old substrate through the use of gluing tape. This all occurs in one motion and causes the machine to process multiple production rolls without stopping the machine. The substrate is guided through the forming plates as depicted in Figure 14.

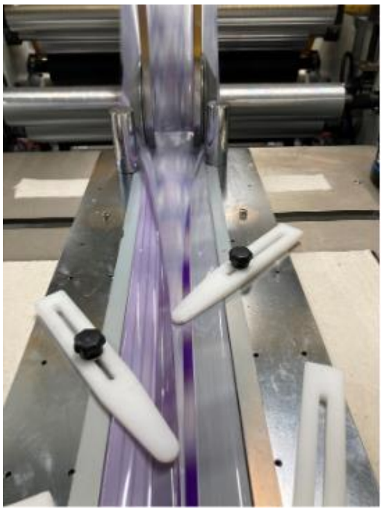
Figure 14. Forming plates

These forming plates are set by the operator before the processing speed is applied. The plates will fold the substrate into a sleeve and after this, a solvent is applied to the surface which ensures that a seam can be made, and the sleeve is created. This solvent is called tetrahydrofuran and is applied on the surface with a needle as shown in Figure 15.


Figure 15. Tetrahydrofuran being applied to the substrate

A sensor is placed on the machine after the sleeve is formed which registers if the tetrahydrofuran is present. When the sensor does not register any tetrahydrofuran, an acoustic sound will be played that indicates the absence of the solvent. The operator will check the situation and register defects in the production roll if there any. The machine also makes a sound when a weld is noticed by the machine. A weld can be present in the production roll when waste is cut out at the previous stage and the substrate on both ends of that waste needed to be attached to each other. If a weld is processed through the machine, it is important to check if the forming plates are still set in the right place since the material of the weld is stiffer than the normal plastic that is processed by the sleeve machine. The sleeving machine normally uses a speed of 300 meter per minute and its maximum speed is 500 meter per minute. So, when defects occur, the high speed of the sleeve machine causes more production waste in contrast to offset printing and the gluing and cutting machine.

The sleeving machine normally creates roll sizes of 1715 meters. When talking about roll sizes, I refer to the length of the substrate of shrink sleeves on that roll. The roll size of 1715 meters is determined based on the fact that Company X demands end rolls of 16,000 shrink sleeves. This amount of shrink sleeves is approximately 1707 meters in roll size. Therefore, Eshuis creates roll sizes of 1715 meters in the sleeving stage to account for 8 meters of waste during the process of the next stage to create an end roll of 1707 meters. Because the sleeving stage gets roll sizes of 6880 meters, it can create four production rolls of 1715 while accounting for some waste. However, the sleeving machine can also process roll sizes of 8600 meters, which means that five production rolls can be created out of one input production roll.

2.1.4 Inspection unwinding machine

At the last stage in the production process the production roll from the sleeve machine will be unwound completely in order to inspect every sleeve in the roll. The machine that performs this action is the inspection unwinding machine, depicted in Figure 16.

Figure 16. Inspection unwinding machine

The operator uses the output of the sleeve machine to unwind and inspect the sleeves. The operator places a production roll on the unwind guide of the inspection unwinding machine. The machine inspects the quality of the sleeves, and the operator cuts out defects which are indicated already at an earlier stage in the production process. As discussed in Section 2.1.3, Company X demands end rolls of 1707 meter long. Because Eshuis cannot always complete the end roll to a maximum of 1707 meters, Company X also accepts a limited amount of end rolls that deviate from the 1707 meters. Other than an end roll of 1707 meters, a half roll of 853.5 meters, and a rest roll of anything between 853.5 and 1707 meters is accepted.

When there are defects present in production roll, the operator cuts the defect labels out and welds the parts which are acceptable of the single file production roll together. When the inspection unwinding machine has unwound the whole production roll into a new roll, this new roll is considered an end roll and can be manually placed into a carton box which is sent to the last inspection stage where the specifications of the order will be noted on the box and where the quality and order amount will be checked.

This station has three inspection unwinding machines that could all perform the same job. However, the three inspection unwinding machines have some different properties regarding their process speed. The differences between the inspection unwinding machines are visualized in Table 3.

Table 3. Specifications of the inspection unwinding machines

Specifications	Inspection unwinding machines		
Unit	N39	N37	N16
Age	2 years	22 years	6 years
Automatic stop	YES	NO	YES
Max. process speed	250m/min	200m/min	200m/min

In Table 3 it is seen that the ages of the machines vary. The two newest machines stop automatically when the desired number of meters is wound on the Company X tube while the oldest machine has to be stopped manually by an operator. The maximum process speed with which the production rolls are unwound is another property that differs between the three inspection unwinding machines. Therefore, while the process of inspecting the production rolls is the same at every inspection unwinding machine, the choice on which machine to execute certain orders when not all three machines have to be used can make a significant difference in lead time and operating hours.

2.2 Risks of waste in the production process

At the first stage the printing is executed and the operator determines the number of meters needed to fill the order at 105% and the total waste produced at the post-processing stages. During the post-processing stages, the roll sizes become smaller and are processed such that the inspection stage ends with roll sizes of 1707 meters. The areas where the risk of avoidable waste is highest are therefore listed below:

- The first stage makes an educated guess to fill the order at 105% and account for the waste during the post-processing stages. However, the operator does not know how much waste is produced during the last three stages. This waste can be analysed and predicted.
- The roll sizes created at the gluing and cutting stage are generally 6880 meters. However, this can be increased to 8600 meters. This can result in producing five production rolls of approximately 1715 meters instead of four out of one input roll. This seems to be more efficient in terms of time and plastic waste. This is analysed further in Chapter 4.
- The inspection stage consists out of three different inspection unwinding machines. Because the machines have different properties, it is possible that one machine is more efficient in terms of waste relative to another.

3 Literature

This chapter introduces the theory of lean manufacturing. Initially, in Section 3.1, I define lean manufacturing. In addition, in Section 3.2, five lean principles are presented. This will get the reader familiarized with the theory that is used to identify the production waste within the production line. In Section 3.3 I focus on the seven waste types that exist according to lean theory. In Section 3.4 I present tools that will help in identifying, measuring, and reducing waste in a production process.

3.1 Lean manufacturing

Lean manufacturing can be defined in a variety of ways. According to Shah & Ward (2003), lean manufacturing is a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, and supplier management in an integrated system. The core idea of lean is that all these practices can work together to create a streamlined, high-quality system that produces finished products at the pace of customer demand with little or no waste. Next to the lean practices that can be implemented in a manufacturing process, lean manufacturing also includes descriptions of values and philosophies such as avoiding seven cardinal wastes and respecting customer, employees and suppliers (Schonberger, 1986). These descriptions are more difficult to measure than lean practices such as total quality management (TQM) or just-in time (JIT), since these descriptions are often a broad concept that do not have specific dimensions such that it can be measured specifically. These descriptions and philosophies are also part of lean manufacturing and can have a significant impact on organisations.

Therefore, in lean theory there are a great number of practices that help in producing according to a more efficient way. However, not every practice in lean manufacturing is suitable for any production process. It should be carefully analysed what the process needs, and which lean practice could be used to fulfil that need. Furthermore, implementation of the practices requires changes in work approaches and can be very challenging for older organizations. The longer an organization has experience with the practices, even if the results are inferior relative to the new practices, the harder it is for the organization to replace the older, inferior practices (Pil and MacDuffle, 1996). When the lean ideas can be implemented successfully, the effect can be immense. Until this day, lean ideas are the single most powerful tool available for creating value and eliminating waste in any organization (Womack & Jones, 1996).

3.2 Lean principles

According to Womack & Jones (1996) the lean theory includes five principles. Descriptions of these principles are stated below.

1. Specify value

Understanding what value is, is crucial in applying lean manufacturing. The definition of value in this case is: everything that the customer is paying for. Processes such as quality assurance do not generate direct value for the end customer. However, these processes are necessary to ensure that the development process's value does not get lost. Therefore, the company should focus on all the activities that add a direct value to the end customer.

2. Identify the value stream

When the value is specified, the stream of all actions needed to bring a product to the customer should be identified. When these streams are known, unnecessary and slow value streams can become visible in the process. Such a stream could flow from a stage in the process that meets or exceeds the capacity. These stages are called bottlenecks and can be identified with the help of value streams. Knowing where the biggest bottlenecks in a process exist could help an organization in creating the right solutions to achieve a more efficient process.

3. Create flow

Now that the bottlenecks are identified in the process, the focus should shift to alleviate these bottlenecks to create a smooth flow. Flow of value ensures a smooth process from the moment that an order is received until the delivery to the end customer.

4. Establish pull

In order to reduce overproduction and only produce the amount that is demanded by the customer, a pull system must be established. The idea of this system is that you only create products when there is a demand for it. Producing based on forecasting is not always reliable and can increase the cost of carrying inventory and increase the risk of producing products which are not needed by the customer.

5. Pursue perfection

Constant improvement should be the goal of the entire organization. This entails generating the most value for your customer while reducing as many activities as possible.

3.3 Seven types of waste

Seven types of waste are found in any process, according to Womack and Jones (1996). This also applies to production process at Eshuis. These types of waste are defined as follows:

1. **Transportation**
   This type of waste is created due to unnecessary transport of parts under production. The waste can occur due to long distances between consecutive stages in production process or due to lay-out issues that causes unnecessary transportation of parts.

2. **Inventory**
   The waste that is associated with unprocessed inventory fall into the category of inventory waste. Excess inventory means an inefficient production process because of the waste capital tied up in excess stock, the space in the facility that it uses, and the wasted transported moving the inventory.

3. **Motion**
   Any movement by people that does not contribute to the production process is a waste of motion. This waste occurs for example when tools are inefficiently sorted at a workstation, and it causes an operator to waste unnecessary energy and time.

4. **Waiting**
   This type of waste occurs when either staff or machinery must wait to complete a task. This can happen in production processes where one machine is slower than the consecutive machine in the process, resulting in waiting times. The waiting times causes unproductivity for employees and machinery.

5. **Overprocessing**
   Any work that does not add value for the end customer is waste due to overprocessing. It delivers more value than necessary and causes inefficiency in using the materials to create the end product.
6. **Overproduction**
   The waste of overproduction is the most obvious form of manufacturing waste. All the processes needed to create the products which are not being sold are considered to be a waste. It leads to the depletion of raw materials and also results in serious environmental issues if the company needs to dispose of the products.

7. **Defects**
   When a product is not meeting the demanded specifications of the customer, the product is considered to be defect. The defected products need to be disposed of and cause huge amount of waste in terms of time and money. Furthermore, if a defect is not noticed during the production process, it can cause damage to the reputation of the company, resulting in loss of customers.

3.4 Integration of the theory

Now that the general principles of lean manufacturing are identified, I can start on identifying the waste in the production process. This can be done by methods that exist in the theory of lean manufacturing. The methods resulting from the systematic literature research are listed and explained in the following sections.

3.4.1 5 Why's method

The 5 Why's method is a tool in root cause analysis. When a problem occurs, you drill down to its root cause by asking "Why?" five times. The primary goal of this tool is to find the exact reason that causes a given problem. Despite the number 5 in the method's name, the process can be repeated as many or as few times as is necessary to determine the root cause (Chen and Shady, 2010). This could be a helpful method in waste management identifying the root of the waste problem.

3.4.2 Industrial Solid Waste

The management methodology of Industrial Solid Waste (ISW) is structured into four stages. The first stage focuses on the characteristics of the waste and the environment where it is created. It uses these characteristics to define a set of indicators in the second stage of this methodology. The main idea here is to efficiently meet the relevant waste categories with a manageable number of concise indicators. After selecting the indicators, possible solutions will be analysed in order to find out which treatment fits best to the type of waste that should be reduced. The last stage focuses on choosing the best treatment by looking at the set of indicators for each possible solution. To summarize, the four steps below create this methodology.

1. Waste and environment characterisation

2. Indicators selection

3. Treatment processes identification

4. Treatment solution selection

3.5 Integration into Eshuis

These two methods can be considered in the case of the production line that is assigned to Company X. The 5 Why's method can be used for identifying a possible solution of one of the factors that contribute to the total production waste. Questioning why it is that a certain action results in waste can narrow the problem down to a scale which can be solvable. This means that the 5 Why's method should first be applied to all the factors that contribute to the waste. After this is completed, the problem that is the most effective to solve can be the centre of focus. The second method, ISW, is a general method that identifies waste and uses indicators to identify each type of waste. The type of wastes is important in the case of Eshuis since there are a lot of different factors involved in the production waste.

3.6 Conclusion of the theory

In conclusion, these methods can be considered to apply to my research in order to identify, analyse and visualize all the types of waste that are present in the production line of Company X. The 5 Why's method is helpful in finding the root cause and focusing on the right problem within a problem cluster. Identifying the root cause is the most important part in the beginning of the research since understanding what the problem exactly is will ultimately result in solutions that are going to be effective.

The Industrial Solid Waste method helps in finding indicators to the relevant waste types in the production process. This should be used in the stage of the research where I propose solutions to find the best kind of solution to a particular waste type.

4 Analysing the current situation

In this chapter I analyse the current situation in terms of the waste that is produced in each stage of the production process. First, in Section 4.1 I elaborate on how the data that is used in the analysis is valid and reliable. Second, in Section 4.2 I describe the limitations of my research and explain the reasons of those limitations. Third, in Section 4.3 I analyse the waste produced at each stage in the production process. Finally, in Section 4.4, I focus on the types of wastes individually. This shapes an overview of how the current production process produces waste and what type of waste could be reduced or removed.

4.1 Data collection

The data that is used to analyse the current situation in terms of waste is mostly gathered through observations. Eshuis makes use of an ERP system in which all data of the machines are stored regarding the orders processed on the different machines. Although this provides a great amount of data, the data regarding the number of meters that is produced on a machine is unreliable and invalid. From the data gathered through the ERP system, the numbers often do not add up to the numbers produced and delivered. There are two primary reasons for this phenomenon. Firstly, the ERP system is dependent on the operator's ability to provide immediate feedback to the system. However, due to factors such as workload constraints and human error, the operator may not consistently deliver the required immediate feedback. Secondly, the ERP system possesses its own counting mechanism that may not always be deemed reliable. The machine's own counting mechanism is much more reliable and therefore more widely used to determine production values. This why current data regarding waste is not gathered through the ERP system, but only through observations.

