REDUCING THE EXCESSIVE WASTE PRODUCTION IN THE CRACKER PRODUCTION LINE AT COMPANY X

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Preface

Dear reader,

I am pleased to share this thesis with you, which represents the culmination of months of dedication. I want to express my sincere thanks to everyone who has been a part of this journey.

First and foremost, I would like to express my gratitude to my Company supervisor, Wendy Ligtenberg, for her support and guidance throughout the process of completing this bachelor's thesis.

On top of that, I want to thank my University of Twente thesis supervisors, Dr. Niels Pulles and Dr. Ipek Seyran Topan, for their guidance, patience, and support. Their expertise, insightful feedback, and encouragement were instrumental in shaping this research project.

Lastly, I want to acknowledge everyone at Company X that was subject of this study, who generously contributed their time and insights, without whom this research would not have been possible.

Roosmarijn van Luijtelaar
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Management Summary

This research was conducted at Company X, a prominent Dutch food manufacturing company, founded in 1867, that specializes in a diverse range of bakery products. Operating two factories in the Netherlands with over 500 employees, Company X has established a reputable position in the European food industry.

The focus of this report is on Line 154, a technologically advanced production line facing challenges, notably excessive unpacked waste. This issue directly impacts the Overall Equipment Effectiveness (OEE) metric, currently at 74.5%. This is below the OEE-norm of 85% that was set by Company X. The waste production exceeds the set norm of 7.5%. The identified problem area involves excessive waste of baked crackers after the oven and before the packing stations, quantified at 232,006 kilograms, costing €772,632.

The primary goal is to reduce the waste percentage from 15.1% to 12%, enhancing Line 154's OEE. A percentage of 12% was chosen after preparatory research in which the percentage of 12% seemed a feasible aim.

To address waste production in Line 154, a root cause analysis was conducted. Measurements on the conveyor belt, RobertPack, and Terminator 2 revealed issues contributing to waste. Key findings include outer cracker misalignment, delicate cracker breakage, and stacking problems in Terminator 2, causing line stops.

In addressing the waste production issues in Line 154, three strategic solutions have been proposed:

1. (1) To tackle the problem of missing or misaligned crackers, a system will be implemented to correct misalignment before crackers reach the end of the Conveyor Belt.
2. (2) This solution involves modifying the steel structure of Terminator 2 by introducing a sloped surface. This alteration is designed to prevent improperly stacked crackers from getting stuck, thereby reducing errors in the Flowpacker.
3. (3) To mitigate the impact of line stops, a dynamic U-shape buffer with a capacity of four minutes will be introduced between RobertPack and Terminator 2.

The costs and gains accessory to each solution are given in the following table:

Solution	Waste reduction in kg	Cost of Solution in €	Cost saving in €
1: The correction of missing and/or misaligned crackers	11,255 kg	€1000	€22,510
2a: Preventing crackers from getting stuck in Terminator 2 with Sloped Iron Structure	52,308 kg	€2000	€104,616
2b: Preventing crackers from getting stuck in Terminator 2 with Cardboard Wall	28,658 kg	€0	€57,315
3: Installing a buffer in between RobertPack and Terminator 2	54,046 kg	€350,000	€107,266 worth of waste is being saved each year. The investment of the buffer would be 'paid off' in 3.5 years.
TOTAL	117,609 kg	€354,000	€235,218

The work proposes to address problems in management as well, namely addressing high turnover among line operators involves motivation and recognition. Recommendations include encouragement, highlighting achievements on social media, quarterly improvement meetings, and a structured path for professional development.

Implementing these solutions and managerial recommendations can significantly reduce waste, enhance employee satisfaction, and improve Line 154's overall efficiency, contributing to Company X's long-term success.

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1 Introduction

Chapter 1 introduces the research and explains the main problem to be addressed. In *Chapter 1.1*, we talk about the company where the research is happening. *Chapter 1.2* gives more background, focusing on the issue in the problem area of Line 154 and its key performance indicators (KPIs). The action problem of this research is discussed in *Chapter 1.3*, including a problem cluster in which related issues are explained. *Chapter 1.4* presents the research questions that guide the whole research. Finally, *Chapter 1* concludes in *Chapter 1.5,* where we explain how we plan to solve the problem based on the research questions we've laid out.

1.1 About the Company

Company X is a prominent Dutch food manufacturing company known for its extensive range of bakery products. Founded in 1867, in the Netherlands, Company X has established itself as a well-respected brand in the European food industry. The company's product portfolio primarily focuses on baked goods, including various types of bread, crackers, rusks, and biscuits. Over the years, Company X has maintained a commitment to quality and innovation, incorporating traditional recipes with modern production techniques to consistently deliver high-quality baked goods to consumers. Their dedication to using wholesome ingredients and adhering to high quality standards has helped them earn the trust and loyalty of customers. Company X has not only served the local Dutch market but has also expanded its presence internationally, exporting its products to various countries in Europe, as well as outside of Europe. Currently, Company X has two factories, both located in the Netherlands. The more than 500 employees are divided over these two locations.

1.2 Context Description

Company X has been manufacturing its crackers since 2010. Over the past three years, the company has been operating Line 154 in its current configuration. The problem area of the line that will be researched is illustrated in *Figure 1*. For ease of explanation in this and subsequent chapters, the problem area has been divided into two sections: Section A and Section B. The exact layout of the line, together with its components, will be discussed in detail in *Chapter 2*. Despite being one of the factory's most technologically advanced production lines, this line has faced various challenges. The part of the line that we will study in this research has one major problem: excessive unpacked waste.

To quantitatively assess the performance of Line 154, Company X uses the Overall Equipment Effectiveness (OEE) metric, a key performance indicator very often used within the manufacturing and production sector. OEE encompasses three components (Kalpande, 2014): the availability percentage, performance percentage, and quality percentage. What these percentages entail will be discussed in *Chapter 2* as well.

For Line 154, the OEE percentage is measured per production shift (Line 154 has three shifts per day). The OEE percentages measured during each shift are summarized and discussed weekly. The average weekly OEE percentage of the current year is 74.5%, which falls below the established norm of 85%. Regarding waste production, the average waste percentage per kilogram produced is currently 15.1%. This stands for 386,316 kilograms dry waste. The norm Compnay X stated for the waste production by Line 154 is 7.5%, which is equal to approximately 191,809 kilograms dry waste.

It is clear that Line 154 does not meet the norm on both the OEE percentage as well as the waste production.

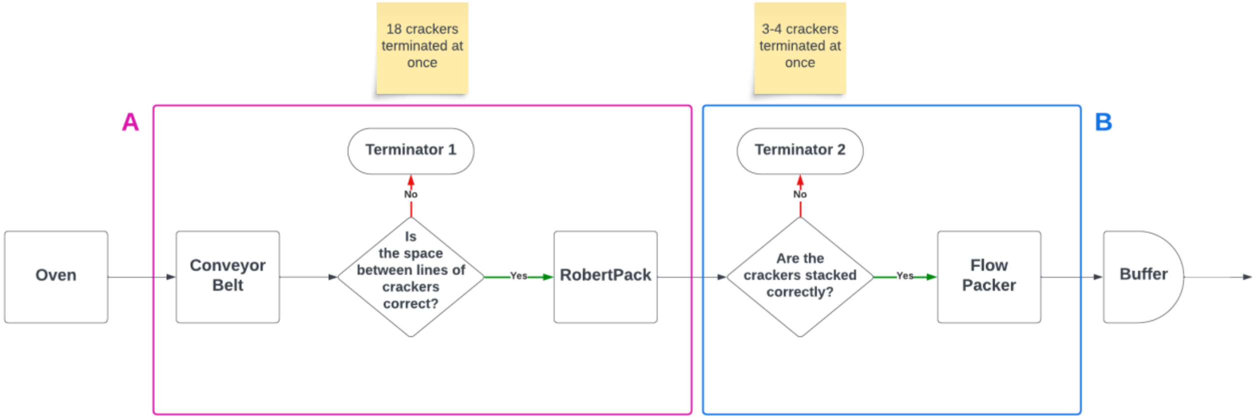

Figure 1 - Problem area of Line 154

With this research, the aim is to reduce the waste percentage from 15.1% to 12%. After doing preparatory research within Company X, reducing to a waste percentage of 12% seems like a feasible waste percentage to aim for. The current high waste number is a result of the excessive number of unpacked crackers that are being discarded by the line for several reasons. The waste percentage impacts the availability percentage indirectly, which will be further explained in *Chapter 2*. As the waste production is reduced, the availability percentage will in turn increase, which will improve the OEE percentage. Improving the OEE percentage of Line 154 is therefore a by-product coming out of this research.

1.3 Identification of the Action Problem

In the production line, the process entails the creation of crackers from raw materials, starting with the production of dough and the precision cutting of the dough into cracker shapes (*Figure 2*). The dough is then conveyed into an oven via a wide conveyor belt.

Figure 2 – Dough is getting cut into shapes

The problem, as stated in *Chapter 1.2*, is that the dry waste production in the line is too high. Dry waste is the waste of baked crackers, so waste that is produced after the oven. The termination of baked crackers, and thus the production of waste only takes place in the problem area of Line 154, sketched in *Figure 1*. This problem area is located after the oven and before the packing stations. As can be seen in the figure, the problem area consists of a few components. Each component causes waste in its own way.

Conveyor belt and Terminator 1

The conveyor belt comes out of the oven and conveys crackers from the oven to the RobertPack. Above the conveyor belt, near the RobertPack a camera system (Terminator 1) is installed that decides whether crackers need to be terminated or not. Particularly at the juncture where the conveyor belt meets RobertPack, the waste problem is excessive. At this juncture, the problem takes place in two ways:

(1) In the first, it relates to crackers missing or not being properly aligned on the conveyor belt. At the end of the conveyor belt, Terminator 1 discards rows of crackers whenever an outer cracker is missing or is not aligned properly. The conveyor belt transports crackers to the RobertPack in groups of 18. Terminator 1 relies on precise spacing detection. Therefore, whenever crackers on the outside of the rows are not in their correct position or are missing, crackers are discarded in their groups of 18.

(2) In the second, machine stoppages that occur due to line congestion caused by waste or errors result in the rejection of crackers. Whenever an error occurs in a machine down the line, crackers are discarded until the error has been resolved and the line starts working again. The robotic arms in RobertPack stop picking up crackers when an error occurs because the entire line is being paused. However, because crackers cannot stay in the oven and need to get through it, the conveyor belt keeps rolling. The rows of crackers not being picked up from the conveyor belt by the robotic arms in RobertPack get discarded immediately. When the line stands still for one minute, the conveyor belt discards 196 crackers.

RobertPack

The RobertPack is a machine that stacks crackers in stacks of three or four crackers – depending on the recipe – onto a narrow conveyor belt that leads the stacks through Terminator 2, to the Flowpacker. In the RobertPack itself, the waste issue lies in the delicate nature of the crackers, which are exceedingly thin and fragile – one recipe even more than the other. The robotic arms tend to break or misplace crackers on the belt leading to the Flowpacker. The repercussions of broken or misplaced crackers are that again an excessive number of crackers are being discarded. The aggregate effect of these issues leads to a decline in the availability percentage, ultimately impacting the overall OEE percentage.

Terminator 2

Terminator 2, located after the RobertPack, checks for breakage and proper stacking in the stacks. Whenever crackers in a stack are broken or not properly stacked, Terminator 2 blows them off the line.

Flowpacker

The Flowpacker, a machine that seals the individual stacks of crackers in plastic wrap. The construction of the plastic wrap hanging above the narrow conveyor belt is fragile, making it vulnerable to crackers getting stuck in the plastic wrap. Crackers interfering with the wrap-construction causes the machine to stop working, which in turn results in a line stop.

The indirect impact of the waste on the decline in availability percentage emerges from minor errors within the entire after-oven machinery caused by other waste and the response to this. Errors emerge from small defects in machines caused by waste that was not discarded properly and is now stuck on the line. While these errors, in isolation, might be considered minor inconveniences, they significantly extend the duration of abnormal idle time, which impacts the availability percentage significantly, as depicted in *Figure 3*. This problem contributes to more waste production as well, which will be further explained in *Chapter 2.*

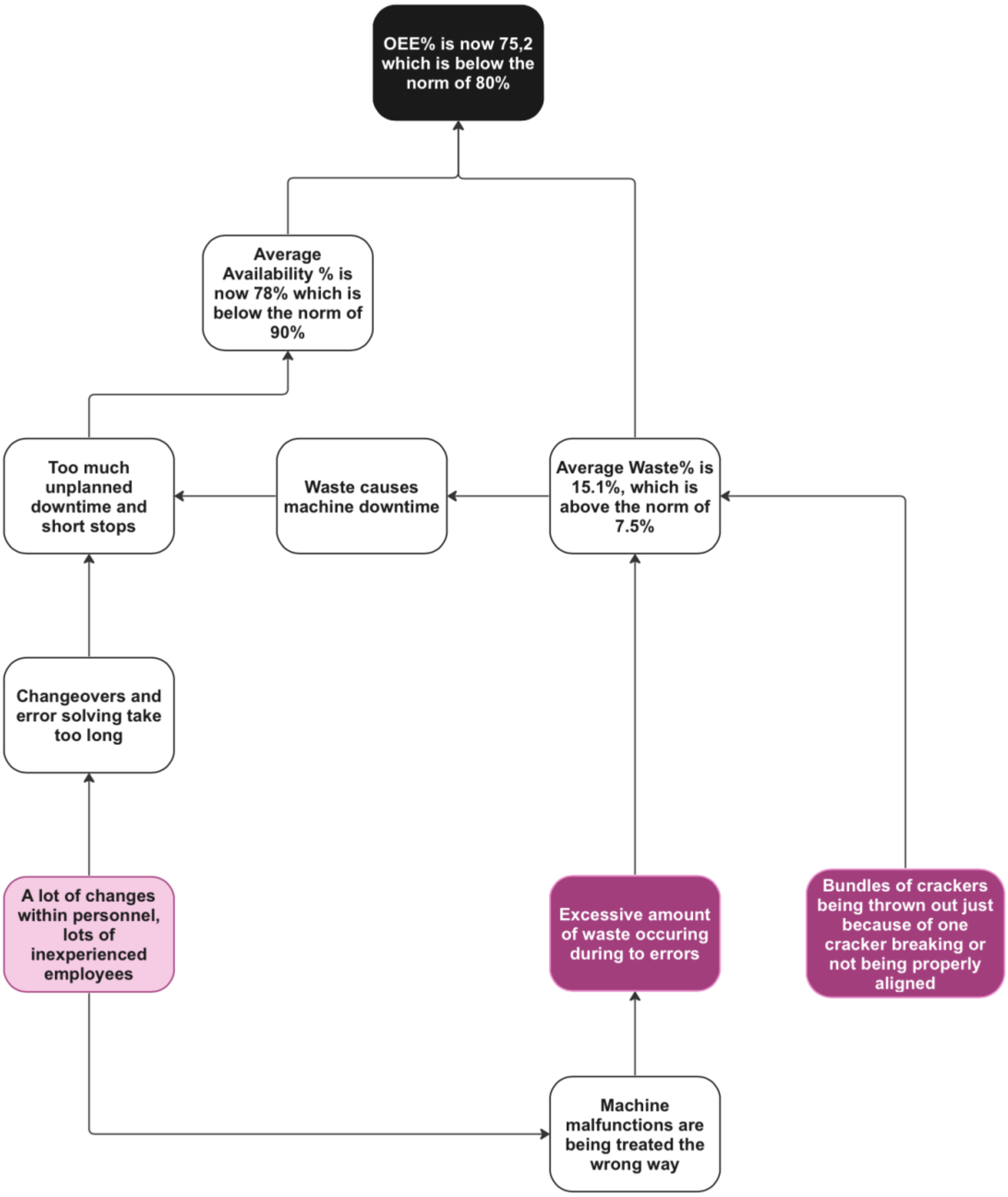

Figure 3 - Problem cluster of Line 154

The problem in numbers:

- The waste percentage is currently 15.1% which is below the norm of 7.5%.
- The current yearly amount of dry waste discarded by Line 154 is 386,316 kilograms, which is thus 15.1%.
- The OEE percentage of Line 154 is currently 75.2% which is below the norm of 80%.
- The availability percentage is currently 78% which is below the norm of 90%.

In summary, initial analyses and interviews conducted within the organization have revealed that among the three key performance factors of the OEE percentage - namely performance, availability, and quality - availability exhibits substantial room for improvement. After this analysis, it could be concluded that excessive waste production is the main issue, which has been decreasing the availability percentage. The idle time within the line, which is connected to the waste since waste can cause errors and congestion, could be viewed as a by-product, to narrow down the scope of this research. Finding solutions for decreasing waste production would in return also allow for reducing idle time. The action problem chosen is therefore: The average percentage of waste production of Line 154 is 15.1%, and the aim is to decrease it to a minimum of 12%.

This action problem means that the aim is to decrease waste production of Line 154 from 386,316 kilograms in a year to a minimum of 307,520 kilograms in a year.

1.4 Research Questions

After identifying the action problem, the main research question can be stated as follows:
"What are the current problems regarding the termination of crackers? Considering those, what are the most effective actions to implement by Company X to reduce the average waste production of Line 154 from 15.1% to a minimum of 12%?"
The research question is further deconstructed into specific research questions. The answers to these specific research questions together will form an answer to the main research question.

Sub research Question 1:
What is the current situation of the after-oven machinery in Line 154?
Sub research Question 2:
What are the key factors influencing waste production?
Sub research Question 3:
What specific strategies can Line 154's management implement to minimize waste production?
Sub research Question 4:
What constitutes the optimal improvement strategy for Company X concerning Line 154?

1.5 Problem-solving Approach

By following the structured problem-solving approach provided in this chapter, the production line issues in Line 154 will be effectively addressed so that the OEE percentage of the line will be optimized. The five steps of the problem-solving approach, including the accessory goals and deliverables of these steps are given in *Table 1*.

Table 1 – The five steps of my problem-solving approach

Step	Goal	Deliverables
1	Gaining a good understanding of the operational workings of Line 154 through observations and interviews with both line workers and individuals responsible for overseeing line performance.	A detailed process flow diagram for the after-oven machinery.
2	Identifying and analyzing literature that is connected to the minimization of waste and idle time within production lines.	Literature review of literature that will provide me with valuable knowledge for solving the problem of my research.
3	Examining data pertinent to the core issues identified in the first step of my problem-solving approach, to identify the root causes of my stated problem. The data will be data supplied by Company X as well as data recorded by me.	An overview of how much waste is being discarded and where. A thorough root-cause analysis.
4	Developing an improvement strategy for Line 154, together with a cost-benefit analysis.	Three solutions, all with a different degree of investment and profit.
5	Creating an overview of managerial advice for Company X to consider.	Managerial recommendations that would contribute to solving the action problem as well.
6	Providing the final deliverable for Company X.	An advisory report containing a comprehensive root-cause analysis, the most optimal course of action for Company X and a cost-benefit analysis.

Each sub-research question stated in the previous section, contains knowledge questions that will structure the research. Besides this, creating a separate research design for each research question enhances the efficiency of the study since each research question requires different techniques for conducting research. The sub-research questions with their accessory knowledge questions and their research designs are given in *Table 2*.

Table 2 - Research questions, their goals and deliverables

Sub research question	Accessory knowledge questions	Research design
What is the current situation of the after-oven machinery in Line 154? (Chapter 2)	**1:** What constitutes the layout of Line 154, and how does the packing process within in operate? **2:** What is the present performance status of Line 154 concerning idle time?	Descriptive research - Cross-sectional - Observation - Interviews
What are the key factors influencing the waste production? (Chapter 4)	**1:** What are the possibilities and constraints regarding changing the line layout? **2:** What are the best ways the waste production can be reduced?	Explanatory research - Identifying causal relationships between variables. - Identifying root causes. - Amount of waste will be counted. - Types of errors will be recorded.
What specific strategies can Line 154's management implement to minimize waste production? (Chapters 5 and 6)	**1:** What are the responsibilities of the different operators? **2:** What are the underlying management issues contributing to waste production?	Prescriptive research - Action-oriented research - Finding solutions by doing interventions and measuring their effects.
What constitutes the optimal improvement strategy for Company X concerning Line 154? (Chapters 5 and 6)	**1:** How can Company X address the identified root causes effectively, leading to a reduction in excessive waste reduction? **2:** What are the results of the cost-benefit analysis for the solutions derived during this research, and what implications do these findings hold for Company X?	Providing deliverables - Comprehensive root-cause analysis. - Determining the most optimal course of action for Company X. - A cost-benefit analysis.

2 Problem Analysis of Line 154 – The current main issues

This chapter aims to answer the research question: "*What is the current situation of the after-oven machinery in Line 154?"*

To accomplish this objective, the knowledge questions related to this research question are being answered in distinct sections. *Chapter 2.1* describes what constitutes the layout of Line 154, and how the packing process within it operates. *Chapter 2.2* touches on the present performance status of Line 154 concerning waste.

2.1 The Process of Line 154

"What constitutes the layout of Line 154, and how does the packing process within it operate?"
Line 154 consists of multiple components. To remain within the set scope of the research, only the components within the problem area of the line will be discussed. The specific part of the line that deals with excessive unpacked waste extends from the conveyor belt entering the RobertPack to the first packing machine, the Flowpacker. The entire problematic area is again illustrated in *Figure 4*. For ease of explanation in all chapters, the problematic area has been divided into two sections: *Section A* and *Section B*. The primary reason the problem area contributes significantly to excessive waste is that crackers remain unpacked in this section. Therefore, it is difficult to reintegrate the crackers back into the line. There is no space in the line for all unpacked crackers to be brought back into it.