Observation is the action of monitoring and measuring the amount of waste produced in meters. The waste is produced in the form of a string of labels. After the waste is produced, it is gathered and measured by hand. Since the width and length of a label are constant, I only need to count the number of labels or sleeves present on the string of waste to calculate the number of meters on that string. For a normal type of sleeve, the dimensions are equal to 206.50 millimetres in length and 106.68 millimetres in width. If n = number of sleeves, then the number of meters on string can be calculated by:

$$0.10668 * n$$

Since Eshuis also produces another type of sleeve with a different dimension in width, I can generalise this formula into:

$$w * n = amount\ of\ sleeves\ in\ meters$$

, with w = width of the type of label and n = number of sleeves.

4.2 Analysis of the waste produced at each stage in the production process

In this section I analyse the regular waste that is produced in the production process. In the first stage the labels are printed. The stages two, three and four represent the post-processing stages in which the labels receive an adhesive layer, are getting cut into the right size, transform into sleeves, and receive a final quality check. Although the first stage produces a large amount of waste relative to the post-processing stages, this stage is not analysed since the machine is being replaced in the near future. The replacement is a HP Indigo V12 Digital Press, which is expected to reduce 90% of the waste created at the current offset printing machine. Focusing on the current offset printing machine in terms of waste is therefore unnecessary since most of the drawbacks in this stage will be removed in a noticeably short time.

In multiple stages the same type of waste can occur. The sample waste and machine waste are examples of this. I discuss those waste types in the earliest stage in which the waste occurs and then refer this discussion if the same waste type also appears in another stage.

Furthermore the analysis is partly carried out with an iterative program made in Visual Basic for Applications (VBA). In this program the production process is simulated in terms of the amount of meters which are processed, the roll sizes that are used, and the waste that is produced. In the dashboard, a user can fill in variables related to the order in terms of quantity, type of sleeve, desired number of sleeves on an end roll and more. In Appendix B, a user guide is presented to show how the dashboard works according to the current production process. For the analysis, this dashboard is used to simulate the total regular production waste over a multiple of order quantities to find out what areas in the production process contribute the most to the total production waste.

Because some quantities are more frequently ordered at Eshuis by Company X than others, I first looked at the range of order quantities that are produced and their frequency over the past 12 months. In Figure 17 a column diagram shows this range of order quantities against the frequency of production at Eshuis.

Figure 17. Frequency of order quantities over the past 12 months

In Figure 17, one can see that order quantities below 200,000 shrink sleeves are more in demand that order quantities above this number. Now we can add the total production waste at each order quantity together with the frequency resulting in a diagram that shows per order quantity the contribution to total production waste over a year. This diagram is shown in Figure 18.

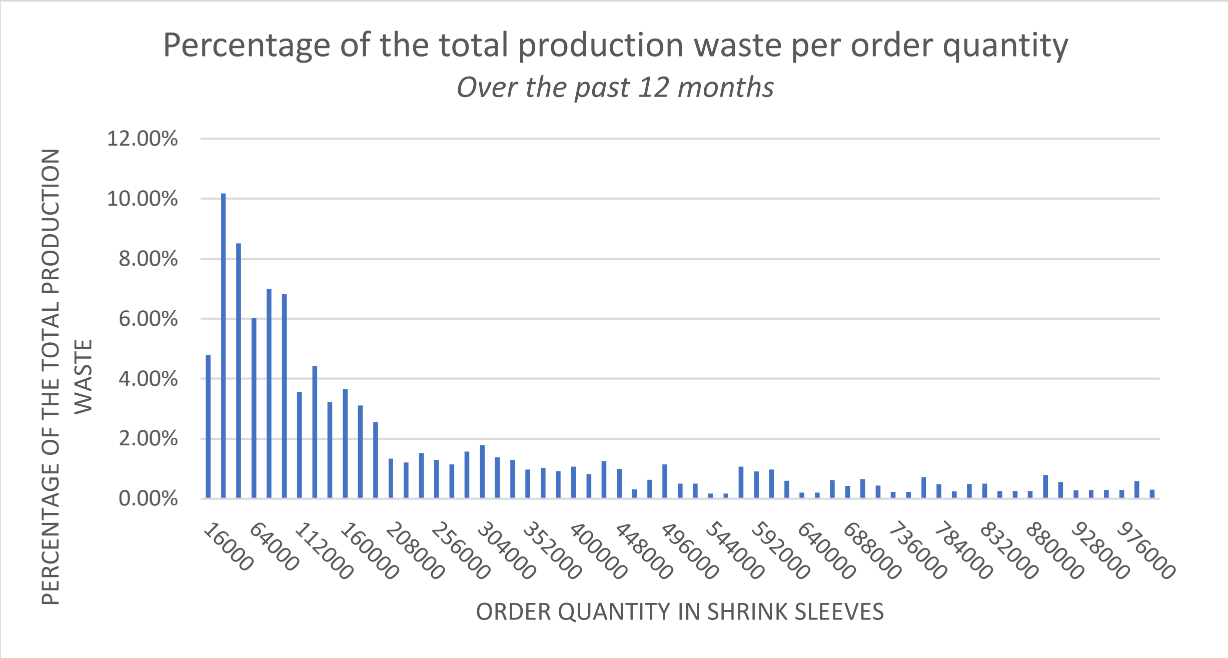

Figure 18. Percentage of the total production waste per order quantity over the past 12 months

This diagram shows the weight that can be attached to each order quantity when simulating over all the different order quantities resulting in a weighted average that improves the data's accuracy.

4.2.1 Gluing and cutting waste

Transport waste

The waste that occurs right before the process of gluing and cutting is the transport waste, which is logically derived from the fact that a production roll needs to cover approximately 80 meters until it arrives at the area where the input of the gluing and cutting machine is set. The roll is transported using a pallet carrier from one area to another, but the surface of the production roll also has contact with the ground while the production roll is stored on a wooden or metal construction that keeps the production roll in place. This waste is avoidable waste since it could be prevented by using other types of material for the storage of production rolls such that it would not cause the friction that results in scratches on the surface of the production roll.

Sample waste

The operator cuts 10 labels from the output production roll and secures those labels. These labels represent the output of the order at this stage in the process and are archived at Eshuis. At every stage in the production process several samples are cut from the production roll. When the corresponding order is delivered and a complaint is filed by the customer because of defects in the product, Eshuis can retrieve the samples and deduce where in the production process the mistake was made. This can help in learning from the mistake and solving the issue quickly. This type of waste is called the sample waste because the operator takes a small quantity of the production roll to show what the whole is like. The sample waste is avoidable since it is not a requirement of the customer that samples must be preserved. But the samples are particularly useful when a complaint is filed because of defects in the product and the origin of the defect is unknown. The sample can now be used as an indicator that shows where in the process the product should be acceptable and where it likely went wrong. Because Eshuis does get complaints from time to time, the sample waste serves a functional role in customer service and is worth the waste.

At this stage 10 samples are cut from the production roll and secured in an order bag.

Unwinding waste

After the sample waste is taken, the operator takes a winding from the output production roll, cuts the winding off and marks the production roll as complete. The unwinding from the completed output production roll is waste and is usually done because the machine runs on a low process speed while stopping, creating labels that do not have the adhesive glue layers applied to them properly. The waste is therefore unavoidable.

Machine waste

This waste is left behind in the machine such that the next production roll can be attached to it to pull the new substrate through the machine, removing the step of guiding the substrate manually through the machine. This type of waste is necessary because of the complexity of the machine. Machine waste is a recurring waste and is also discussed in the other stages. Each stage has a different type of machine; therefore, it is worth looking into the machine waste per machine and finding out if the machine waste is worth reducing the time that it takes to guide the substrate through by hand. In this case, the machine is too big and complex to guide the substrate through by hand every order. Therefore, the operator leaves some of the old substrate in the machine, attaches it to the new substrate, and guides the new substrate through by turning on the machine.

The machine waste at the gluing and cutting stage is equal to 25 meters per order. This waste is deemed unavoidable.

Analysis

Overall, the weighted average waste created at the gluing and cutting machine is relatively low compared to the other stages. The sample waste is insignificant in terms of contributing to the total waste and can help quickly to uncover mistakes and problems in the production process. The only avoidable waste is the transport waste. This waste is created due to insufficient care of the production rolls destined for the gluing and cutting machine and could be reduced in this stage. To summarize the waste distribution at this stage, a pie chart is created in Figure 19 to show the weighted average waste distribution over all the occurring order quantities for Company X.

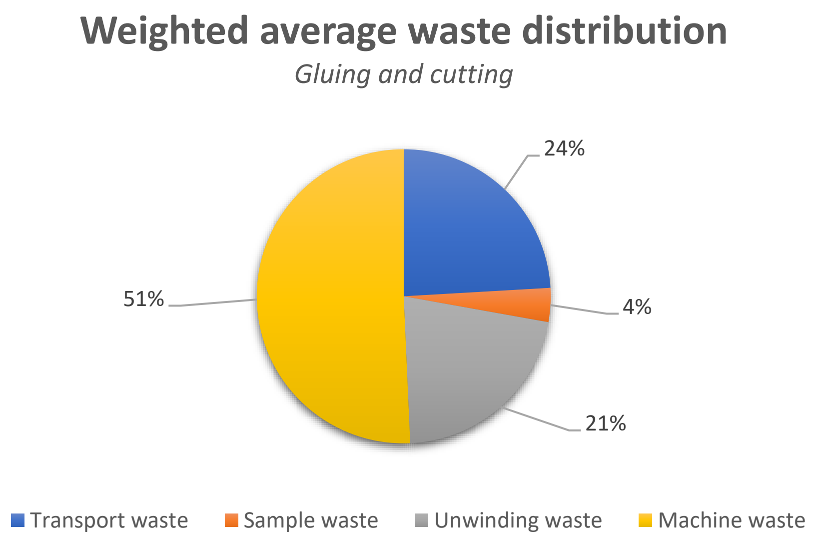

Figure 19. Weighted average waste distribution at the gluing and cutting stage

The contribution of the gluing and cutting stage to the total regular waste production is on average 13.90% which makes it the least important stage to focus on in terms of waste reduction.

4.2.2 Sleeving waste

The sleeving machine uses the single file production rolls to fold the labels, add a solvent and make a seam such that the shrink sleeve is complete. The waste is measured in single file labels and sleeves in meters. Labels are the product going into the machine and sleeves are the product coming out of the machine. The two kinds of substrate are equal when talking about production waste.

Leftover waste

One factor that contributes to the total production waste is the number of meters that are left on the production roll that is used as an input for the sleeving machine. Because the machine processes at a fast rate and can process multiple production rolls in parallel, the operator needs to push a button when the current roll almost has no meters left to process. This results in a switch between the new roll and the current roll by cutting the substrate of the current roll and rotating the new roll in. Simultaneously the new substrate is attached to the old substrate. The timing of the switch will determine the number of meters that are still on the production roll that is almost completely processed. This amount left on the roll is not sleeved and will be thrown away. The sleeving machine can process one order continuously and cutting the current substrate such that the new substrate can be processed is an integral part of this continuous process. This is why the leftover waste is unavoidable at the sleeving machine that is used in this process.

Unwinding waste

The waste that results from removing a couple of windings at the end of the sleeving process is removed because of attachment of the old substrate to the new substrate. This attachment is made with tape and causes the machine to process continuously. However, attachment is not sleeved correctly in the machine and thus should be removed from the process. This attachment happens once per new input roll in the machine and is removed at every last created production roll of that input roll. This type of waste is unavoidable since the machine is only able to produce a good seam when the speed is high and consistent. This is caused by the oscillation of the machine, needed to create strong production rolls. If the machine stops and an operator attaches the new substrate to the old substrate by hand, the seam created during the acceleration of the machine would be weak because the oscillation creates deviating seams. This results in defects in the shrink sleeves and thus more waste.

Sample waste

Another type of waste is the sample waste which for the sleeving machine is equivalent to 5 shrink sleeves or 0.5334 meters per production roll. This waste is unavoidable as discussed in Section 4.2.1. Eshuis also delivers samples with the order for Company X such that Company X can determine upfront if the order is suitable for their production process. These samples are equivalent to 25 shrink sleeves and are taken from the first output production roll that is created. Because these samples are taken from an output production roll without compensating for it, these samples are not considered waste.

Analysis

In analysing the waste created at different order sizes for the sleeving machine, I executed an observation research and investigated recent checklists to figure out what the input and output at the sleeving machine was. This displays Figure 19, in which the waste per 1000 meters can be seen over different order sizes. The waste is displayed per 1000 meters of input quantity because if I use the total input quantity as variable, the graph displays that the total waste increase when the input quantity increases. This is not hard to understand since most total waste produced at the sleeving machine depends on the number of input production rolls and output production rolls processed and created. Displaying the total waste based on the same number of meters for all input quantities reveals the different rates for the input quantities at which the total waste increases.

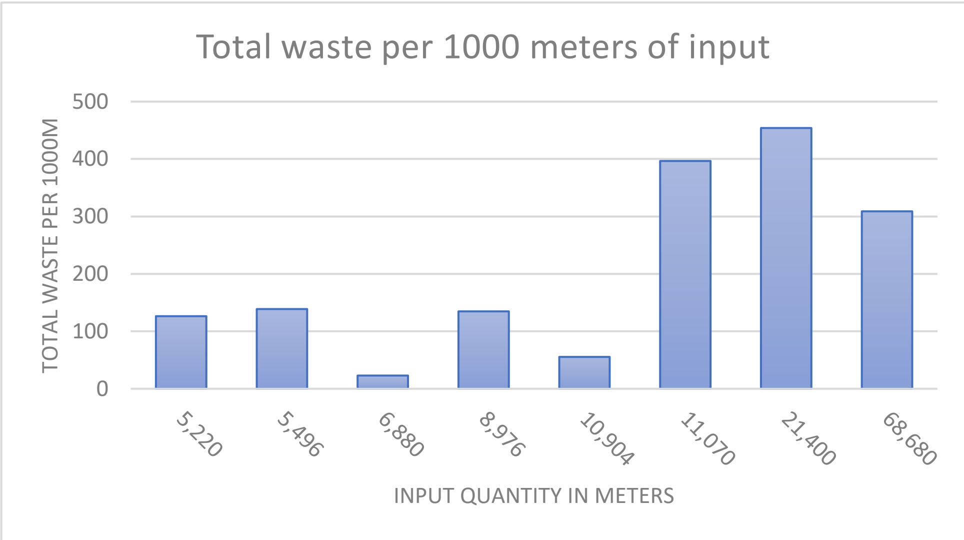

Figure 20. Total waste per input quantity at the sleeving stage

Looking at Figure 20, the increase in rate of waste at around 11.000 meters stands out and shows that the waste is stable when one production roll is processed into four rolls, but when a new production roll is used for the same order, the waste increases immediately. A reason for this change in waste is the extra waste that is created when a new input roll is used for an order. This increases the leftover waste and the unwinding waste. When analysing the number and sizes of the output production rolls created, I can base the sudden increase in waste per 1000 meters on the fact that a bigger order size requires more input rolls, resulting in more waste. Hence, the rate of waste at the sleeving machine increases dramatically when the order size increases. The weighted average waste distribution of the waste types present at the sleeving stage is given in Figure 21.