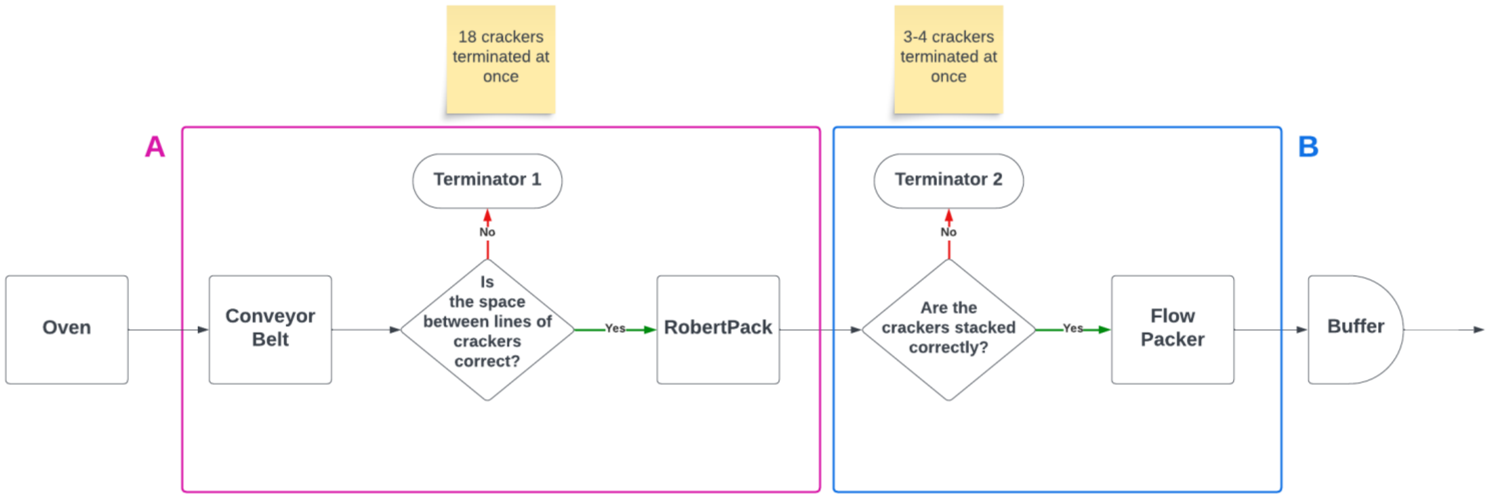

Figure 4 - Problem area of Line 154 repeated

In the explanation of the process of Line 154, we start with *Section A*.

Conveyor belt
After the crackers are baked in the oven, the conveyor belt carries the crackers through Terminator 1 to the RobertPack. The crackers are always grouped into 18 crackers, placed in two rows consisting of nine crackers. The two rows of 9 are separated by a small space. The next two rows of crackers start after a bigger space. *Figure 5* shows two groups of 18 crackers, thus four rows of 9 crackers, being conveyed by the conveyor belt.

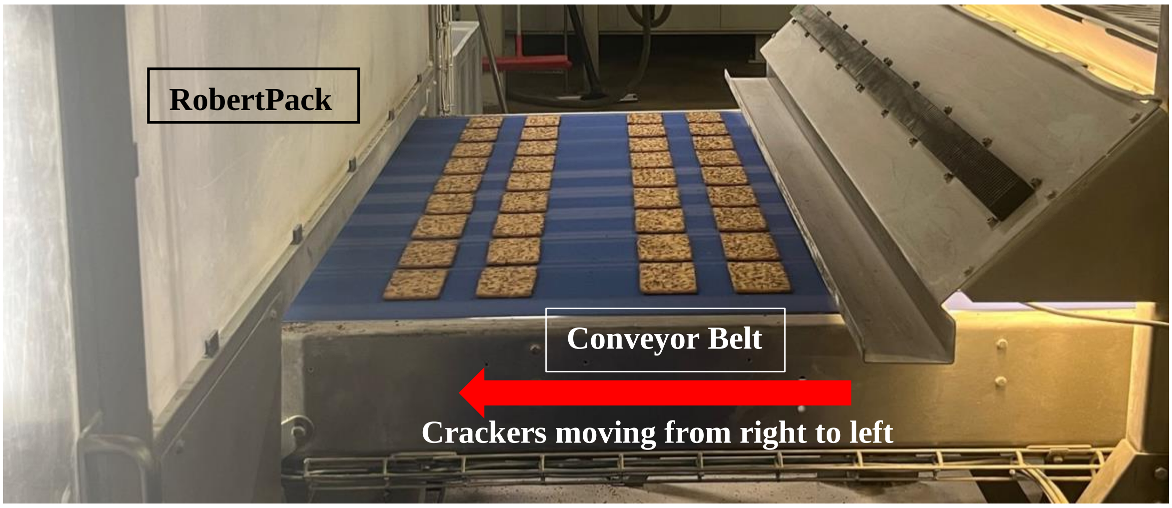

Figure 5 - The conveyor belt leading into the RobertPack

Terminator 1

Terminator 1, located at the end of the conveyor belt, near the RobertPack, terminates crackers in two scenarios. The first scenario occurs when one or more crackers are misaligned in their row. If an outer cracker is not correctly positioned, Terminator 1 discards the entire group of 18 crackers (*Figure 6*). This is because the first robot arm of the Robert Pack relies on the correct placement of outer crackers to estimate the positioning of its ramifications. Consequently, the robot arm cannot function properly when these crackers are misaligned. In the second scenario, a cracker in the middle of the row is not aligned or missing. In this case, Terminator 1 does not discard the group of crackers as that missing or misaligned cracker does not affect the spacing estimation. (*Figure 7*).

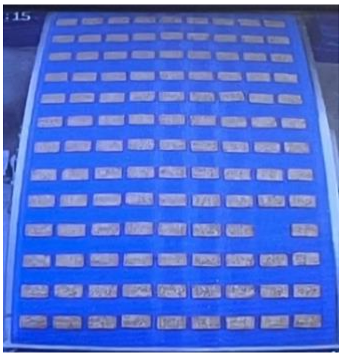

Figure 6 - A cracker in the middle is missing

Figure 7 - Outer and inner crackers are missing

RobertPack

The RobertPack is a machine equipped with two robotic arms responsible for transferring crackers from the conveyor belt into stacks of three or four, depending on the recipe, onto the belt leading to the Flow Packer. The first robotic arm simultaneously picks up two rows of nine crackers and places them on separate belts, employing a suction procedure involving vacuum assistance (*Figure 8*). Once each belt accumulates nine stacks of three (or four) crackers, it transfers the two rows of stacks to the second robotic arm. Subsequently, the second robotic arm (*Figure 9*) picks up the first row of nine stacks and deposits them onto the rolling belt directed towards the Flow Packer, repeating this process with the second row of nine stacks. Robotic arm 2 contains 9 small arms that can pick up the stacks of crackers.

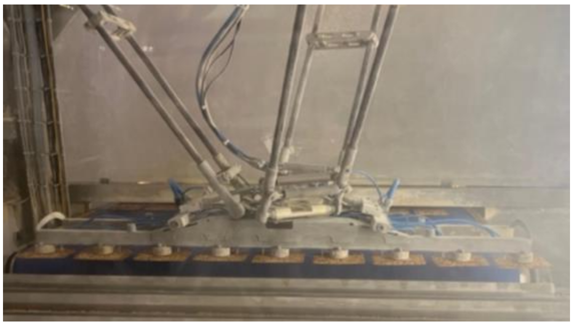

Figure 8 – Robotic arm 1 RobertPack

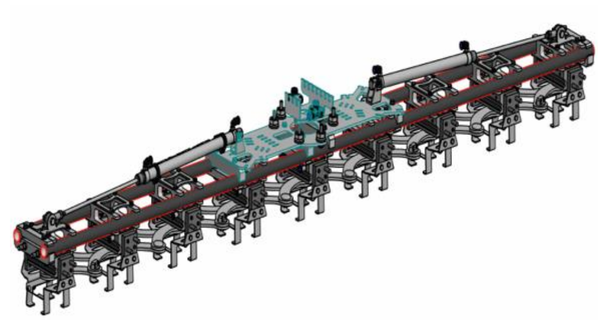

Figure 9 - Robotic arm 2 RobertPack

Terminator 2

Terminator 2 is positioned two meters after the RobertPack, consisting of a camera and a terminator (*Figure 10*). The crackers are conveyed on a belt in stacks of three or four from the RobertPack, passing through Terminator 2, and reaching the Flow Packer. The reason why Terminator 2 has been installed in the line is to ensure that the cracker stacks are free from any broken or deformed crackers. Additionally, it serves to prevent stacks from having fewer than three or four crackers. In one recipe, the Espelta recipe, Terminator 2 is being reinforced with a 'vision'. This vision has been installed to make sure all crackers are perfectly flat and not broken. The vision is therefore even more precise and critical than the regular camera of Terminator 2.

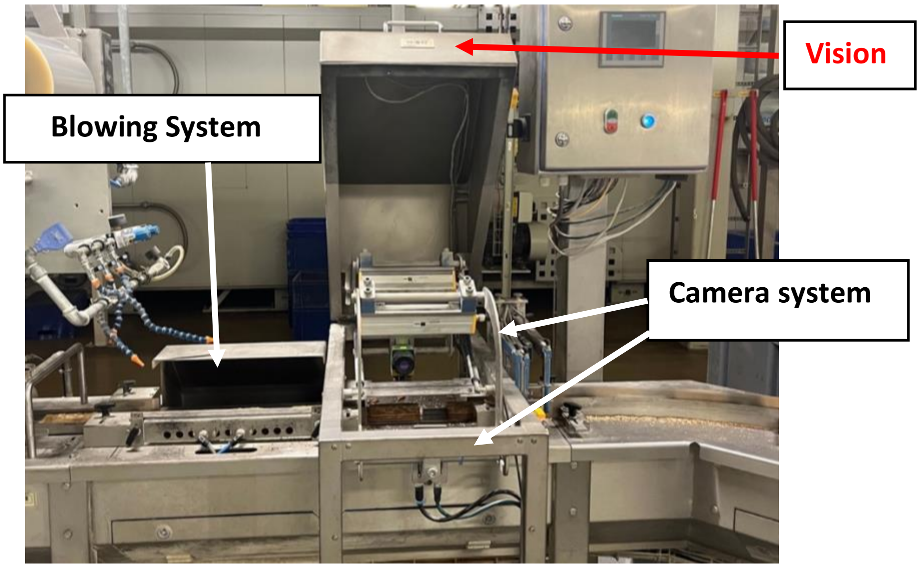

Figure 10 – Terminator 2

Flowpacker
Before the crackers are stacked and placed in a box destined for shipment to stores and other customers, each stack of crackers undergoes individual packaging in sealed plastic. The task of handling this individual packing process is assigned to the Flowpacker (*Figure 11*). Following the RobertPack, the stacks of crackers are then conveyed through Terminator 2 to reach the Flowpacker. To stay within the research scope, the technical workings of the Flowpacker will not be explained further. The sole significant aspect of the Flowpacker in this research context is its role in contributing to errors that impact waste production both before and within the RobertPack.

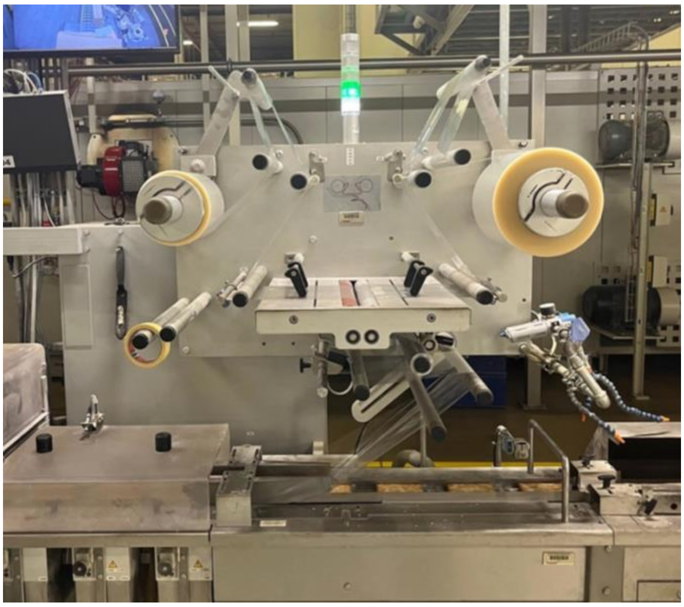
Figure 11 – Flowpacker

Recipes produced by Line 154
In total, eight recipes are being produced by Line 154. Each recipe has a certain number of production hours. During my research and when calculating costs, it is very helpful to know the exact production hours and cracker weight per recipe. Therefore, the different recipes and their number of production hours, including the percentage of the total production hours are given in *Table 3*.

Table 3 - Cracker recipes with accessory production hours

Recipe	**Production hours in a year**	**Cracker weight in grams**
Ontbijtcrackers Espelta	2540.77	20
Lichte Crackers Spelt	851.96	11,88
Ontbijtcrackers Spelt Volkoren	801.47	22,5
Lichte Crackers Volkoren	581	11,88
Ontbijtcrackers Meerzaden	408.34	22,5
Ontbijtcrackers Volkoren Meergranen	361.99	22,5
Zadencrackers Zonnebloem	53.74	22,5
Zadencrackers Pompoen	24.19	22,5
TOTAL	5,623.46	-

2.2 Key KPI's at Company X

The following knowledge question will be answered in this section:
What is the present performance status of Line 154 concerning idle time?

This section is divided into two parts. In the initial part, we will focus on the OEE percentage. In the subsequent part, we will focus on waste. This involves a thorough analysis of the current amount of waste generated by the line and its impact.

2.2.1 OEE Percentage

To quantitatively assess the performance of Line 154, Company X utilizes the Overall Equipment Effectiveness (OEE) metric, a well-recognized key performance indicator, particularly within the manufacturing and production sector. OEE encompasses three primary components (Kalpande, 2014), availability, performance, and quality:

Availability (%): This factor measures the proportion of time the equipment is operational compared to the planned production time. It considers various factors leading to downtime, including equipment breakdowns, changeovers, and maintenance.

(1) Availability (%) = (Operating Time / Planned Production Time) x 100

Performance (%): Performance evaluates how closely the actual production output aligns with the maximum achievable production rate, considering factors such as machine speed and efficiency.

(2) Performance (%) = (Actual Production / Ideal Production) x 100

Quality (%): Quality assesses the ratio of defect-free products to the total number of products produced, reflecting the line's ability to maintain consistent product quality.

(3) Quality (%) = (Good Units Produced / Total Units Produced) x 100

The Overall Equipment Effectiveness is derived by multiplying these three factors together:

(4) OEE (%) = Availability (%) x Performance (%) x Quality (%)

Company X uses this formula to calculate the OEE percentage of Line 154 with the help of a software application called *OEEblue*. *OEEblue* is a tool in which all production data of a production line can be recorded. Data such as idle time, types of malfunctions, and amount of waste are being recorded and inserted into the tool by line operators (Operator B's) and operators responsible for the line (Operator C's). The tool will then make clear overviews that showcase the performance of the production line. A precise breakdown of the OEE formula used by *OEEblue* is given in *Table 4*.

Element of the formula	**Calculation**
The *Availability rate* is the time that the machine is actually producing products, compared to the time that it could have been producing products. Less than 100% *Availability rate* indicates time loss: breakdowns, waiting, and line restraints.	$Availability\ rate =$ $\frac{\sum production}{\sum production + \sum Idle + \sum Failure + \sum Linerestraint} \times 10$
The *Performance rate* is the actual output compared to the theoretical output (expected output given the theoretical maximum speed of the machine and the actual production time.) Less than 100% *Performance rate* indicates speed loss: speed loss and reduced speed.	$Performance\ rate = \frac{actual\ output}{target\ output} \times 100\%$ $actual\ output = good\ products + scrap + rework$
The *Quality rate* is the good output (number of good products) compared to the actual output. Less than 100% *Quality rate* indicates quality loss: scrap, rework, and start-up loss.	$quality\ rate = \frac{good\ products}{actual\ output} \times 100\%$ $actual\ output = good\ products + scrap + rework$

Table 4 - Components of the OEE percentage

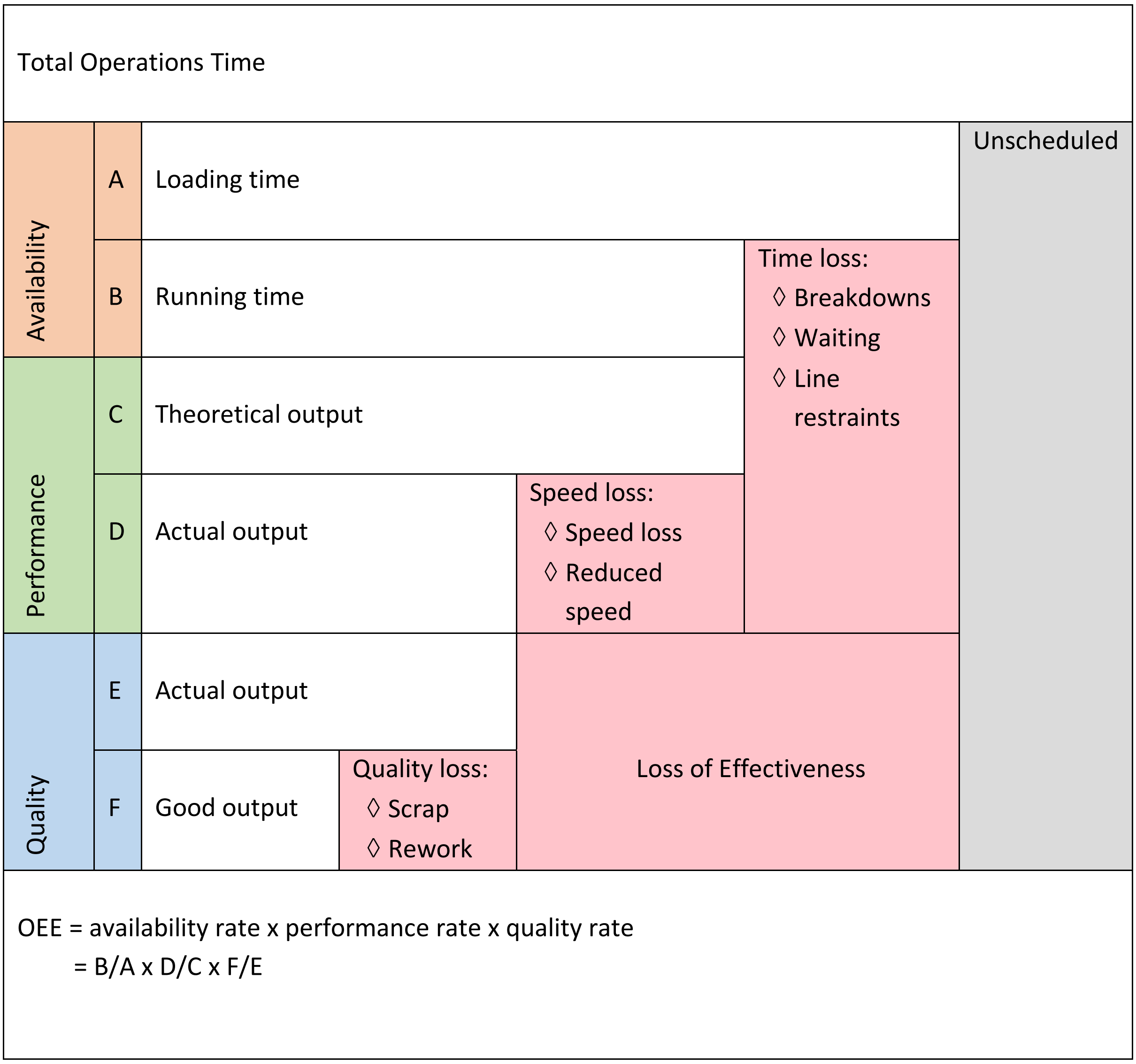

Figure 12 – How losses in availability, performance, and quality relate to each other

Figure 12, shows how losses in availability, performance, and quality relate to each other and reduce the effectiveness of machinery.

For clarity, the meaning of the bars in Figure *12* are being explained in more detail:

- Total operations time: Indicates the total time that a machine is available to manufacture products—usually 480 minutes per 8-hour shift (or 510 minutes including a break).
- Loading time: The time available for production (Total operations time) minus the time not scheduled for production (e.g. due to holidays, no orders, or no personnel available).
- Running time: The time during which actual output was produced, i.e., loading time minus times losses (e.g. breakdowns, waiting, changeover, and line restraints).
- Theoretical output: The expected output of the machine during the actual production time based on the theoretical maximum speed (Running time x theoretical maximum speed).
- Actual output: Contains the total number of units actually produced: the difference between the theoretical and actual output indicates the occurrence of speed losses.
- Good products: All products that were 'IN SPEC': in other words, the actual output minus quality losses such as scrap and rework.