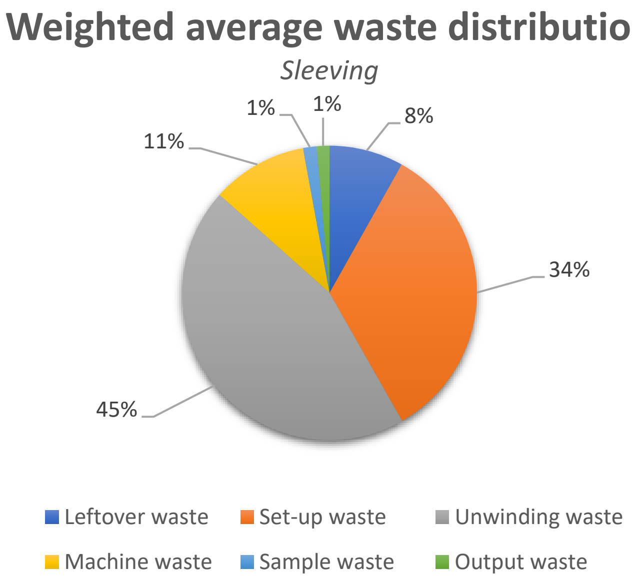

Figure 21. Weighted average waste distribution at the sleeving stage

The contribution of the sleeving stage to total production waste is on average 42.20%, making it the stage that contributes the most to the total production waste in the post-processing stages.

4.2.3 Inspection waste

At the last stage in the production process, the production rolls are unwound and winded again to check the production roll on any quality issues and to replace welds made during the gluing and cutting process for welds which are suited for Company X's production process.

Overproduction

Company X uses a quantity tolerance on delivered goods of 5%. This means that Eshuis is allowed to produce 5% less or 5% more than the ordered amount of shrink sleeves. Eshuis always intends to deliver 105% of the order, maximizing their revenue. To deliver 105% of the ordered goods, an amount of meters should be printed at the offset printing stage to account for the ordered amount by Company X, a 5% quantity increase, and the waste that is produced during the production process. At the first step in production, where offset printing is performed, an amount between the 105% and 108% is produced to account for the waste in the following production steps and still target the 105% order completion. The operator at the offset printing machine decides what amount will be printed and usually will print the percentages presented in Table 4 depending on the quantity of the order.

Table 4. Percentage of the order printed relative to the order quantity by the operator

Order quantity in labels	Percentage of the order size printed
≤ 100,000	108%
> 100,000 and ≤ 200,000	107%
> 200,000 and ≤ 300,000	106%
> 300,000	105.5%

In Table 4, the percentage of the order size printed decrease as the order quantity increase. The reason for this is that for the smaller order quantities it is expected that the total waste consists more out of the waste that is independent on the number of production rolls produced. Set-up waste and the machine waste at the gluing and cutting stage and sleeving stage are such types of waste that are big contributors of total waste at smaller order sizes and small contributors at large order sizes. Because the numbers in Table 4 are not strict guidelines that operators follow according to a work instruction, it can occur that operators deviate slightly from these figures. The result of this is that the amount shrink sleeves produced at the end of the production line can be more than the 105% that is tolerated by Company X. The excess amount cannot be sold and thus contributes to the total production waste. Although this waste is noticeable at the inspection stage, its origin lies at the offset printing stage.

Sample waste

The last samples are taken from the production roll at this stage. This sample waste includes 10 samples from each end roll destined for the order bag. The waste is a recurring waste at every stage in the production process as discussed in Section 4.2.1.

Unwinding waste

After cutting out samples from the end roll, the operator cuts out a couple of windings from the end roll to make sure the end roll only consists out of high-quality shrink sleeves. These windings from the end roll can contain weaker seams because previous problems in oscillation at the sleeving machine. Now, these problems are resolved but the same unwinding waste is still produced at the inspection stage due to standardized work methods. This waste has an average of 5.65 meters per end roll, making it one of the biggest contributors at the inspection stage. This waste is unavoidable waste but can be reduced since 5.65 meters per end roll is more waste than necessary.

Machine waste

When the end roll is created, there are still shrink sleeves left in the inspection unwinding machine. The waste can lie between 22 and 35 shrink sleeves, depending on the inspection unwinding machine that is used. As discussed in Section 4.2.1, this waste is avoidable but at some stages it is worth it since it consumes too much time for the operator to guide the substrate through the machine manually. At the inspection unwinding machine is not difficult for the N37 and N16 and takes about 15 seconds. For the N39, the machine waste is more useful since this machine is more complex.

Counting waste

The waste created due to poor counting of the meters on a production roll causes the end rolls to be smaller or bigger in size. This waste is avoidable and the biggest contributor in the terms of waste at the inspection unwinding machines. This waste is caused by machine inaccuracy and is analysed deeper in the following section.

Analysis

In analysing the counting waste at this stage, the differences in the three inspection unwinding machines that are used are significant. The N39, which is the newest and processes the production rolls at a rate of 250 meters per min, will consistently have a high number of meters left on the production roll of 1707 meters that is unwound. However, production rolls of the exact same length will have less or no waste when processed on the N37 or N16. This observation led to the conclusion that the machine counters of each inspection unwinding machine were not calibrated and that a production roll processed on one inspection unwinding machine would not result in the same production waste as processing the same roll on the other. I therefore processed a test roll on one inspection machine and afterwards count by hand how many shrink sleeves are present on that test roll. This test roll was already processed on the sleeving machine. The sleeving machine indicated that the test roll was 1441.55 meters long. The same test roll was processed on the N39 inspection unwinding machine which indicated that the total length was 1452 meters. After counting the test roll manually, the number of meters turned out to be 1442 meters long. This confirmed that the sleeving machine is highly accurate and that the counter on the N39 inspection unwinding machine deviates from the actual number of meters. Through observations I analysed the differences between the three inspection unwinding machines and came to the ratios defined in Table 5 that indicate the amount of meters displayed when an actual amount of 1 meter is processed.

Table 5. Overview of the ratios of actual meters to displayed meters for each inspection unwinding machine

Machine	Ratio of actual meters to displayed meters
Inspection unwinding N39	1.006935
Inspection unwinding N37	0.988869
Inspection unwinding N16	0.995313

Margins between the +0.7% and -1.2% of the actual number of meters do not seem that significant, but when end rolls of 1707 meters are produced those margins can be equivalent to anywhere between 112 and 187 shrink sleeves. Therefore, these counters can result in significant unnecessary production waste or delivery levels inferior to the ones promised to Company X

I analysed all the inspection unwinding machines and determined that the sleeving machine was highly accurate in terms of counting the amount of meters present on a output production roll, while the inspection unwinding machines deviate from the actual number of meters. I analyse the waste resulting from this inaccuracy with the understanding that 1 meter displayed on the sleeving machine is equal to 1 meter. In order to understand how this results in waste, Table 6 gives an overview of the waste created when three production rolls of 1715 meters are processed on the N39, the N37, and the N16 inspection unwinding machines. I use 1715 meters since this is the regular amount that is produced on the sleeving machine.

Table 6. Amount of waste created per inspection unwinding machine in meters

Machine	Counting waste	Sample waste	Unwinding waste	Machine waste
N39	16.74876	1.17348	No unwinding waste	3.43
N37	No counting waste	1.17348	5.65	2.45
N16	No counting waste	1.17.48	5.65	2.34

This example shows that the waste created at the three inspection winding machines causes the end roll to be less than 1707 meters. However, the end rolls are marked and sold as 1707 meters.

Since the N37 and N16 do not count until the desired 1707 meters, there is no counting waste present. Furthermore, the unwinding waste does not occur at the N39 since it already throws out the waste created due to counting waste. Because these are the last shrink sleeves on the roll and the unwinding waste is thrown out because these are the last meters, there is no unwinding waste anymore since it replaced by the counting waste. To summarize and visualize the fraction each waste represents of the total waste at every inspection unwinding machine, the pie charts in Figure 22, Figure 23 and Figure 24 give the weighted average waste distributions.

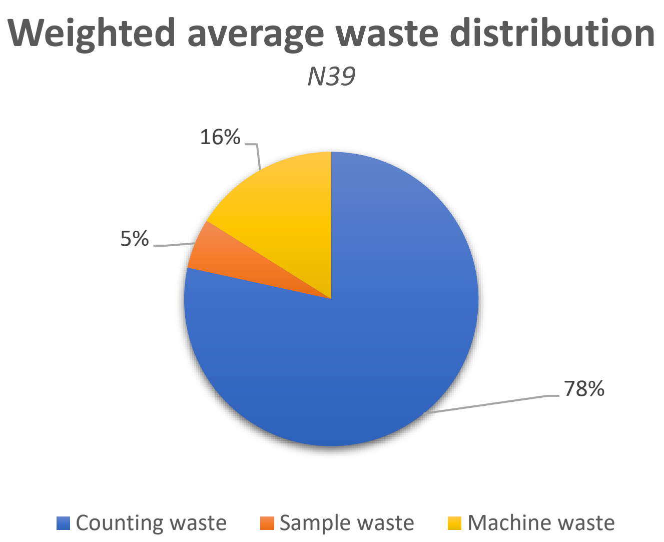

Figure 22. Average waste distribution at the N39

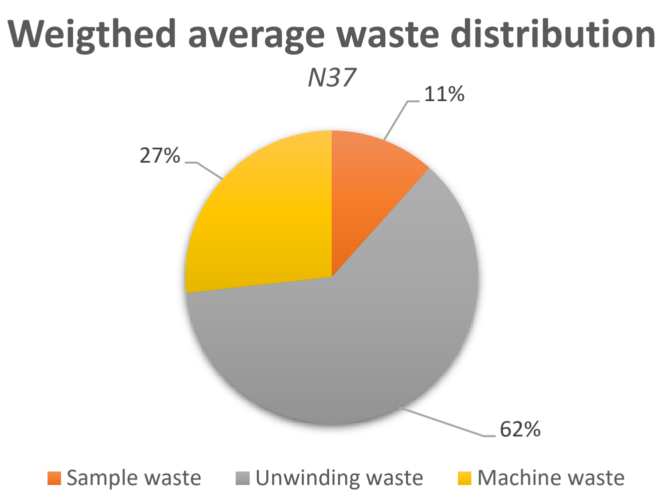

Figure 23. Average waste distribution at the N37

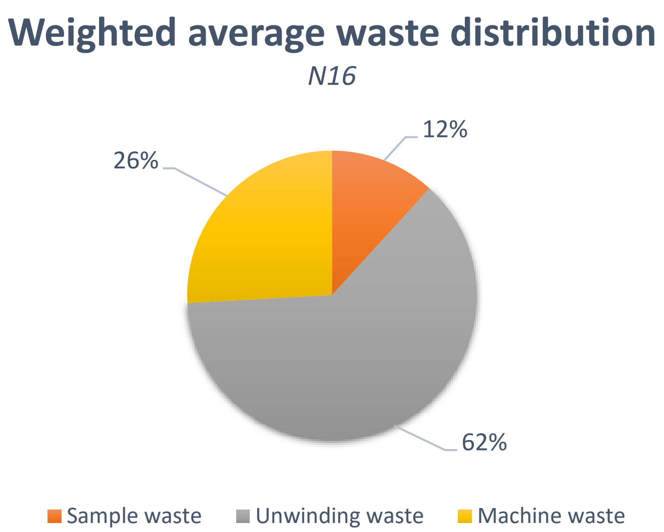

Figure 24. Average waste distribution at the N16

The amount of total waste per inspection winding machine is a key difference between the pie charts. While the total waste on the N39 is 24.49 meters per end roll, the total waste at the N37 and N16 is 9.18 and 9.07 respectively. This key difference shows that while the unwinding waste at the N37 and N16 are big contributors to total waste, the biggest contributor is the counting waste at the N39.

4.3 Conclusion of the waste produced at each stage

Now that I uncovered all types of waste that are produced during the production process in the four stages, I can categorize the types in either the avoidable or unavoidable waste category. These categories show which type of waste could be removed or reduced, and which type of waste is still necessary for the production process. It does not mean, however, that a type of waste that is avoidable is worth removing from the production process. In Table 7 a brief overview of the types of waste at each machine and their corresponding category and average quantity are displayed.

Table 7. Overview of the types of waste at each stage in the production process

Stage	Type of waste	Category	Average amount in meters
Gluing and cutting	Transport waste	Avoidable	7.88 per input roll
	Unwinding waste	Avoidable	2.24 per roll
	Sample waste	Avoidable	0.85 per roll
	Machine waste	Avoidable	23.23 per order
Sleeving	Leftover waste	Unavoidable	3.64 per input roll
	Set-up waste	Unavoidable	65.00 per order
	Unwinding waste	Unavoidable	20.02 per roll
	Sample waste	Unavoidable	0.53 per roll
	Machine waste	Unavoidable	15.68 per order
Inspection	Counting waste	Avoidable	16.75 per roll
	Unwinding waste	Unavoidable	5.65 per roll
	Sample waste	Avoidable	1.17 per roll
	Machine waste	Avoidable	2.74 per roll

Next to this, the pie chart in Figure 25 shows us the distribution of waste throughout the post-processing stages.