OEEblue showcases all calculated and recorded data in bar charts and pie charts. The *OEEblue* tool records the weekly measurements of the availability, performance, and quality percentages, enabling the summarization of weeks of OEE data. Two OEE summaries are given in the following figures: The first overview encompasses the performance of Line 154 from 15-11-2022 to 15-11-2023, as depicted in *Figure 13*.

Figure 13 – OEE summary of period 15-11-2022 to 15-11-2023

The second overview (*Figure 14*) shows the performance of Line 154 from 02-01-2023 to 26-11-2023, showcasing the performance from the start of 2023 until the end of November.

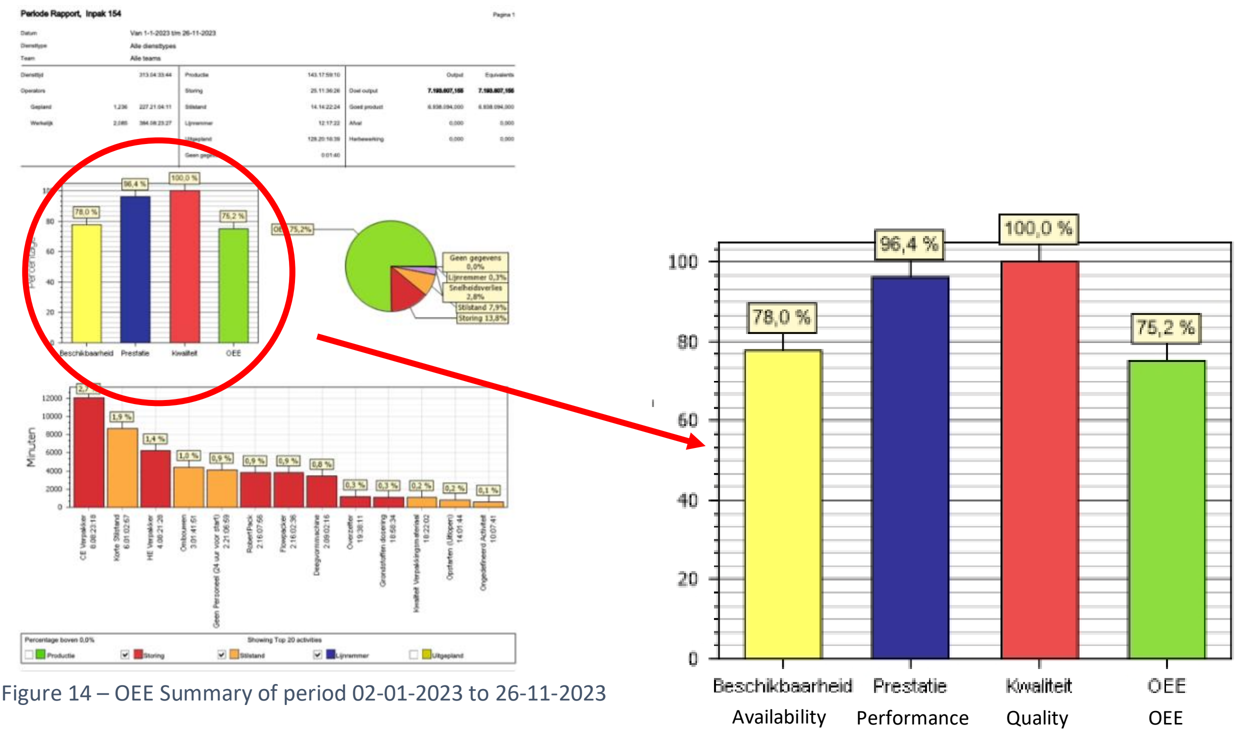

Figure 14 – OEE Summary of period 02-01-2023 to 26-11-2023

Several conclusions can be drawn from these overviews. Firstly, the quality percentage is impeccable, signifying that Line 154 is designed in such a way that only high-quality boxes of crackers pass through, with any substandard ones being discarded within the line. Secondly, the performance percentage is notably high, although there have been occasional instances of speed loss attributed mostly to misunderstandings and miscommunications among line operators. This issue may be linked to the challenge of excessive waste production, which will be explored further in *Chapter 4*. Thirdly, the availability is relatively low, particularly when compared to the other two percentages.

2.2.2 Waste Production

Company X uses a 'waste logbook' to record the amount of waste that is produced by Line 154 per day. The logbook showcases the type of recipe with its accessory date and waste production. For Company X 1 kilogram of dry waste counts as a cost of €2. Based on the data provided by the 'waste logbook' and given that 1 kilogram dry waste costs Company X €2, a summary of the total costs based on Company X's waste data, given the kilograms in waste produced per recipe has been made. The summary is provided in *Table 5*.

Table 5 - Total yearly costs based on waste data provided by Company X

Total Costs based on Waste data provided by Company X in the period of 15/11/2022 to 15/11/2023			
Recipe	**Dry waste in kg 15/11/2022 - 15/11/2023**	**Total costs of dry waste**	**Kg dry waste per production hour**
Espelta	113,582	€227,164	44.7
Lichte Crackers Spelt	29,815	€59,630	35.0
Ontbijt Spelt Volkoren	37,459	€74,918	46.7
Ontbijt Volkoren Meergranen	19,043	€38,086	52.6
Lichte Crackers Volkoren	18,078	€36,156	31.1
Ontbijt Meerzaden	13,879	€27,758	34.0
TOTAL	**231,856**	**463,712**	**-**

As can be seen, the total dry waste production of Line 154 has cost Company X €463.712 this year. The 'Espelta' recipe generates the most waste but also has by far the most production hours. In proportion to production hours, the recipe 'Ontbijt Volkoren Meergranen' has the highest number of kg waste per production hour.

3 Literature review

Finding useful information regarding waste reduction in a production line is very important to answer the remaining research questions. This chapter will therefore focus on the valuable insights and techniques that have been gathered that will contribute to answering the research questions stated at the beginning of this thesis. When confronted with a problem regarding excessive waste in a production line, it is key to have a structured approach to tackling the problem.

During the search for methods and tools that could be implemented in the approach, a case study was found of a ceramics factory in Thailand dealing with excessive waste (Narapinij, 2016). This case study highlights what methods are very useful for solving this specific problem. The methods that seemed most valuable for the research query were chosen, which will be discussed now.

3.1 PDCA cycle

The first tool discussed in the case study is the PDCA cycle. The Plan, Do, Check, Act (PDCA) cycle proves to be an invaluable tool in addressing the research problem at hand and acts as a foundation for the research in the case study. After seeing the similarities between our study and the Ceramics Facotry case study, it can be stated that the PDCA cycle would be a proper foundation for our research as well. The PDCA cycle consists of four steps (Johnson, 2002):

(1) Plan: Recognize an opportunity and plan the change. Identify the problem and analyze the problem. Then, come up with possible solutions (changes) that are in line with the problem statement.
(2) Do: Test the change. Develop solutions and implement the solution(s).
(3) Check: Review the test. Evaluate the results; was the desired goal achieved?
(4) Act: Take action based on what you learned in the 'Check' step. Standardize the solution.

To initiate the cycle, the first step involves meticulous planning of three crucial elements: crafting the problem statement and the desired goals, conducting a root cause analysis, and coming up with possible solutions. This first step we have already started at the beginning of the research. The solution's scope, objectives, and criteria have been set, and the necessary resources, roles, and responsibilities have been identified (explained in *Chapters 1, 2,* and *4*) The generation of solutions will be happening in *Chapter 5,* which is still a part of the first step. Moving on to the second step, the identified solution(s) are implemented on a small scale or within a controlled environment. Adhering closely to the devised plan is key, with an emphasis on documenting all actions and observations. In my research, this step is described in *Chapter 5.2.* The third step revolves around checking the outcomes, entailing the analysis of data and feedback acquired during solution implementation. A critical evaluation is conducted, comparing actual performance against expected performance to determine whether objectives and criteria outlined in the planning stage have been met. In my research, a critical evaluation is conducted in *Chapter 6*. The final step entails acting upon the findings, where decisions are made based on the analysis. Three potential options are considered: standardize, adjust, or abandon. The end goal of our research is to provide Company X with an advisory report regarding possible options to reduce waste production and improve the OEE percentage of Line 154. The choice to standardize, adjust, or abandon is for Company X to make eventually. However, the last step will still be kept in mind when giving the advice.

3.2 Pareto Chart

After strategizing their problem-solving approach, the researchers delving into the ceramics factory case study proceeded by gathering data on production process waste. They meticulously documented each type of waste in two distinct tables, combining the information into a Pareto Chart. The first table's columns displayed the recorded month/year, the overall number of produced pieces, the quantity flagged as waste, and the corresponding waste percentage. Simultaneously, the second table delineated the various waste types, such as chipping, pinhole, and crack (*Figure 15*). Subsequently, the researchers synthesized this data to generate a Pareto Chart illustrating the distribution of waste within the production line (*Figure 16*). The way in which these researchers have documented their measurements is clean and concise and so this type of data registration will be used for the measurement recordings off our research. These measurments will be discussed in *Chapter 4*.

Table 1 The data before improvement.

Month/year	Production (pieces)	Waste (pieces)	Waste (%)
September/2013	1,086	196	18.04
October/2013	1,392	132	9.48
November/2013	2,404	213	8.86
December/2013	2,794	148	5.29
Total	7,676	689	8.97

Table 2 The type of waste.

Type of waste	Waste (pieces)	Waste (%)
Chipping	276	40.0
Pinhole	243	35.3
Crack	114	16.5
Bubble	50	7.3
Other	6	0.9
Total	689	100.0

Figure 15 – "Distinct tables for waste," Puttasayan Narapinij, *Waste reduction in a Manufacturing Process: A case study of Ceramics Factory in Thailand*, 2016.

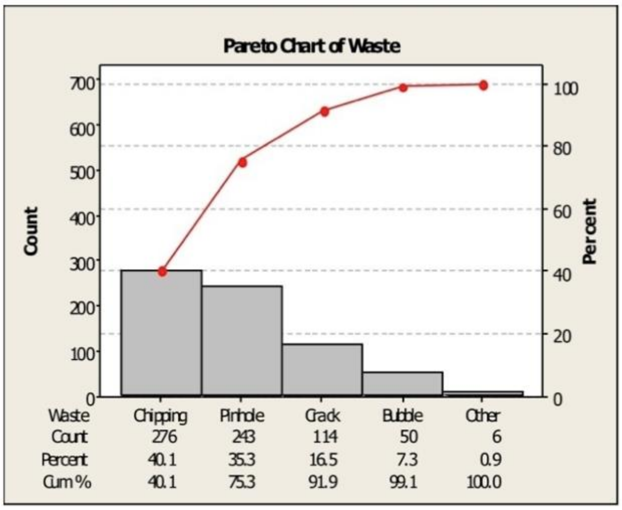

Figure 16 – "Pareto chart displaying waste," Puttasayan Narapinij, *Waste reduction in a Manufacturing Process: A case study of Ceramics Factory in Thailand*, 2016.

3.3 Ishikawa Diagram

Building on the data found in the Pareto Chart section, the researchers started analyzing the causes of waste generated in the production process. The analysis was done by using an Ishikawa Diagram (*Figure 17*), focusing on waste generated by the man, machine, material, method, and environment.

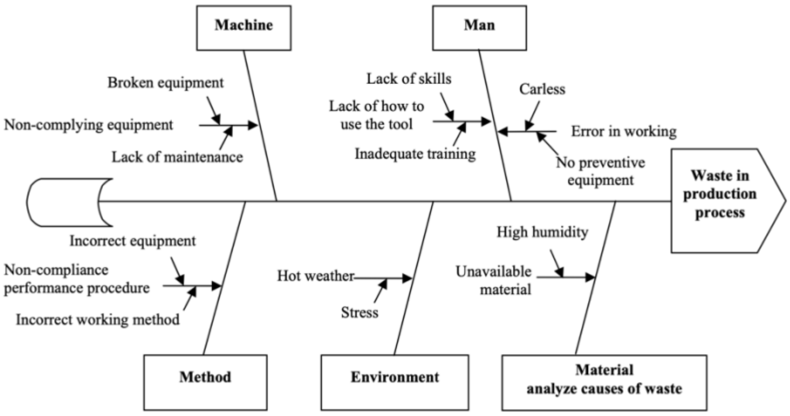

Figure 17 – "Ishikawa Diagram," Puttasayan Narapinij, *Waste reduction in a Manufacturing Process: A case study of Ceramics Factory in Thailand*, 2016.

This represents a classic version of the Cause-and-Effect diagram, a highly regarded tool for pinpointing the root causes of industrial issues. This method proves to be effective in guiding the identification of areas where additional data might be required (Slack, Brandon-Jones & Johnston, 2016). The potential causes of the problem typically gathered from brainstorming sessions or research, are outlined in the branches, often referred to as fish bones, of the diagram (Heerkens & Van Winden, 2017). Though the Cause-and-Effect diagram provides a good structure, it does seem like it would make the focus of our research a bit too broad. When looking at the root causes, we will focus on the 'machine', 'man', and 'method' branches of the diagram, but very tailored to the problem area and its components. After doing preparatory research at Company X, it can be concluded that the 'environment' and 'material' branches are out of scope for my root-cause analysis. Therefore, the exact layout of the diagram will not be used within the research, but a part of it will be kept in mind when doing the root-cause analysis in *Chapter 4*.

3.4 Why-Why Analysis

This method has not been mentioned in the case study of the ceramics factory in Thailand. However, the Why-Why Analysis can be used together with the Ishikawa Diagram. A root cause is the primary factor behind the existence of a problem. Eliminating or correcting this root cause is crucial to preventing the problem from recurring (Suárez-Barraza & Rodríguez-González, 2018). The Why-Why Analysis proves to be a valuable tool for identifying these root causes. It involves initially stating the problem and asking why it occurred. Once the reasons for the problem are identified, each reason is explored by asking why it occurred, and this process continues iteratively. The analysis proceeds until either a cause appears self-contained enough to be addressed independently or no further answers to the question 'Why?' can be generated (Slack, Brandon-Jones & Johnston, 2016). As it is clear where the problems occur, the Why-Why Analysis can be used to trace everything back to the root cause(s).

3.5 Poka Yoke

Preventing Mistakes Before They Happen. In factories and workplaces, there's a clever way to avoid mistakes, called Poka Yoke. It's like a safety net to stop errors before they happen. This method, created by a Japanese engineer named Shigeo Shingo, is all about making sure things are done right from the start (Shingo, 1986).

Imagine Poka Yoke as your helper to avoid mistakes. It's like having a friend watching out for you so you don't mess up. This idea comes from Japan, and it's used in many industries to make work smoother and better. Poka Yoke has two main jobs: finding mistakes as they happen and stopping them from happening at all. It's a mechanism of prevention and correction (Dudek-Burlikowska & Szewieczek, 2009). Poka Yoke likes to keep things simple and foolproof. For example, if you're in a car with an automatic transmission, it won't start unless you press the brake pedal. This simple rule prevents accidents. Poka Yoke pays attention to what you can see, hear, or feel. If something is about to go wrong, it gives you a signal. It's like a friendly beep or a visual sign telling you to fix things before they get messy.

In the root-cause analysis of our research, Poka Yoke will be kept in mind, to look for whether root causes are solvable with solutions that prevent mistakes. In the solution-generation phase, Poka Yoke will be kept in mind, to look for whether solutions are as simple as possible and whether they have a preventative function.

3.6 Muda, mura, muri

In Lean manufacturing, three Japanese terms - muda, mura, and muri - represent concepts related to waste, unevenness, and overburden. These principles are key components of the Toyota Production System and are aimed at improving efficiency, quality, and overall effectiveness in manufacturing processes.

Muda (Waste) refers to any activity or process that consumes resources but does not add value to the final product or service from the customer's perspective. There are seven types of waste identified in Lean thinking: transportation, inventory, motion, waiting, overproduction, overprocessing, and defects. The goal is to identify and eliminate these wastes to streamline processes and enhance overall productivity.
Mura (Unevenness) refers to variations or unevenness in the production process, such as fluctuations in demand, supply, or workflow. Unevenness can lead to inefficiencies, overburdening certain resources while leaving others underutilized, resulting in increased lead times, excessive inventory, and reduced overall productivity. The focus is on creating a more balanced and predictable production flow by identifying and addressing sources of unevenness.
Muri (Overburden) is the concept of overburden or strain on people, equipment, or processes beyond their designed capacity. Overburden can lead to fatigue, errors, increased defect rates, and decreased overall efficiency. The goal is to identify and eliminate sources of overburden by optimizing workloads, improving processes, and ensuring that tasks are within the capabilities of the individuals or equipment involved.

We will use these three terms to determine in what way all components of the line could contribute more to the improvement of the OEE percentage.

4 Root Cause Identification

Chapter 4 answers the research question "*What are the key factors influencing the waste production?"*. In *Chapter 4.1*, the measurements conducted in each component of the problem area and their results are being explained. *Chapter 4.2* dives into the root-cause analysis behind the waste production per component, based on the results of the measurements. *Chapter 4.3 puts focus on the Flowpacker in itself, discussing the types of errors occurring in the Flowpacker and the effects of it on the waste production by the line.* A summary of *Chapter 4* has been given in *Chapter 4.4*.

4.1 Measurements

In *Chapter 1 and 2*, a lot has already become clear about the severity of the waste production in the problem area of the line. To establish a useful overview of the waste produced in the distinct departments of the problem area by Line 154, we have done several measurements. Company X's 'Waste logbook' has provided us with information about the total amount of waste produced per recipe in the line. However, we want to know what section in the problem area contributes the most to waste production. That is why three measurements were done, each measurement focusing on another section in the problem area: the conveyor belt, the RobertPack, and Terminator 2. After this, two separate measurements were conducted, focusing on the big box next to the conveyor belt catching terminated crackers, and the errors occurring within the Flowpacker. The exact content and the aim of these measurements will be described below.

As discussed in *Chapter 2.1*, eight recipes are being produced by Line 154. Since the number of hours spent on the production of 'Vezelrijke Zadencrackers Pompoenpitten' and 'Vezelrijke Zadencrackers Zonnebloempitten' is minimal, and because of time constraints, these two recipes are not included in the first four measurements. The last measurement on the errors occurring within the Flowpacker does include these two recipes.

For the first three measurements, each measurement was repeated five times. This implies that a total of 15 measurements for each recipe were conducted. The average outcomes of these measurements are illustrated in graphs. The data generated during the measurements can be found in *Appendix A*. To be clear and concise; the measurements were conducted on the recipes mentioned in *Table 6*.

Table 6 - Cracker recipes with accessory production hours and cracker weight

Recipe	Production hours per year	Cracker weight in grams
Ontbijtcrackers Espelta	2540.77	20
Lichte Crackers Spelt	851.96	11,88
Ontbijtcrackers Spelt Volkoren	801.47	22,5
Lichte Crackers Volkoren	581	11,88
Ontbijtcrackers Meerzaden	408.34	22,5
Ontbijtcrackers Volkoren Meergranen	361.99	22,5

The results of all measurements are expressed in "number of crackers", not in "kilograms". For the sake of continuity, the results are converted into kilograms at the end.

4.1.1 Measurement 1

Measurement 1 focuses on the conveyor belt in Section A of the problem area, shown in *Figure 18*. As discussed in *Chapter 2*, the conveyor belt carries the crackers in groups of 18, two rows of 9, through the oven to the RobertPack. There are two scenarios in which the conveyor belt discards crackers:

(1) In the first scenario, in case of a malfunction, the entire line stops working, but the conveyor belt keeps going. The conveyor belt is forced to carry through, to prevent crackers from burning in the oven. This results in the conveyor belt not being able to retain all crackers. The conveyor belt throws crackers away until the line starts working again and the robot arms of RobertPack start to pick up the crackers from the belt.

(2) The other scenario in which the conveyor belt rejects crackers is whenever the outer crackers of the rows are not properly aligned or missing. Terminator 1 then comes into play and terminates two entire rows of crackers. This is a total of 18 crackers per time an outer cracker is not aligned or missing.

Both scenarios happen frequently in a production shift. To estimate the amount of waste this section produces in a set amount of time, two things were recorded during Measurement 1:

1. *What is the average hourly count of crackers thrown off the conveyor belt in case of a malfunction?*
2. *What is the average hourly count of crackers thrown off the conveyor when the outer crackers of the rows are not properly aligned or missing?*

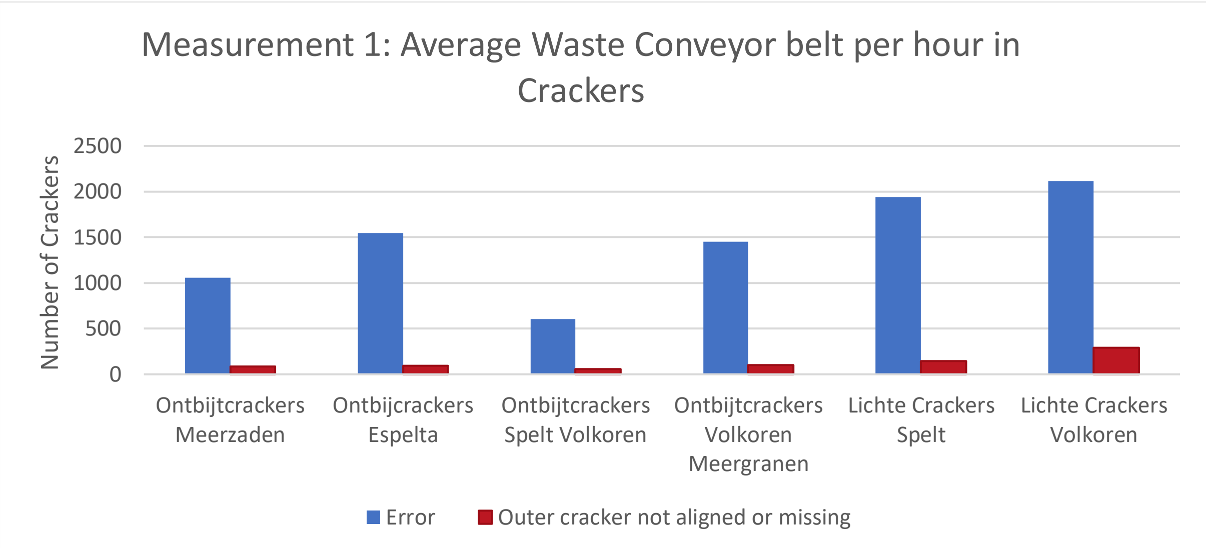

Figure 18 - Measurement 1 (conveyor belt)

There are a few remarkable things that can be seen in the graph in *Figure 18*. First, the amount of waste per hour caused by errors down the line is much more than the amount of waste per hour caused by outer crackers that are not aligned or missing. Second, both 'Lichte Crackers' recipes ('Lichte Crackers Volkoren' and 'Lichte Crackers Spelt') produce the most amount of waste per hour in this section. Third, the 'Ontbijtcrackers Spelt Volkoren' recipe produces the least amount of waste per hour in this section. On average 1,581 crackers are discarded per hour, only in this section.