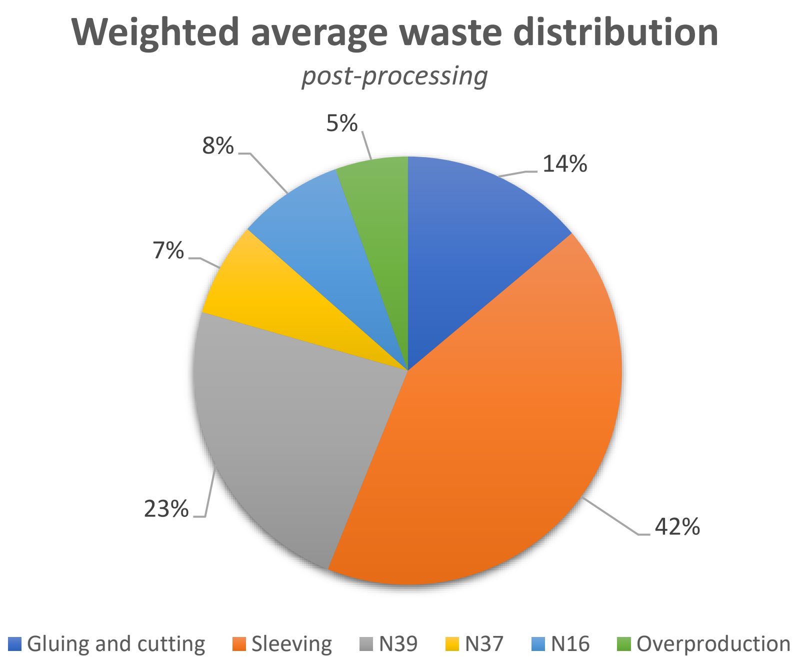

Figure 25. Average waste distribution over the post-processing stages

The following conclusions are made based on the analysis in Chapter 4:

- The gluing and cutting stage only contribute 14% to the total waste distribution in the post-processing stages. The transport waste at this stage should be removed. The other types of waste such as sample waste, unwinding waste, and machine waste are necessary for the production process.

- The sleeving stage causes 42% of the total waste in the post-processing stages. All types of waste in this stage are unavoidable. This stage should not be an area of focus to reduce waste.

- The inspection stage contributes 38% of the total waste produced in the post-processing stages. The N39 creates the most waste in this stage, mostly because of the counting waste that results from this machine. This waste could be removed completely when more accurate counters are used. The machine waste at the N37 and N16 is unnecessary because of the less complex structure of the machines. The N39 is a more complex machine, and the machine waste fulfils the purpose of saving valuable time. Therefore, the machine waste should be removed at the N37 and N16 and should be kept at the N39. The amount of unwinding waste produced at the N37 and N16 is unnecessary due to resolved problems at the sleeving machine. This waste can be reduced if different work methods are given to the operators.

- The overproduction resulting from poor estimation of the amount of meters necessary to fill the order is accountable for 5% of the total waste produced. To resolve this issue the roll sizes and number of meters processed throughout the production process should be calculated for every order quantity to account for the regular production waste.

To introduce solutions that will decrease the total production waste I should aim to remove the following waste types at their given stages corresponding to Table 8.

Table 8. Overview of the waste types that should be removed or reduced

Stage	Remove/Reduce
Gluing and cutting	Transport waste
Inspection N39	Counting waste
Inspection N37	Machine waste, Unwinding waste
Inspection N16	Machine waste, Unwinding waste
All stages	Overproduction

5 Solution Method Design

In this chapter I design solutions to decrease the total production waste effectively. The solutions aim to remove or reduce the waste types which are unnecessary or excessive. In Section 5.1 I introduce a dashboard aimed to simulate the production process and to eliminate overproduction. In Section 5.2 a solution is presented to remove the transport waste. Section 5.3 introduces solutions regarding the unwinding waste and Section 5.4 focuses on the reduction of machine waste. The dashboard is also used to calculate the expected reduction in waste when solutions are successfully implemented.

5.1 Dashboard for the production process

In the current situation, the operator at offset printing takes an educated guess to account for the order and the waste based on experience. The roll sizes are determined during production and are created such that the rolls are not too big or too small for the subsequent stage. It would be easier to calculate back from the last stage in production to the first stage such that Eshuis always creates end rolls of 1707 meters and accounts for the regular waste at each stage. Since I analyse the regular waste data at each stage in post-processing, I can use that to estimate the minimum unavoidable and necessary waste at each stage and calculate more ideal roll sizes to cover that waste and fill the order at 105%, using Visual Basic for Applications (VBA) as programming language. In Figure 26 this dashboard is visualized.

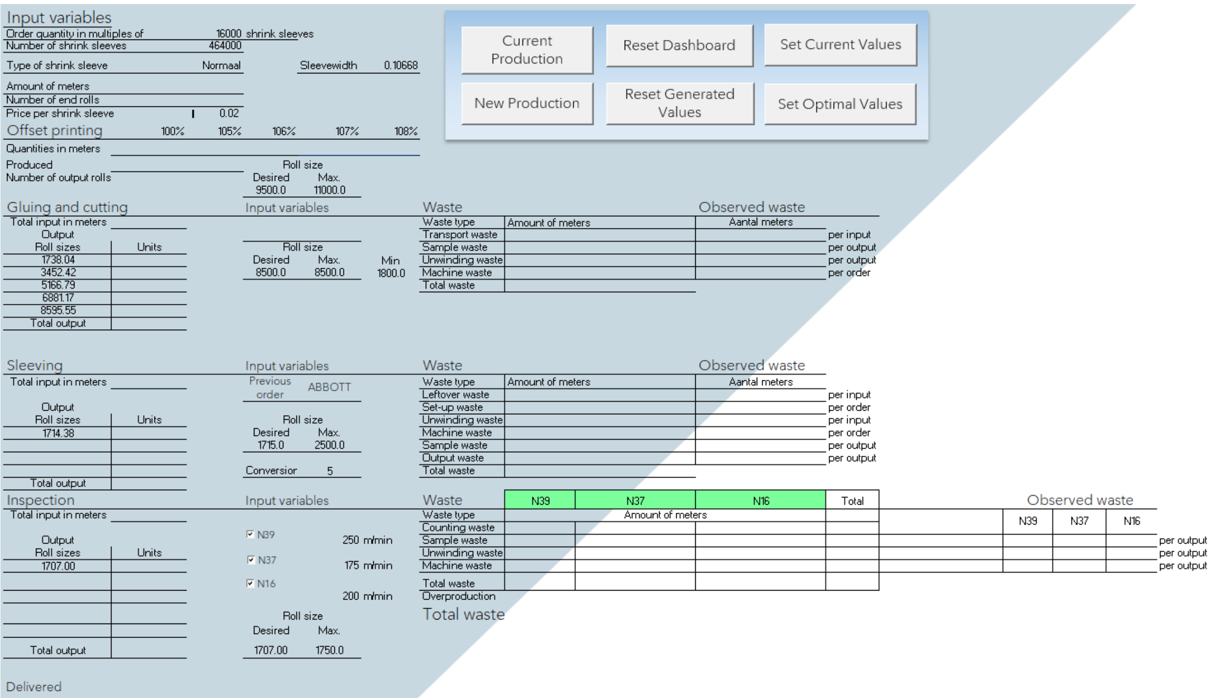

Figure 26. Dashboard for simulating the production process

In the dashboard, a user can fill in variables related to the order in terms of size, type of sleeve, desired number of sleeves on an end roll and more. In Appendix B, a user guide is presented to show how the dashboard works according to the current production process.

5.1.1 Simulating a new production process

For the programming of a production process where no overproduction occurs, I use the dashboard from the current production simulation and calculate the numbers and sizes of the production rolls by using the desired output of the production process as input. The desired output of the production process is to produce 105% of the order quantity and produce the corresponding unavoidable production waste. For now, the optimal production process can also contain avoidable waste types, but in a later stage these values can be set to zero. In Figure 26 the dashboard is made up out of five rows that represent the input variables and the four stages in the production process. At each of the post-processing stages a column "Observed waste" is added to set the average amount of waste for each regular waste type present. These numbers are variables that can be adjusted to see how total production waste changes when a waste type is reduced or removed.

For the new production process, the input variables are entered, and the dashboard calculates the target amount in meters which represents 105% of the order quantity according to the following formula:

$$Target\ amount = \ order\ quantity * sleeve\ width * 1.05$$

The order amount is in terms of shrink sleeves and the sleeve width is in meters. The dashboard calculates how many end rolls should be produced to match the target amount and it should calculate the most ideal sizes of those end rolls. The desired size of an end roll can be determined by the user of the dashboard. When this value is determined, the dashboard calculates how many full end rolls of that size can be produced within the target amount and how many rest rolls and half rolls are needed to match the exact amount of 105% of the order quantity. With the following equations, the difference in roll sizes between these three end rolls should become clear:

$$Desired\ endroll < Rest\ roll < Half\ roll$$

$$Half\ roll = Desired\ endroll\ /\ 2$$

In general, almost all orders have rest rolls because 105% of the order is in most cases not feasible with just a multiple of desired endrolls. Furthermore, the number of different sizes of end rolls are always even because the gluing and cutting machine can only produce two rolls of the same size each time. This causes the sleeving stage and the inspection stage to have a number of different roll sizes that is even. The following algorithm determines the roll sizes and their corresponding numbers at the inspection stage.

Algorithm 1: Algorithm Inspection unwinding stage		
	Input: Desired endroll, TargetAmount	
	Output: Amount and sizes of desired endrolls, restrolls, and halfrolls	
1	**Initialize: TargetAmount, DesiredEndRoll**	
2	**If** RoundDown (**TargetAmount / DesiredEndRoll)** is even **Then**	
3		**DesiredEndRollSize = DesiredEndroll**
4		**DesiredEndRollAmount** = RoundDown (**TargetAmount / DesiredEndRoll) – 2**
5		**RestRollSize = ((TargetAmount** Mod **DesiredEndRoll) + (2 * DesiredEndRoll) – (2 * (DesiredEndRoll / 2)) / 2**
6		**RestRollAmount** = 2
7		**HalfRollSize = DesiredEndRoll** / 2
8		**HalfRollAmount = 2**
9	**Else**	
10		**DesiredEndRollSize = DesiredEndRoll**
11		**DesiredEndRollAmount** = RoundDown**(TargetAmount / DesiredEndRollBC, 0)** – 1
12		**RestRollSize = ((TargetAmount** Mod **DesiredEndRoll) + DesiredEndRoll)** / 2
13		**RestRollAmount** = 2

End If

This algorithm uses the amount of meters that should be produced “TargetAmount” and the size of the desired endroll to calculate the amount of desired end rolls and the sizes of the rest rolls that should be produced to match the 105% of the order quantity. For the order quantities 16,000 and 32,000 shrink sleeves, the variable TargetAmount is 100% of the order quantity since filling the order at 105% at these amounts will not create any full desired endrolls.

To show how the dashboard displays this, an example is visualized in Figure 27 at an order quantity of 384,000 shrink sleeves.

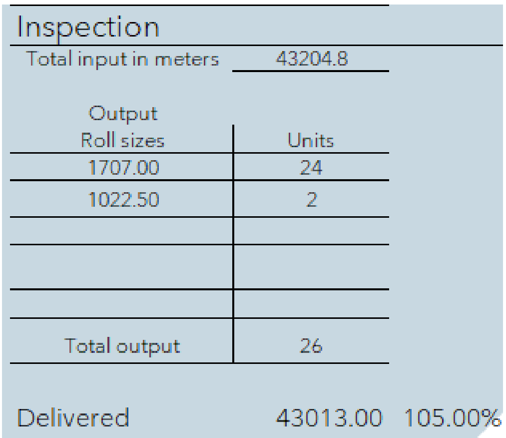

Figure 27. Inspection stage example

The sizes of the end rolls and their corresponding amounts are determined. The average regular waste that corresponds to these roll sizes and their amounts is also determined through the values displayed in Table 7. Therefore the amount of meters necessary for this stage is calculated and the sleeving stage can now make its roll sizes based on the roll sizes at the inspection stage. Algorithm 2 is used to determine the roll sizes and their corresponding amounts at the sleeving stage.

Algorithm 2: Algorithm Sleeving stage
Input: DesiredEndRoll, DesiredRollSleeving, WastePerRollInspection, DesiredEndRollAmount,
Output: Amount and sizes of sleeving rolls
Initialize: DesiredRollSleeving = DesiredEndRoll + WastePerRollInspection
FirstRollSize = DesiredRollSleeving
FirstRollAmount = DesiredEndRollAmount
If There is a halfroll present at inspection **Then**
SecondRollSize = RestRollSize + HalfRollSize + (2 * **WastePerRollInspection**)
SecondRollAmount = RestRollAmount
ElseIf there are only restrolls present **Then**
SecondRollSize = RestRollSize + WastePerRollInspection
SecondRollAmount = RestRollAmount
End If

The algorithm determines the roll sizes based on the roll sizes produced at the inspection stage. To account for the waste a variable "WastePerRollInspection" is created. This variable is determined by first adding all the waste for each inspection unwinding machine. This results in three numbers, each corresponding to the total waste at an inspection unwinding machine. Those numbers are then multiplied by the percentage of rolls processed on their inspection unwinding machine based on the different speed that each machine uses. An inspection unwinding machine with a higher processing speed will process more end rolls than a machine with a lower processing speed. Therefore, we calculate that percentage of total rolls process on that machine and multiply it by the regular waste per roll on the corresponding machine. When those numbers are added together and divided by the number of inspection unwinding machines in use, we get the average waste per roll based on the speed and waste of the active inspection unwinding machines. This variable is used to account for the waste at the inspection stage. In the dashboard, with an order quantity of 384,000, the sleeving stage produces the amount displayed in Figure 28.

Sleeving

Total input in meters	43423.2
Output Roll sizes	Units
1714.38	24
1029.88	2
Total output	26

Figure 28. Sleeving stage example

For the roll size calculations at the gluing and cutting stage we can make bigger rolls that can yield up to five desired rolls at the sleeving stage. Because the sleeving stage is a continuous processing machine it is crucial to make sizes at the gluing and cutting stage resulting in a steady output of the same desired roll sizes at the sleeving stage. Table 9 displays the five roll sizes that are ideal for the sleeving stage to create desired end rolls for the inspection stage.

Table 9. Ideal gluing and cutting roll sizes

Output Gluing and cutting	Resulting output sleeving stage
1738.45 m	1* 1714.38 m
3453.24 m	2 * 1714.38 m
5168.03 m	3 * 1714.38 m
6882.83 m	4 * 1714.38 m
8597.62 m	5 * 1714.38 m

Algorithm 3 is used for the gluing and cutting stage in order to create at least two rolls of an ideal roll size and create other roll sizes to complete the amount of meters that is needed for the sleeving stage. In this algorithm the program first finds the number of desired rolls produced at the sleeving stage to determine the ideal roll size at the gluing and cutting stage that could serve as an input for these desired rolls.

ALGORITHM 3: ALGORITHM GLUING AND CUTTING STAGE	
	INPUT: FirstRollSize,
	OUTPUT: AMOUNT AND SIZES OF SLEEVING ROLLS
1	**INITIALIZE:**

```
2  For i = 1 to 5
3      If AmountFirstRolls > (11 – 2i) Then
4          IdealRollSize = (6 – i) * DesiredRollSleeving
           If amountFirstRolls < 10 Then
               IdealRollAmount = RoundUp(AmountFirstRolls / 10) * 2
               If SecondRollSize > 0 Then
                   SecondRollSizeGlueCut = SecondRollSize
                   SecondRollAmountGlueCut = 2
               End if
               Exit For
           Else
               IdealRollAmount = RoundDown(AmountFirstRolls/ 10) * 2
               If SecondRollSize > 0 Then
                   SecondRollSizeGlueCut = ((AmountFirstRolls Mod 10) *
                   DesiredRollSleeving / 2) + SecondRollSize
                   SecondRollAmountGlueCut = 2
               End if
               Exit for
           End if
       End if
   Next i
```

In the example shown in Figure 29, the dashboard determined that there were enough desired roll in the sleeving stage to create ideal maximum sized rolls at the gluing and cutting stage of 8597.62 meters. Four of those sizes result in 20 desired rolls at the sleeving stage. The residual size of 4549.16 meters covers the other six rolls at the sleeving stage.

Gluing and cutting

Total input in meters	21806.6
Output	
Roll sizes	Units
8597.62	4
4549.16	2
Total output	6

Figure 29. Gluing and cutting stage example

When the waste of the gluing and cutting stage is now added to total number of meters need for the roll sizes displayed in Figure 29, it is known to the first stage what number of meters should be printed in order to fill the order at 105% and account for the regular waste that is produced. Overproduction cannot occur anymore when the roll size in the dashboard are produced and the waste values at each stage do not change over time. However, if a certain waste type changes at a stage, this value can be adjusted in the dashboard and new roll sizes and corresponding amounts can be recalculated.

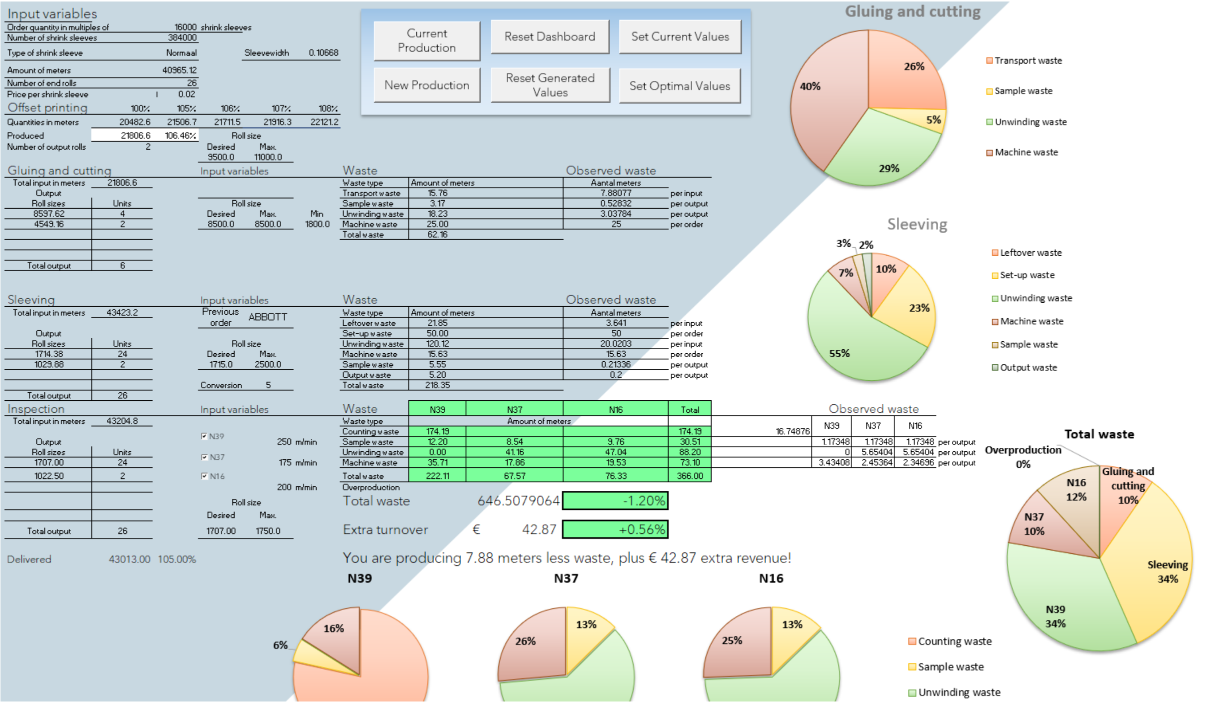

Figure 30. Dashboard for simulating the new production process without overproduction

In the dashboard the user can see that 21806.6 meters should be printed at offset printing in order to produce 105% and account for all the waste. The overproduction is totally removed from the production process and the turnover is maximised. At the bottom of Figure 30, the user can see the total waste and the turnover compared with the current total waste and turnover. The total waste decreased by 1.20% because the roll sizes are more ideal than current roll size since there is less variety in sizes. The pie graphs give the waste distribution at each stage over the regular waste types that are produced at this order quantity.

5.1.2 Analysing the production at offset printing

The new production at offset printing can now be simulated over all the order quantities. In Figure 31 the percentage of the order quantity printed at offset printing for each order size is visualized such that 105% of the order is filled and the corresponding production waste is accounted for.

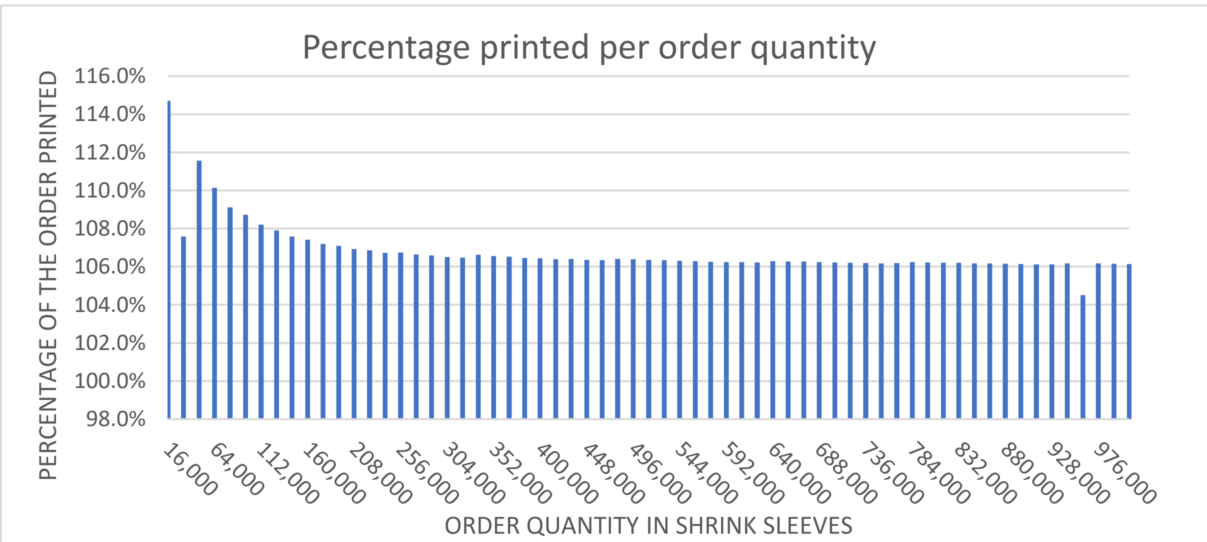

Figure 31. Percentage printed at offset printing for each order size

These percentages are determined using the new production method explained in Section 5.1.1. All One can see that the percentage printed per order quantity shifts to 106.20% when the order quantity increases. The outliers are placed at the lower order quantities in Figure 31. For the order quantity of 16,000 shrink sleeves only one full end roll is delivered, but since there is a relatively high production waste to the order quantity, the dashboard recommends printing 114.72% of the order quantity to account for the waste and fill the order at 100%. Next to this outlier, another outlier is visualised at order quantity 32,000. This quantity is also filled at 100% since 105% does not result in delivering full end rolls. Since the order quantity is now doubled relative to 16,000 shrink sleeves, the recommend percentage to print at offset printing has dropped to 107.58%. This is logical since the difference between 7.58% of 32,000 and 14.72% of 16,000 is less than 70 shrink sleeves. When the order size increases above 32,000 it is recommended to fill the order at 105%, this is why the percentage printed at the first stage increases again. The total waste created in the new production process is shown in Figure 32.

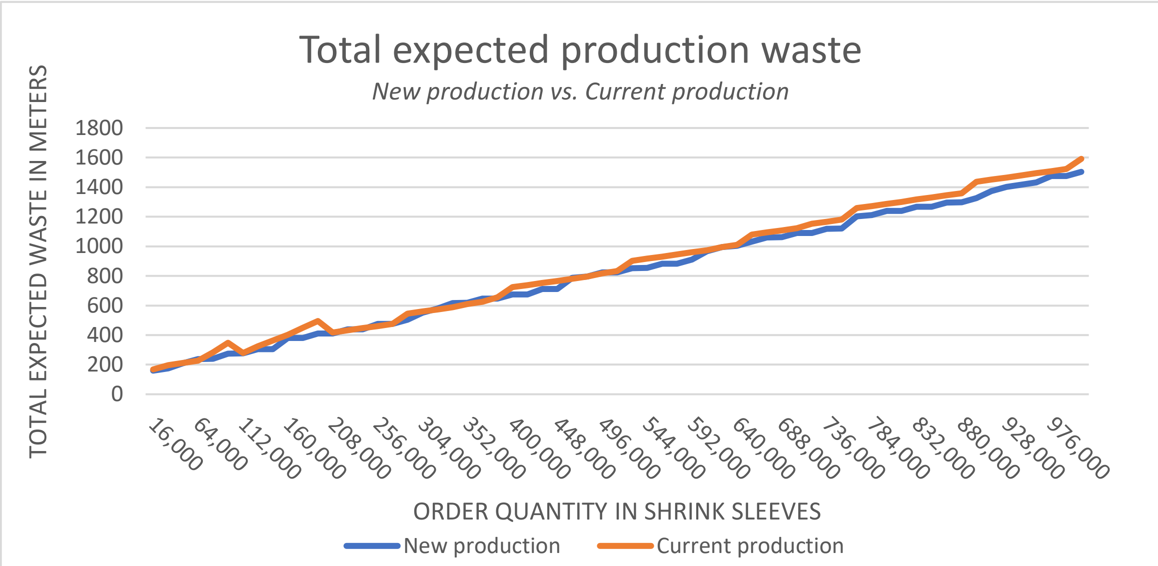

Figure 32. Total expected production waste in the current and new production process

In Figure 32 the orange line represents the current production methods while the blue line represents the new production methods. The new production methods always fill the order at 105% while current production fills the order on average at 104.48%. Furthermore, when the weighted average is used to calculate the total production waste over all the order quantities based on frequency of the order quantities, the new production methods result in a 5.64% reduction in total production waste relative to the current methods used.

5.1.3 Conclusion of the dashboard

The dashboard containing the new production process can be used for all order quantities at Eshuis and is also effective when waste values at certain stages in the production process change. The waste values can be adjusted for all types of regular waste and the dashboard will calculate the new outcomes. When Eshuis decides to remove all the sample waste for example, the dashboard can set this type of waste to zero and the program will calculate the new expected total production waste.

The dashboard does not calculate the waste produced due to irregularities such as technical issues or mistakes made by operators. It only accounts for the regular waste that is known to take place because of certain work approaches and limitations of the machines through the production line.

The dashboard is therefore a useful tool for the determination of the following values in the production process for Company X:

- The number of meters that should be printed at the offset printing stage to account for regular waste and fill the order at 105%
- The roll sizes for each stage
- The expected total regular production waste
- The expected percentage delivered of the order quantity
- The difference between current and new production in terms of waste
- The distribution of waste at each stage of post-processing

Because of these features, I will use the dashboard in the other proposed solutions to measure the expected reduction in waste.

5.2 Solution for the transport waste

The transport waste that is created during the process of storing and transporting the output production roll from offset printing is on average 7.88077 meters. In perspective of the total production waste, this amount does not appear to be significantly damaging the efficiency of the production process. However, since the transport waste can be easily avoided, one solution comes to mind in order protect the surface of the output production rolls at the beginning of the production process.

The surface of the production rolls contacts the floor of the factory during the process of storing it on a metal or wooden construction. When the production roll is rotated on the construction, the surface of the production roll contacts the surface of the construction, causing damages to the labels. The reason for the damages is the contact between the surface of the labels and the surface of the construction or the factory floor. When the operator removes this contact by using a production roll cover to protect the surface of the roll from any friction, the damages are avoided, and the transport waste is removed from the production process. When the transport waste is removed the total expected production waste is shown in Figure 33.