Since the graph showed the large impact of an error within the line on the waste production by the conveyor belt, a third small measurement was done within this component:

3. *How many crackers are being discarded by the Conveyor Belt when the line stops working for one minute due to an error?*

The answer to this question is that when an error lasts one minute, 196 crackers are discarded. This does not differ per recipe since the conveyor belt has approximately the same speed for each recipe. The belt throws off crackers at the same constant speed, with 196 crackers per minute. This answer is not displayed in the graph.

4.1.2 Measurement 2

Measurement 2 focuses on the RobertPack and its robotic arms, located in Section A of the problem area. As previously described in *Chapter 2.1,* the RobertPack has two robotic arms. Robotic arm 1 picks up two rows of 9 crackers from the conveyor belt at a time and puts them on Belt 1 of the RobertPack. Robotic arm 1 does this three (or four, depending on the recipe) times back-to-back, until there are 18 stacks of three or four crackers. Robotic arm 2 proceeds by picking up the same two rows of 9 stacks from Belt 1 and places them one after another on the belt that carries all stacks of crackers out of the RobertPack, through Vision 2, to the Flow Packer.

Robotic arm 1 works with a vacuum mechanism to pick up the crackers. Robotic arm 2 picks up the stacks of crackers with tiny arms. It often so happens that robotic arm 1 does not pick up the crackers correctly, which results in one or more crackers breaking. This causes waste. Robotic arm 2 makes it then even worse since it is not able to pick up crackers in a correct manner anymore. Robotic arm 2 is not made for picking up stacks containing broken crackers. Waste production is therefore prevalent in the RobertPack. To estimate the amount of waste the RobertPack produces in a set amount of time, one thing was recorded during Measurement 2:

1. *How many crackers, within one hour, are on average broken by the RobertPack arms?*

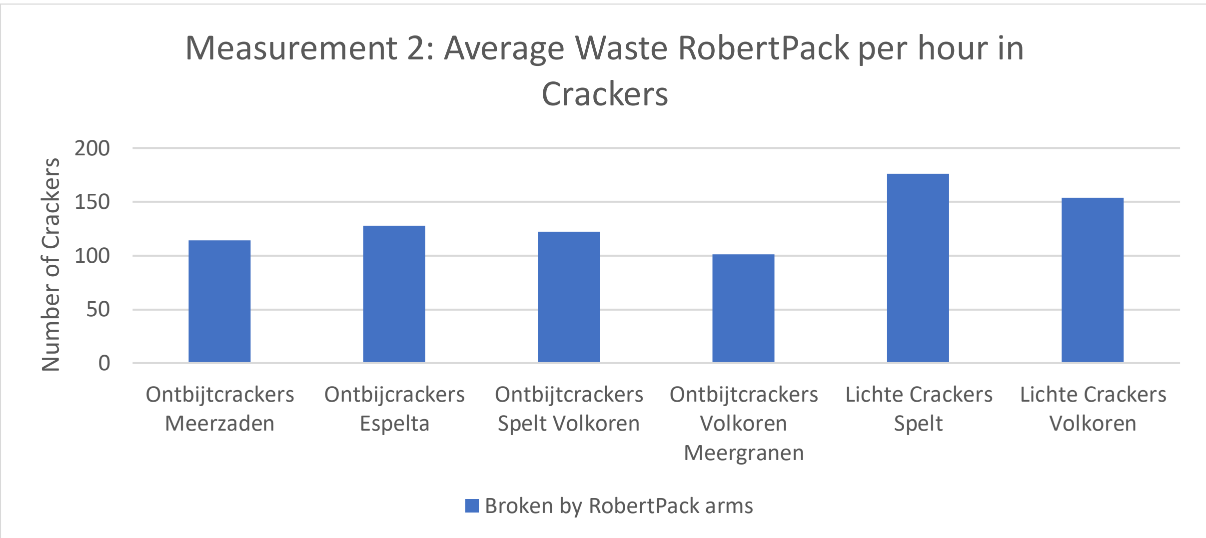

Figure 19 - Measurement 2 (RobertPack)

As can be seen, the number of crackers ending up as waste in the RobertPack component (Measurement 2) is considerably less than the number of crackers ending up as waste in the conveyor belt (Measurement 1). It can therefore be stated that the RobertPack generates overall less waste than the conveyor belt junction. What also can be seen, is that again the 'Lichte Crackers Volkoren' and the 'Lichte Crackers Spelt' generate the most waste compared to other recipes.

Looking at the numbers in *Figure 19*, we can calculate that on average, the component of the RobertPack discards 133 crackers per hour.

4.1.3 Measurement 3

Measurement 3 focuses on Terminator 2, stationed in Section B of the problem area. After the stacks of crackers are placed on the belt leading to the Flow Packer, the stacks go through Terminator 2. Terminator 2 uses a camera installation to check whether each stack of crackers is properly stacked and whether a stack does not contain broken crackers. In the situation that a stack is correct, Terminator 2 lets it through so it can be packaged by the Flow Packer. In the situation that a stack is not correct, Terminator 2 applies high air pressure to blow away the entire stack out of the line. The terminated crackers are captured by boxes placed underneath the belt. In the case of the 'Lichte Crackers Volkoren' or the 'Lichte Crackers Spelt' recipe, a stack of four crackers gets terminated each time, for the other recipes a stack of three crackers gets terminated.

For only one recipe, the 'Ontbijtcrackers Espelta', an additional mechanism is applied to Terminator 2: the Vision. The Vision is installed for this recipe because the customer ordering this product demands even stricter rules for the stacking of the crackers. This implies that the Vision is more critical and thus terminates stacks of crackers even faster. It will therefore increase the quality of the product, but at the same time increase the waste percentage as it will terminate cracker stacks even faster. To estimate the amount of waste Terminator 2 produces in a set amount of time, three things were recorded in Measurement 3:

1. *Within one hour, how many crackers are rejected/blown away by Terminator 2 when the Vision is activated?*
2. *Within one hour, how many crackers are rejected/blown away by Terminator 2 with the Vision turned off? This question is only of value for the "Ontbijtcrackers Espelta".*
3. *In the course of one hour, how many crackers are approved by Terminator 2 despite not being in good condition?*

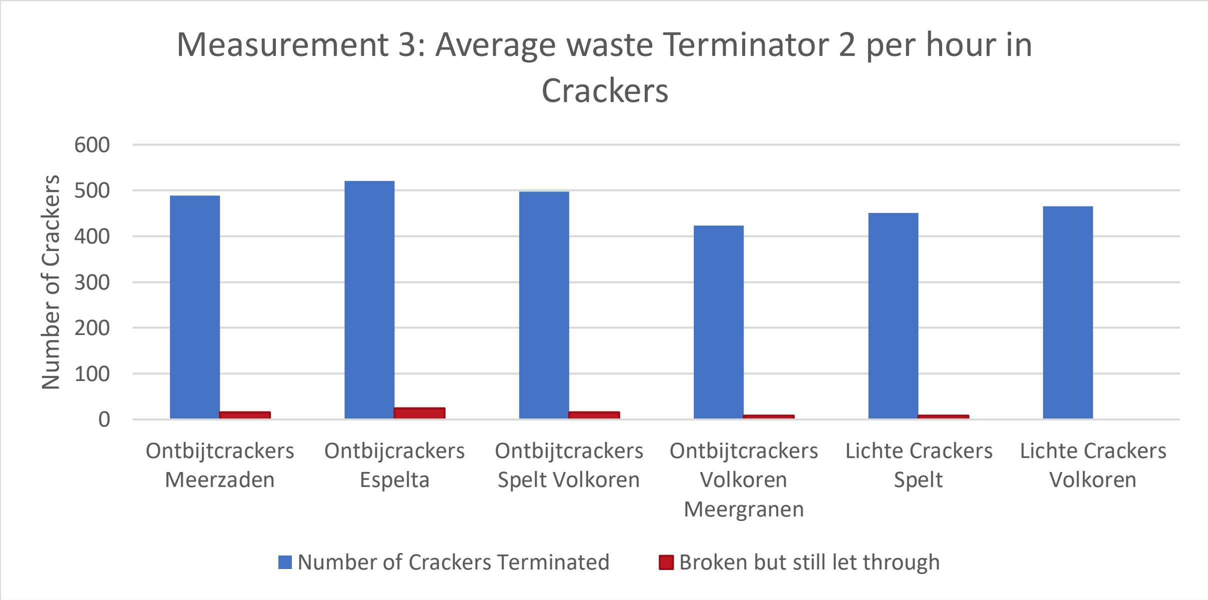

Figure 20 - Measurement 3 (Terminator 2)

Because the Vision is stricter, a distinction between measurements has been made: measurements with the Vision turned on and measurements with the Vision turned off. For the sake of continuity, the results are still being expressed in 'number of crackers', not in 'stacks'.
Figure 20 shows a minor difference between the distinct recipes when it comes to the amount of waste generated by Terminator 2. The waste production of the 'Ontbijtcrackers Espelta' recipe, when the Vision is turned on, is only a tiny bit higher than with the other recipes when the Vision is turned off. However, the number of crackers that are broken but still let through by Terminator 2 is higher for 'Ontbijtcrackers Espelta' than for the other recipes. The Vision thus causes more incorrect stacks to get through Terminator 2.