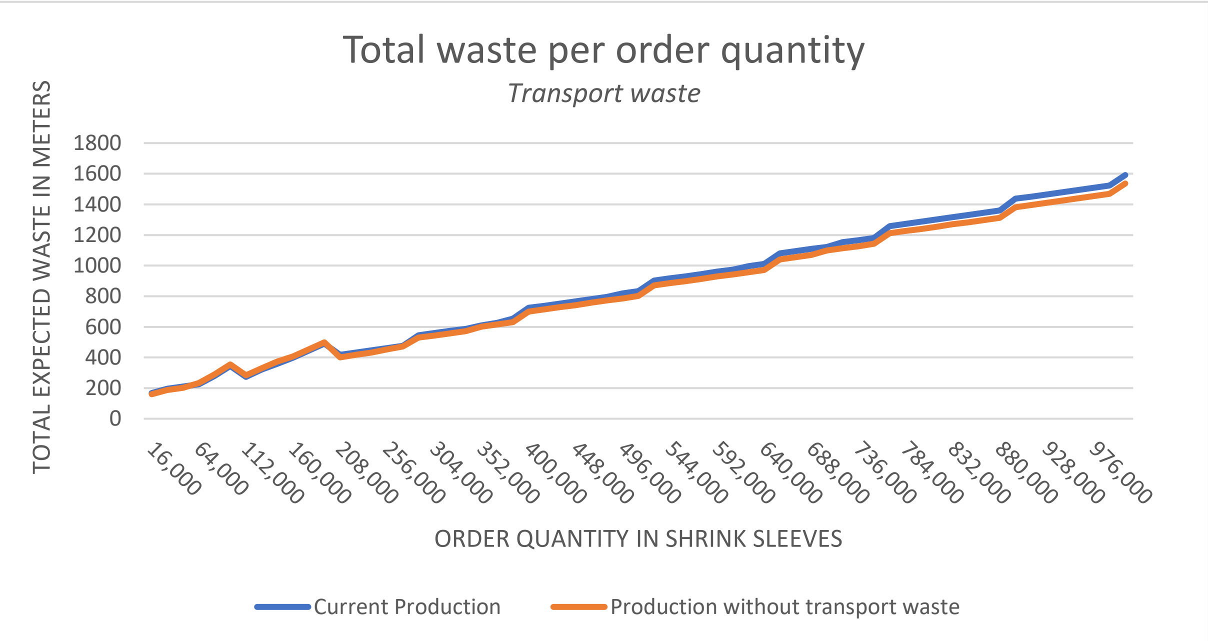

Figure 33. Total waste per order quantity with transport waste and without transport waste

In Figure 33 one can see the difference in waste between production with and without transport waste. The expected average reduction in waste over 63 different order quantities is 0.87%

5.3 Reducing the unwinding waste

The unwinding waste created at the inspection stage serves little purpose after some resolved problems at the sleeving stage. Since the unwinding waste is caused by standardized work methods dating back to periods where the unwinding waste was justified, the solution is to communicate effectively to the operators that the previous issues are not present anymore.

Therefore, reducing the unwinding waste is a matter of improving transparency through the production line. This transparency can be achieved by evaluating orders with the operators at the inspection stage. When operators understand that part of the waste that is produced is high quality shrink sleeves, it can bring understanding in creating new work methods that involve a reduction in the unwinding waste.

In Figure 34 the total waste per order quantity is given for a production process with unwinding waste at the inspection stage and a production process with reduced unwinding waste. The current production process uses 5.65 meters unwinding waste per end roll while the new production process uses 2 meters per end roll.

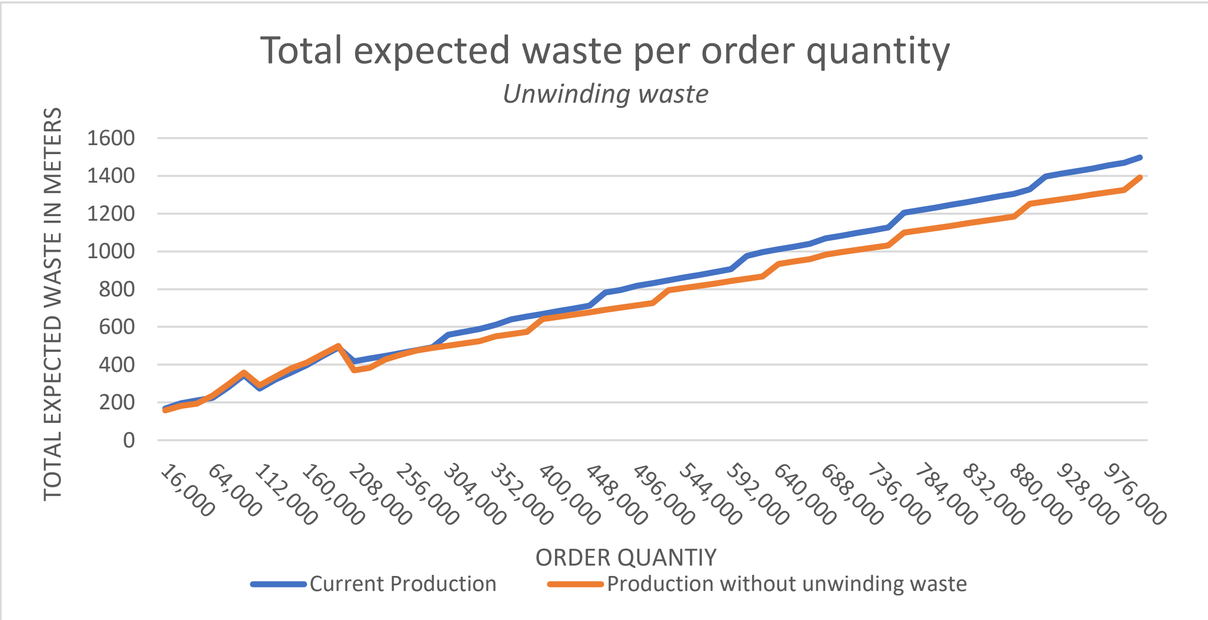

Figure 34: Total waste difference between current production with and without unwinding waste at the inspection stage

Because the unwinding waste is equal to 5.65404 meters per end roll created at the inspection stage, the total waste difference between a production process with unwinding waste and a process with reduced unwinding waste at the inspection stage is already significantly noticeable at an order quantity of 496,000 shrink sleeves where the difference has already reached 100 meters in expected total waste. The more the order quantity increases, the higher the difference becomes. However, because the smaller quantities occur more frequent than larger orders the weighted average expected reduction in total production waste is just 2.85%.

5.4 Removing the machine waste

The machine waste can be removed at inspection machines N37 and N16 as discussed in Section 4.3. Since these machines are simpler than the N39 in terms of accessibility, these machines should remove the machine waste while the N39 can keep a string of substrate in the machine in order to speed up the process of inspection.

For this machine waste to be removed at these machines, it should be clearly communicated to which of the three inspection machines this applies and why. For operators, the machine waste of 2.45 meters does not sound that much in the perspective of a full end roll of 1707 meters. But when using the dashboard to determine the difference in total waste in the current production process, Figure 35 displays the outcome of that simulation.

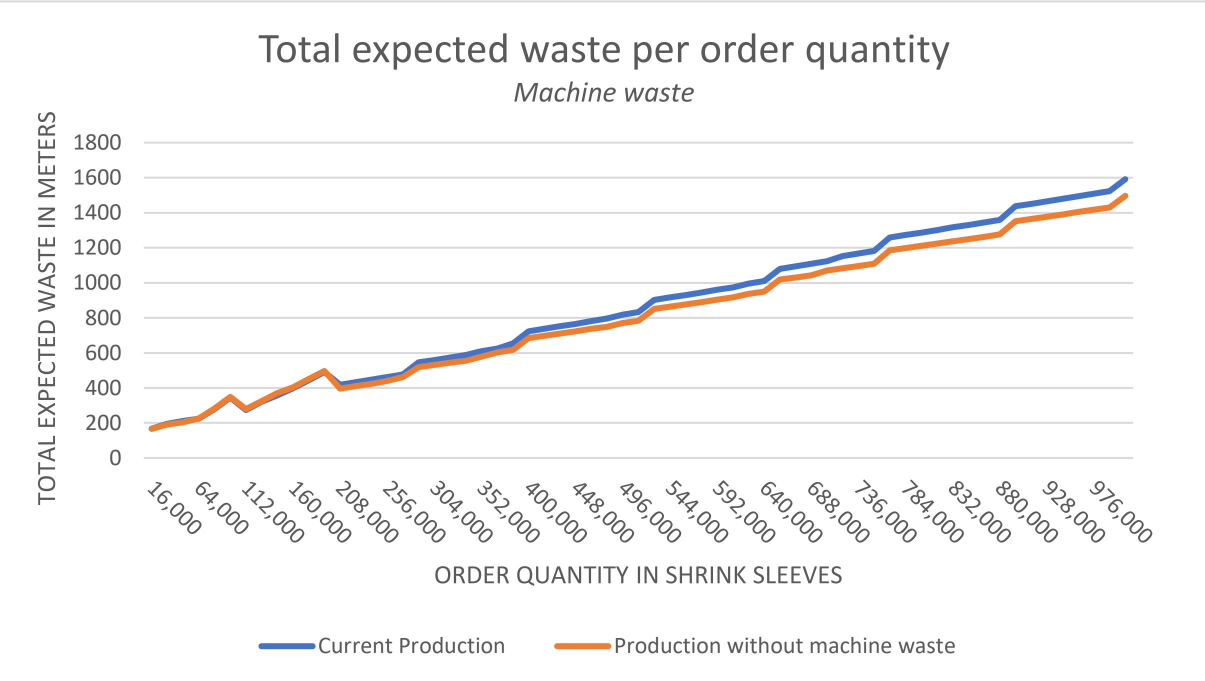

Figure 35. Total expected waste difference between current production with and without machine waste at the inspection machines N37 and N16

From the fact that machine waste depends on the amount of end rolls created it stems naturally that the difference between the total waste with machine waste and without machine waste at the N37 and N16 increases as the order quantity increases. At the order quantity of 976,000 shrink sleeves the difference is already 94.91 meters. If I convert this difference to an amount of shrink sleeves, the difference is equal to 890 shrink sleeves.

Therefore, removing the machine waste at large orders can have immense consequences. However, the weighted average expected reduction in waste over all 63 different order quantities is equal to 1.96%.

5.5 Removing the counting waste

The counting waste is the result of the inaccuracy of one inspection unwinding machine. Due to its inaccuracy, it counted faster to 1707 meters, resulting in approximately 16.75 meters of waste. This waste was good enough to sell but because the machine stopped, operators were under the impression that the full 1707 meters were processed. The removal of the counting waste is therefore easy to implement by calibrating inspection unwinding machine N39 or changing machine setting such that all the meters are processed through the machine. It is possible to change the automatic stop setting to 1719 meters such that the full roll is unwound, inspected, and delivered. To check how this changes the total expected production waste at Eshuis another iterative process is executed in VBA. In Figure 36, the result of this removal is shown.

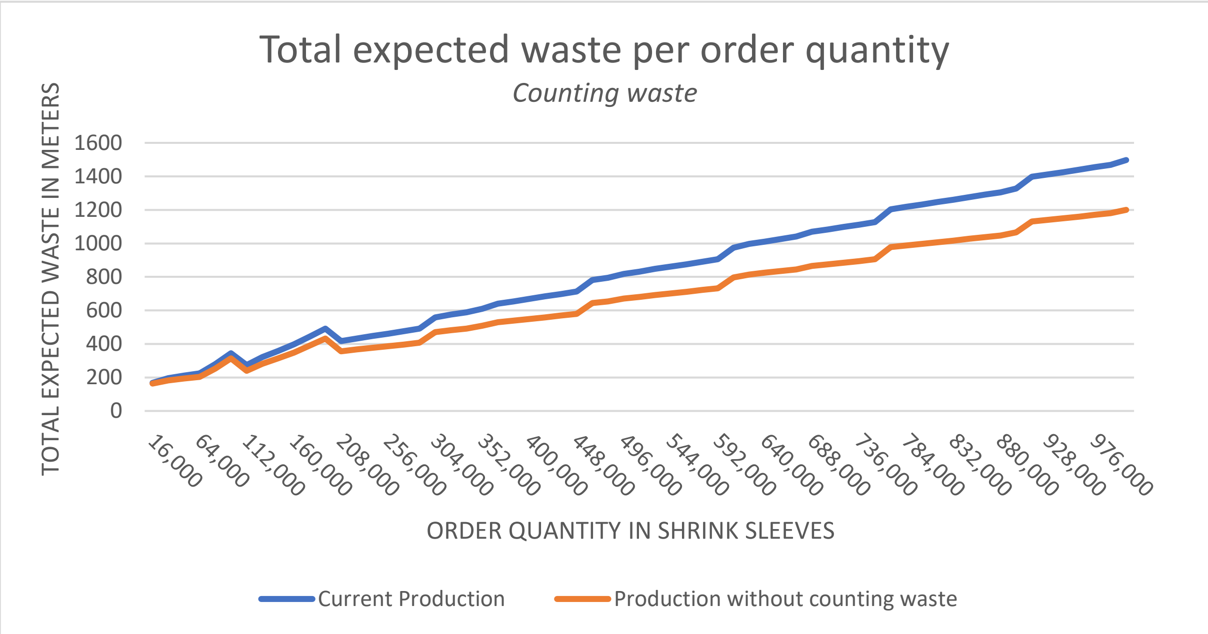

Figure 36. Total expected waste difference between current production and production without counting waste

In Figure 36 the difference in total expected waste becomes very clear from order quantity 304,000 onwards. It shows that at larger order quantities this type of waste contributes more and more to the total waste and could reduce the total expected waste effectively when the solution is implemented successfully. The weighted average expected reduction is therefore also the largest reduction out of all the proposed solutions. With 12.35% in expected reduction this is key area of waste in the post-processing stages.

Eshuis has already taken steps to achieve this reduction and after implementation of the new machine setting there seems to be no more counting waste present at the N39. In the long run this should be noticeable in terms of total regular waste.

6 Conclusion of the proposed solutions

This chapter concludes the proposed solutions to remove and reduce different waste types mentioned in Chapter 5. In Section 6.1 I give a brief summary of the solutions and their expected results. In Section 6.2 I propose recommendations based on the solutions. In Section 6.3 the limitations of the research are stated. In Section 6.4 I give a brief description of further research.

6.1 Solutions and expected results

The proposed solutions throughout Chapter 5 reduce the total waste using the dashboard discussed in Section 5.1. Since the function that simulates the current production on the dashboard is fairly accurate and the program of the new production does not show any values that are not possible in practice, I believe that the function that simulates the new production is very much applicable to real life and can be useful to Eshuis in multiple ways as shown in the proposed solutions throughout Chapter 5 where the dashboard was used to simulate various situations with different values for the waste types. In Table 10, an overview of the proposed solutions with their expected reduction in total waste at the post-processing stages are given.

Table 10. Overview of the solutions with their expected average reduction in total waste

Waste type	**Where**	**Action**	**Weighted average expected reduction in total waste**
Transport waste	Gluing and cutting	Protecting surface with covers	0.78%
Overproduction	All stages	Using new algorithm to determine production roll sizes	5.64%
Machine waste	Inspection stage: N37 & N16	New work instruction	1.96%
Unwinding waste	Inspection stage	New work instruction	2.85%
Counting waste	Inspection stage: N39	Calibrate inspection machine N39	12.35%

When counting waste, the machine waste at the N37 and N16, and the overproduction is removed while we reduce the unwinding waste at the inspection stage, we can calculate the total expected average waste reduction through the dashboard. In Figure 37 it is visualised how the total expected waste would reduce in that case.

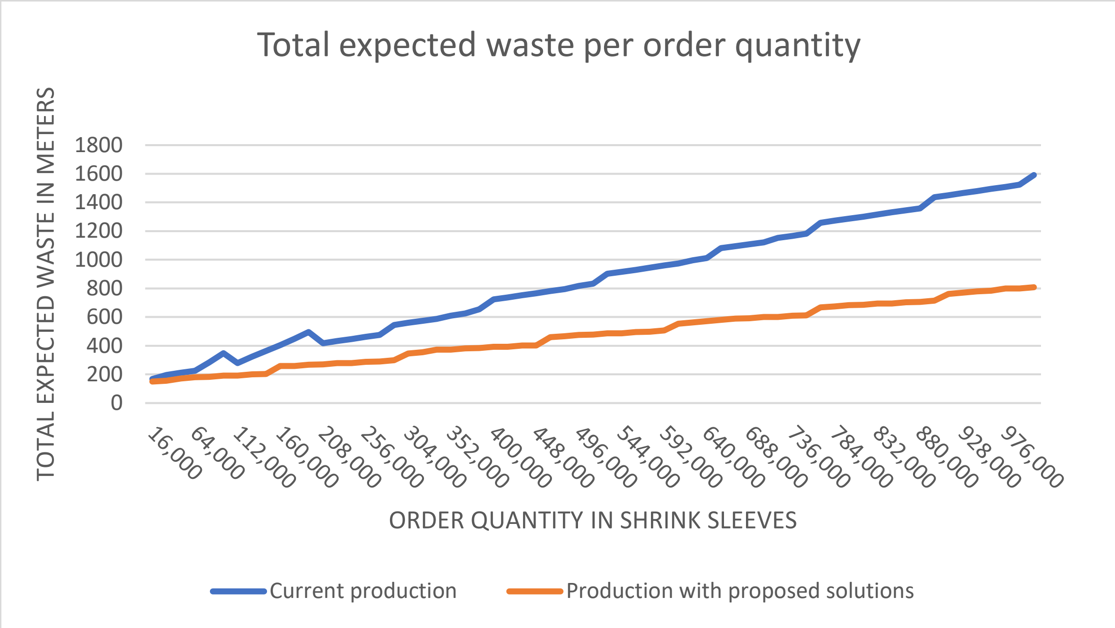

Figure 37. Total waste per order quantity in the current and optimal production

The weighted average expected reduction in total production is in this case 34.48% when all the proposed solutions are implemented successfully. This shows that these waste types have major influence on total production waste and that Eshuis can achieve reduction effectively when focusing on the right areas.

6.2 Recommendations

In line with this research and the proposed solutions, the following recommendations are made to Eshuis:

- Implement new policies on the machine waste and the unwinding waste at the inspection stage. Introduce new work methods that clearly instruct to not leave any string of shrink sleeves in the N37 and N16 of the inspection stage to use it for the next end roll. Instead, this can be used as part of the unwinding waste. Furthermore, make new instructions that target all the machines in the inspection stage to reduce the unwinding waste to a maximum of 2 meters instead of 5.65 which is now wasted on average. Since 2 meters is hard to determine, operators are instructed to take a maximum of two windings of outer surface of an end roll. These are simple steps on reducing the total waste quick and effectively. The key is to communicate clearly to operators why the new policies are made.

- I advise to use the dashboard to create more efficient production processes without overproduction. Because the dashboard is programmed to fill the order at no more than 105%, Eshuis maximizes its turnover when no irregular waste is present during all the processes. In case that irregular waste does present itself within one or more stages, Eshuis can use the buffer of 10% to still fill the order between 95% and 105%.

- The counting waste is already removed because of this research and should be no longer a focus point to Eshuis. However, it is recommended to calibrate the machine instead of adjusting the settings on inspection unwinding machine N39.

6.3 Limitations

Concerning the validity and reliability of this research there are some points open for discussion. First, this research only contains the regular waste throughout the post-processing stage of the production line. This means that the first stage is not considered in terms of production waste and the irregular waste such as waste resulting from technical failures and human errors is also not included. The expected average reduction in waste is therefore only based on the regular waste throughout the production process.

Second, only plastic waste in the form of shrink sleeves is considered. Waste of transport, inventory, motion, and waiting is not analysed since the range of subjects within this research would have been too much.

Lastly, the dashboard was created to simulate the current production process at Eshuis. Building a perfect simulation of the current production process is difficult but in most cases the dashboard in VBA is within a 5% error margin in terms of simulating the amount of waste produced. The dashboard should therefore be used as an indication of what quantities are going to be produced and not as a perfect resemblance of the production process. The data that is required for the waste values are also snapshots of a certain period. These values can change, and it is therefore important to regularly measure the different waste values to keep the dashboard up to date. Although, the data was collected through many observations and does not represent the regular waste perfectly and only averages are used for this dashboard.

6.4 Further research

Areas in the production process that could be further researched at Eshuis are other types of waste that could be reduced. In my research I solely focused on the plastic production waste in the post-processing stages of the production process, but Eshuis can also improve in waste of motion and waste of transport. Now, the production process of shrink sleeves is divided over two areas within Eshuis. The areas used in the production process are given in Appendix A. These two areas are more than 80 meters apart from each other, resulting in a waste of transport that could be reduced by optimising the production process lay-out. This also reduces the waste of motion since the stages are interacting with each other in case of many defects.

Furthermore, Eshuis values high quality very much and incorporates this value through a high amount of quality checks throughout the production process. Although this is necessary to minimize end rolls with defects to be delivered to the customer, it increases the waste of overprocessing. Overprocessing, as discussed in Section 3.3, is any work that does not add value for the end customer. Investing in higher quality machines or better operators in the first three stages of the production process can reduce the rate of defects and can make the inspection stage redundant.

The dashboard that is created is helpful for determining production numbers and predicting total waste. It could be further researched if those numbers can be integrated in the current ERP system of Eshuis such that all data is stored in one place. This would improve the transparency between stages in terms of production and waste values.

7 References

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Appendix A

The factory consists out of two parts. One part is the oldest and is also the place where most of the oldest machinery is set (Figure 38). The other part is built in 2020 and this is where the warehouse, newest machines, and most of the Company X production line is situated. In Figure 25 one can see the oldest part of the factory. This is where the production process of all products for Company X starts. In area 1 the raw materials for offset printing are placed. This is a plastic roll that consist out of around 14.000 meter of plastic. When the offset printing machine needs a new roll, this plastic roll is transported from area 1 to area 2. Area 2 represents the offset printing machine, where offset printing will be executed.

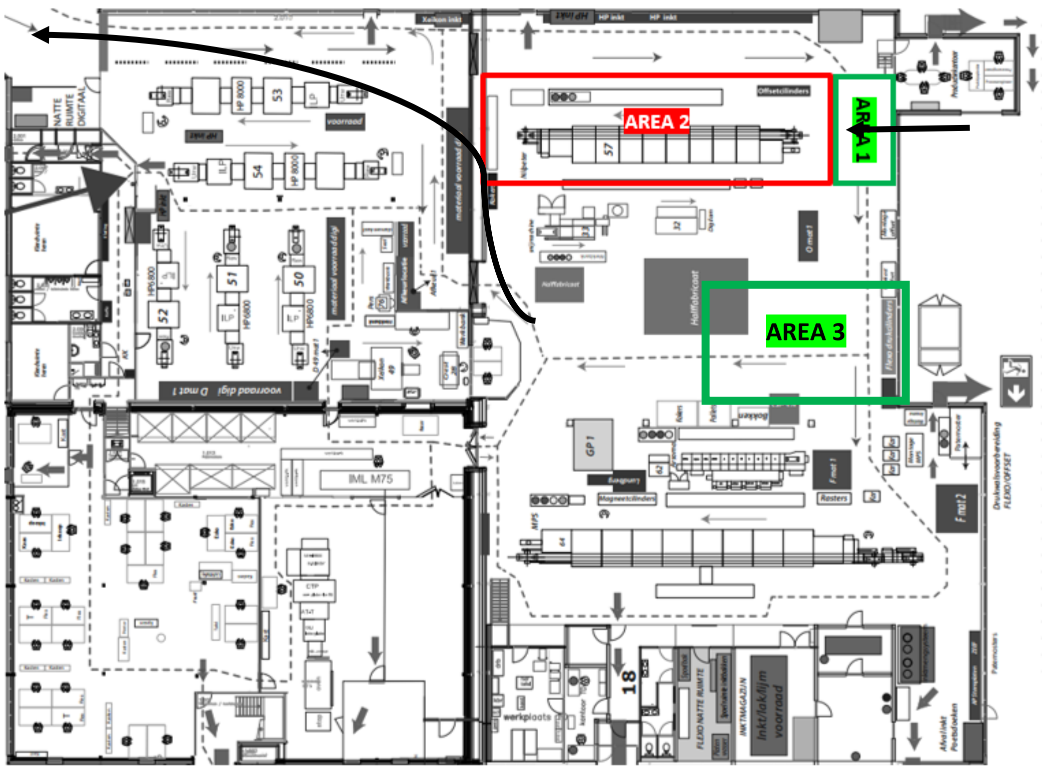

Figure 38: Map of the old part of the factory

When offset printing is completed, the production rolls are set in area 3 where the rolls are situated until the gluing and cutting machine is ready to process these rolls. When the rolls are ready for this second stage, the output will be transported to the newest part of the factory. This newest part can be visualised in Figure 39. Using an automatic pallet truck, the output of offset printing will be transported. The production rolls are placed temporarily in area 4, where it waits until the gluing and cutting machine is ready for the corresponding order. When the gluing and cutting machine is ready, the production rolls for that order can be moved to area 5 by the operator. After adding glue strips and cutting the production rolls into two rolls single file rolls, the finished rolls will be placed in area 6 until they will be ready for the sleeve machine. In area 7, the sleeving of the labels is performed, this process yields production rolls which are placed on a mobile rack. If the mobile rack has reached its capacity, it is moved to area 8. The production rolls are manually transported from the mobile rack to area 9, where the last machine in the production line is performing an inspection.

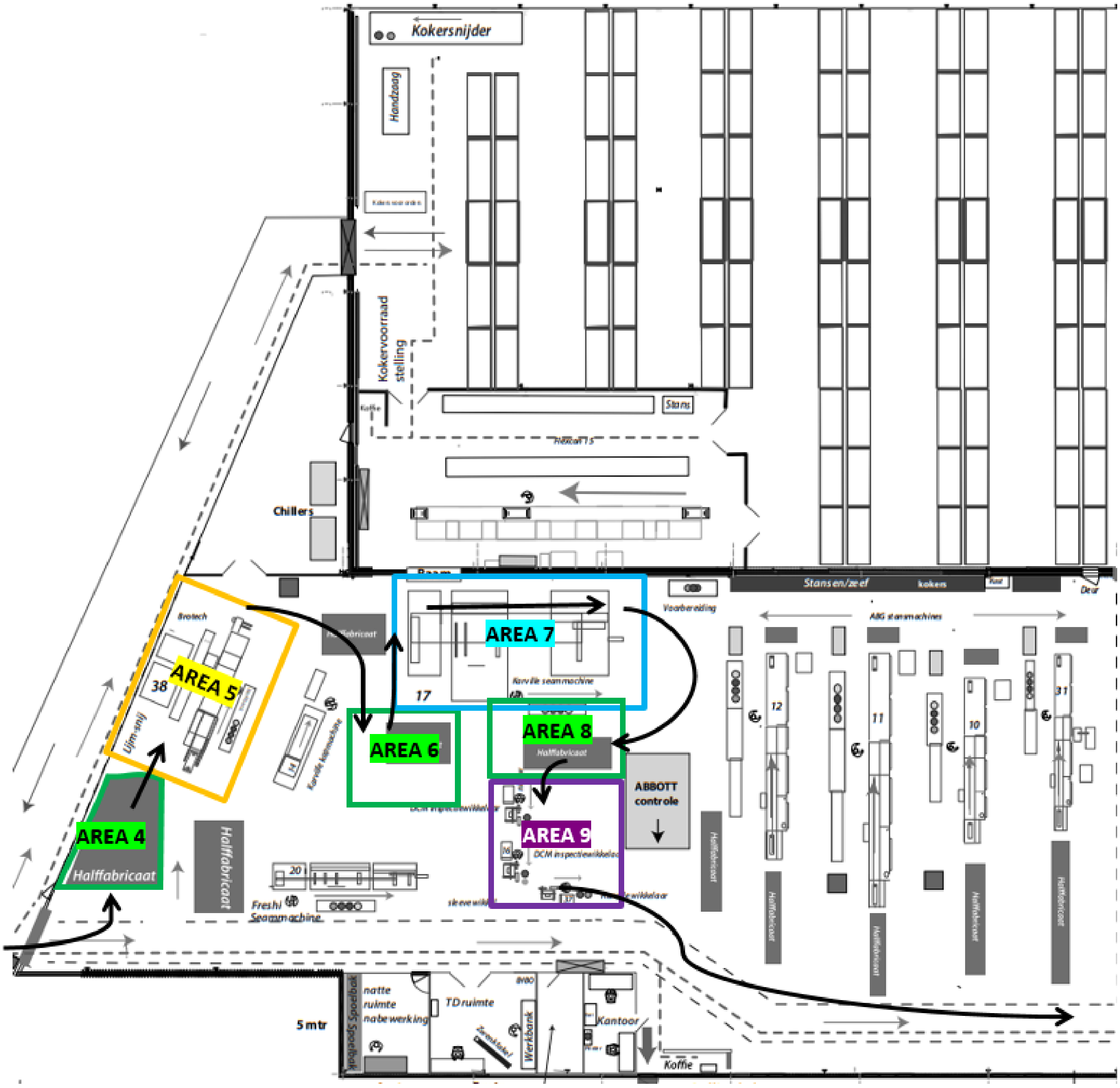

Figure 39: Map of the new part of the factory

After being processed in area 9, the end rolls are placed in a carton box and transported to the other side of the new factory. Here, the packaging department at area 10 will check the specifications of the order and fill in the checklist to ensure every process is completed before shipping the boxes to Company X. A last inspection is performed by a team leader who will confirm the shipping to Company X. If the shipment is not due, the order will be placed in the warehouse which is indicated as area 11 in Figure 40.

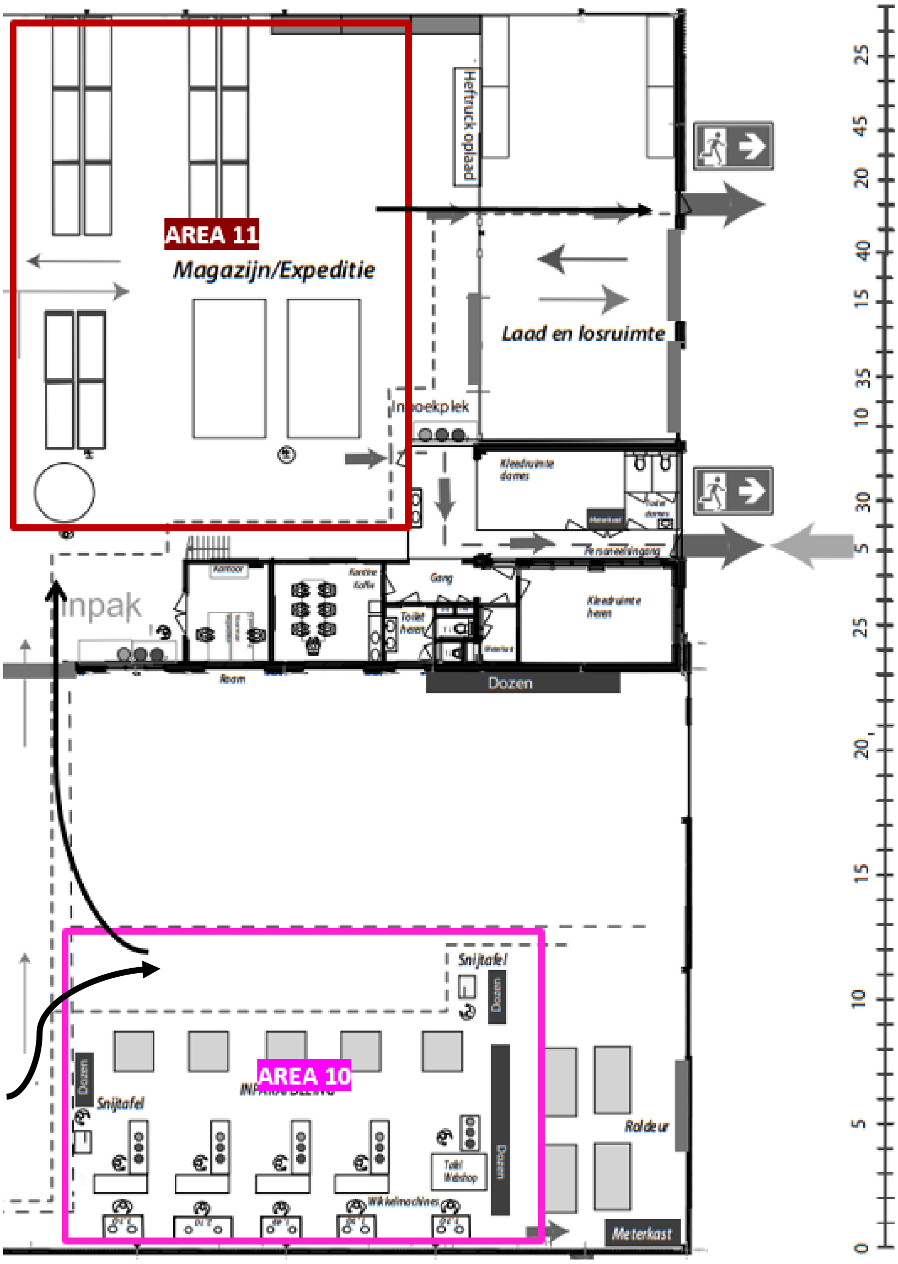

Figure 40: Map of the new part of the factory

Appendix B

Input variables section

At the section input variables, various values can be entered related to the order. The user can determine the desired amount of shrink sleeves on an end roll, the order quantity, and the type of shrink sleeve. Eshuis creates two types of shrink sleeves for Company X. One type is considered "normal" and has the dimensions 206.50 mm x 106.68 mm, while the other type is considered "small" with the dimensions 206.50 x 66.04 mm. Since the width dimension determines the number of meters in production, the type must be specified to calculate the corresponding number of meters. The number of meters that corresponds to the order quantity and the number of end rolls are displayed in this section after the simulation is started.

A few input variables need to determine before starting the simulation. The user can determine the order previously processed on the sleeving machine. Depending on the previous order, the waste created during the set-up of the sleeving machine is determined. Furthermore, the user can insert the desired number of output rolls created out of one input production roll at the sleeving stage. This conversion from one input production roll into multiple sleeved production rolls can influence the waste at the sleeving stage.

At last, the user can determine which inspection unwinding machines are used in the production process and what process speed the machines are using. If for example the process speed of the N39 is higher than the process speed of the N37 and N16, more production rolls will be processed at the N39 since it costs less time to create an end roll on that machine. A critical factor in this statement is that there are always multiple production rolls available to the inspection stage to be processed into end rolls. Hence, the inspection stage is always active and does not have to wait for the sleeving machine to produce production rolls. The fraction of the production rolls processed on an inspection unwinding machine is therefore calculated as a fraction of the process speed divided by the sum of the process speed of every inspection unwinding machine in use. For example, when the process speed of the N39 is equal to 250 meters per minute and the N37 and N16 both process production rolls at a speed of 200 meters per minute. All the meters on the production rolls can be processed at 650 meters per minute if all the three machines are in use. The fraction of those production rolls getting processed by the N39 is therefore 250/650, while the fraction of production rolls getting processed by the N37 and N16 is 200/650 for both machines. The user should define the speed of the different machines, this is not something this optimized by the dashboard itself.

To be able to determine the regular waste that occurs during the production process, the dashboard needs input variables related to the average waste that is produced during each stage. Through observations, all the average waste is determined per stage. If a waste type is increased, reduced, or removed, the user can enter the new waste value that fits the current situation. This makes the dashboard flexible because it can adapt to a lot of different settings. The input variable for the observed waste can be entered at the right side of every section.

Offset printing section

In this section the number of meters is calculated according to Table 3 as discussed in Section 4.2.3. Because the offset printing stage is not further analysed because the current machine will be replaced by a new machine that would reduce the waste immensely, the only figures simulated at this section are the number of meters produced and the number of output production rolls in which that number is produced. Because the maximum roll size that the gluing and cutting machine can process is about 12000 meters, the roll sizes created at the offset printing machine cannot be more than that maximum. The usual roll size at offset printing when a large order is placed is about 9500 meters. Therefore, when an amount below 12000 meters is produced, one output roll is simulated and when the amount is higher it is divided by the usual roll size and rounded to a whole number.

Gluing and cutting section

In this section the output production rolls are simulated which are created after the process of gluing and cutting. The gluing and cutting machine always produces two single file production rolls simultaneously from one double file production roll created at offset printing. In Figure 41 the gluing and cutting section of the dashboard is visualized.

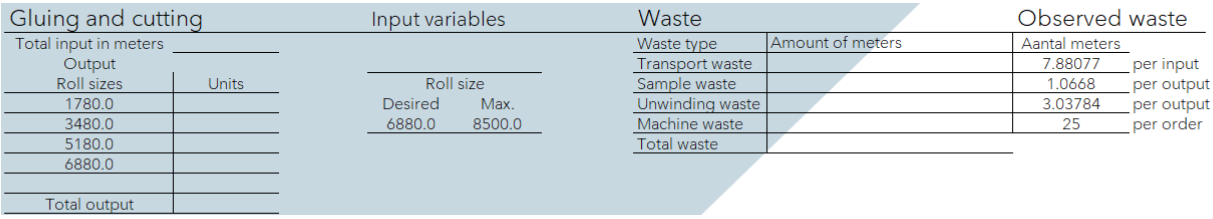

Figure 41. Gluing and cutting section in the dashboard

At the left side of this section, the desired output production roll sizes can be determined. If the user enters the value 6880 as a desired output production roll size in meters, as in Figure 36, the dashboard will calculate the roll sizes based on that preference. When the total input of meters is not equal to or larger than the desired roll size, the total input of meters is entirely processed into an output production roll. The roll size is in that case equal to the total input of meters. To summarize, this section will try to make as many desired roll sizes as possible from the total input and when the total input meters is lower than the desired roll size, it will create a roll size equal to the input meters that are still left. When the total input meters that is left is too low for the subsequent stage, the meters will be processed on top of the last desired roll size, creating two bigger output rolls

When the roll sizes and their corresponding amount of unites are calculated, the waste is calculated. The waste depends on the amount of output rolls created by the offset printing machine and the gluing and cutting machine. The dashboard calculates the transport waste by multiplying the amount of output rolls from offset printing with the average transport waste observed at the gluing and cutting machine. The sample waste, machine waste, and unwinding waste are known as discussed in Section 4.3. The figures are displayed at the right side of this section. Because the roll size created diminish in length because of this waste, the roll sizes are adjusted according to the waste and simulation at the gluing and cutting stage is complete.

Sleeving section

The principles used in the gluing and cutting section are also used in the sleeving section. The key difference is that the roll sizes which serve as an input for this sleeving machine influence the output roll sizes more. In Figure 42 the sleeving section in the dashboard is visualized.

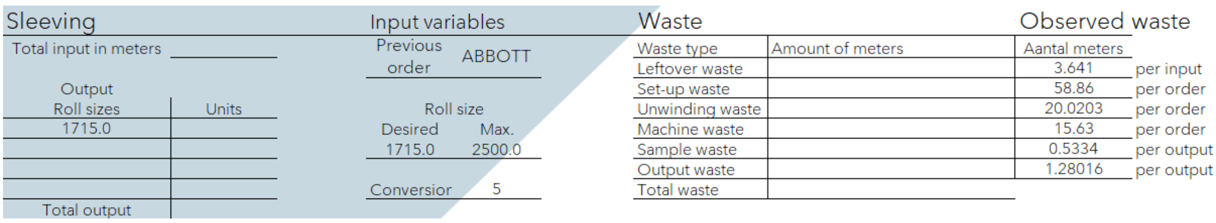

Figure 42. Sleeving section in the dashboard

An input production roll at this stage is normally around 6880 meters. At the left side of this section, the user can determine the desired roll size of an output production roll. In the case of a desired roll size of 1715 meters, the sleeving machine can create three output production rolls of 1715 meters and one output production roll of 1735 if the input production roll is 6880 meters. For the sake of simplicity, I exclude the waste for now. The simulation at the sleeving stage continues to create these roll sizes until the total input meters become too low to execute the same action. At that point, the roll sizes are made such that the lowest roll size is not less than a half end roll and the rest of the roll sizes is between an end roll and a half end roll.

The waste is calculated according to the number of input production rolls, the output production rolls, and the previous order processed at the sleeving machine. This last variable can be determined before the simulation in the middle of the sleeving section. The output production rolls are again simulated since the rolls need to be adjusted according to the waste that is created.

Inspection section

The simulation at the inspection stage determines it roll sizes based on the output production rolls created at the sleeving stage. Operators at the inspection stage create full end rolls of 1707 meters when an input production roll is between the 1707 and 1750 meters. When all the roll sizes between 1707 and 1750 meters are created into full end rolls, the remaining roll sizes can be combined. If the combined total of meters is larger than or equal to a full end roll plus a half end roll, the operators will create as many end rolls as possible until the combined total of meters is smaller than or equal to a full end roll plus a half end roll. When the combined total of meters is smaller, the operator will first create a half end roll and then an end roll which is equal to the remainder of the meters left. This eventually causes the output of the inspection stage to create only end rolls of 1707 meters, one half roll of 853.5 meters and one rest end roll of a size between 1707 and 853.5 meters. In Figure 43 the inspection section is visualized.

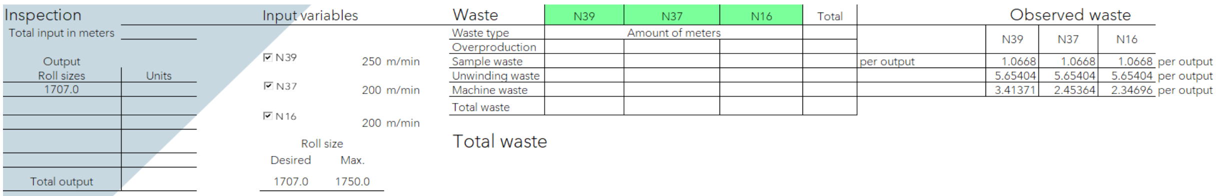

Figure 43. Inspection section in the dashboard

In Figure 43 the green background on the right side indicates which inspection unwinding machine is currently in use. The waste depends on the roll sizes coming from the sleeving machine, the number of input production rolls, and the number of output production rolls. The operators create end rolls of 1707 meters from any input production roll between 1707 and 1750, which implies that waste is created from the input production rolls that are bigger than 1707 meters plus the waste per roll. This waste, combined with the number of meters produced after the 105% order quantity is reached, creates overproduction at this stage. The sample waste, machine waste, and unwinding waste are simulated according to the inspection unwinding machines used. After the waste is simulated, the output production rolls are adjusted according to the waste.

Total waste section

When all the four stages are simulated, the total waste can be simulated. This total waste consists out of the total waste from each stage and the waste created by producing more than 105% of the order quantity. At the end of the simulation of the four stages, the percentage of the order that is filled is calculated by summing up the meters of the end rolls and comparing it to the size of the order. When the total amount of meters produced is more than 105%, the excessive number of meters will be added to the total waste. The total waste is indicated on the dashboard below the four production stages.