4.1.4 Measurement 4

Whenever crackers get discarded by the conveyor belt, they get thrown on another belt that transports them to a large box (*Figure 22*). This large box stores the crackers, until they eventually get transported to a forage factory. Thus, these crackers, are considered waste. It occurred to me the box contained a lot of crackers that were still completely intact and could technically be brought back into the line. To establish what percentage of the crackers in the large box are broken and what percentage is still intact, I conducted Measurement 4 in total 30 times. During each time a measurement was done, around 500 crackers were captured. The number of crackers that remained undamaged and the number that sustained damage were both recorded each time. So, the question accessory to Measurement 4 is as follows: "*How many of the 500 captured crackers are broken, and how many remain intact?*"

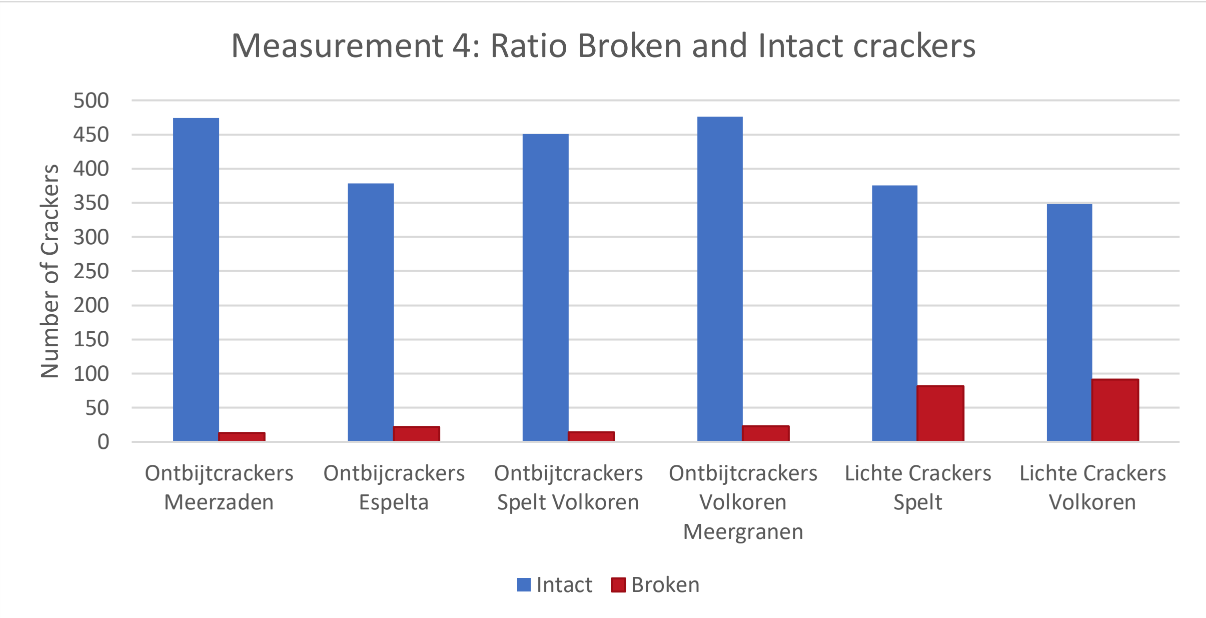

Figure 21 - Measurement 4 (Big box)

One thing that stood out was the fact that the ratio between broken and intact crackers was smaller for the 'Lichte Crackers' recipes than for the others. Including the 'Lichte Crackers' recipes in the average, the average percentage of intact crackers is 82.70%. Excluding the 'Lichte Crackers' recipes, gives an average percentage of 96.05% intact crackers. It can be concluded from these measurements that a high number of crackers labeled as “waste” are still intact and would be eligible to be brought back into Line 154.

Figure 22 - Big box catching terminated crackers from the conveyor belt

4.2 Root Cause Analysis per Component

After completing the measurements, the impact of each component on the total waste production by the line has become clear. The next step is to identify the root causes of waste production in the distinct components of the problematic area. A separate root cause analysis for each component has been conducted, which will be discussed in this chapter. The aim of the root-cause analysis is to eventuallly tackle the waste problem effectively and increase the availability percentage.

Root Cause Analysis Conveyor Belt and Terminator 1

Measurement 1 has shown that the section consisting of the conveyor belt and Terminator 1 contributes the most to the waste production in Line 154. Taking the average of the measurements displayed in *Figure 18,* this component discards 1,581 crackers per hour. Since Line 154 produces crackers for 5,623.46 hours total in a year, this results in 5,623.46 x 1,581 = 8,890,690.26 crackers being discarded per year. Given that the average cracker weight is 19,53 grams, this means that per year, the conveyor belt alone discards 8,890,690.26 x 0,01953 = 173,625.181 kg of waste on average. So, what is the root cause behind the large amount of waste? To find these, the two scenarios in which the conveyor belt discards waste are being analyzed.

The first scenario in which crackers are being discarded by the conveyor belt is about outer crackers on the belt not being aligned or missing entirely. Whenever one or more crackers in the middle of the conveyor belt (not the outer ones) are missing or not aligned, robotic arm 1 of the Robert Pack still proceeds to pick up both entire rows. Whenever one or more outer crackers on the conveyor belt are missing or not aligned, Terminator 1 steps in. It communicates to robotic arm 1 to not pick up any of the two rows, even if the second row is completely fine. Two rows of 9 crackers are then being discarded. This is because robotic arm 1 calibrates its scope based on the outer two crackers in a row. If one of the outer crackers is missing or not properly aligned, the robotic arm cannot estimate what the width of its arm needs to be to pick up all crackers in a proper manner. The question is now; *Why are there crackers missing (inner and outer ones) when they come out of the oven?* Well, before the crackers can go into the oven, the cracker dough is cut into cracker shapes and rolled out. Sometimes, during the rolling process, one piece of cracker dough sticks to the roller. That piece gets recycled back into the rest of the dough but leaves an empty spot on the conveyor belt.

The second scenario in which the conveyor belt discards crackers is when an error occurs somewhere down the production line, the entire line stops, but the conveyor belt keeps rolling. The conveyor belt needs to proceed with rolling because it would otherwise cause crackers to burn in the oven. However, the crackers on the conveyor belt are not picked up by robotic arm 1 and thus are discarded immediately and end up in a large box. The longer it takes for an error to be resolved and the line can start working again, the more crackers are being discarded. An error with a duration of one minute causes 196 crackers to turn into waste, according to *Measurement 1*.

Root Cause Analysis RobertPack

Measurement 2, described in *Chapter 4.1.2*, shows that the RobertPack discards fewer crackers than the Conveyor Belt. However, on average RobertPack discards 133 crackers per hour (*Figure 19*). Roughly converted, this is about 13,667 kg of waste per year, which is still a significant amount of waste.

In the RobertPack, the issue lies in the delicate nature of the crackers, which are exceedingly thin and fragile – one recipe even more than the other. The “Lichte Crackers Spelt” and “Lichte Crackers Volkoren” recipes are far more fragile than all the other recipes and thus break very quickly.

The first thing happening in the RobertPack is that robotic arm 1 picks up two rows of 9 crackers from the conveyor belt at a time. With a vacuum mechanism, robotic arm 1 makes the crackers stick to the ramifications of the arm and lets them go when they are on the transportation belt within RobertPack. This movement repeats itself three (or four, depending on the recipe) times, until there are two rows of 9 stacks of crackers. This stacking procedure does not always go smoothly. Each ramification of robotic arm 1 features a single suction point that is positioned in the center of the crackers. This configuration introduces a propensity for slight rotational movement of the crackers during handling, resulting in misalignment and as a result, breakage. After robotic arm 1 is finished stacking the crackers, robotic arm 2 picks up the stacks. Robotic arm 2 has 9 ramifications, each consisting of two tiny arms. When stacks already consist of broken crackers, before robotic arm 2 has touched them, the tiny arms of robotic arm 2 are not able to pick up the crackers correctly. Stacks of crackers therefore fall out of the tiny arms and end up in the bins installed in the RobertPack.

The crackers ending up in the bin are not the only type of waste produced by RobertPack. The repercussions of stacks with broken crackers that are still placed on the belt that leads to Terminator 2 are that again an excessive number of crackers are being discarded further down the line.

The robotic arms and their ramifications can be finetuned based on the type of recipe. The ramifications of the robotic arms have x-, y-, and z-axis values that can be altered manually by line operators. Every cracker recipe has a distinct moisture content and thus needs a different type of handling by the robotic arms. For every cracker recipe, the axes are thus adjusted to the moisture content. The adjustment of the axes per recipe is not perfected yet. There are two specific things regarding the imperfect and sometimes incorrect finetuning of the robotic arms:

1. A clear decision has not been made on what the perfect setting is for each of the coordinates of each ramification. For each recipe, there are boundaries established. However, these are very broad.
2. For the 'Lichte Crackers' recipes, the robotic arms are too rough in general, and every setting for the robot arms is too crass. This leads to more crackers breaking when those recipes are being produced.

Root Cause Analysis Terminator 2

Terminator 2 expels stacks of crackers from the line whenever they contain broken crackers, or if crackers are missing. A big issue arises when stacks of crackers are not properly stacked by the RobertPack. If a cracker is not properly placed on its stack, it can start moving when being transported on the belt to Terminator 2. A misplaced cracker in a stack can get stuck in the steel structure of Terminator 2 and stay there, causing congestion. Sometimes when the Vision is being used, particles that are stuck even block the view of the Vision. This blockage often leads to the situation that Terminator 2 cannot see properly and thus terminates stacks that are completely fine. When doing my research, it stood out to me that the problems occurring with Terminator 2 happened less frequently when line operators who were focused on keeping the entire line clean were working. Now and then an observant line operator would blow away pieces stuck in Terminator 2, even if those pieces were not causing any problems at that moment. At times when no one cleaned residue, I saw the problems occurring more frequently.

When cracker pieces get stuck in Terminator 2, another issue arises: they block the passing way of the other cracker stacks. Stacks coming out of the RobertPack clash with the broken pieces after the camera of Terminator 2. These clashes cause even more crackers to break. Broken crackers can cause errors within the Flowpacker because the broken pieces can move around on the belt leading up to that machine. The crackers get lifted due to the motion and interfere with the foil construction of the Flowpacker. The crackers do not get terminated as this all happens after the camera of Terminator 2, causing these stacks with lifted crackers to reach the Flowpacker. This exact situation is shown in pictures in *Figure 23* and is displayed in a diagram in *Figure 24*. This can lead to a line stop; all machines, except for the Conveyor Belt stop working until the issue is resolved. A line stop will in turn lead to more waste, since in that case, the situation described in the *Conveyor Belt and Terminator 1* part of this chapter occurs, where the line stops working but the Conveyor Belt needs to keep going.

Figure 23 - Error within Flowpacker because of crackers being stuck in Terminator 2

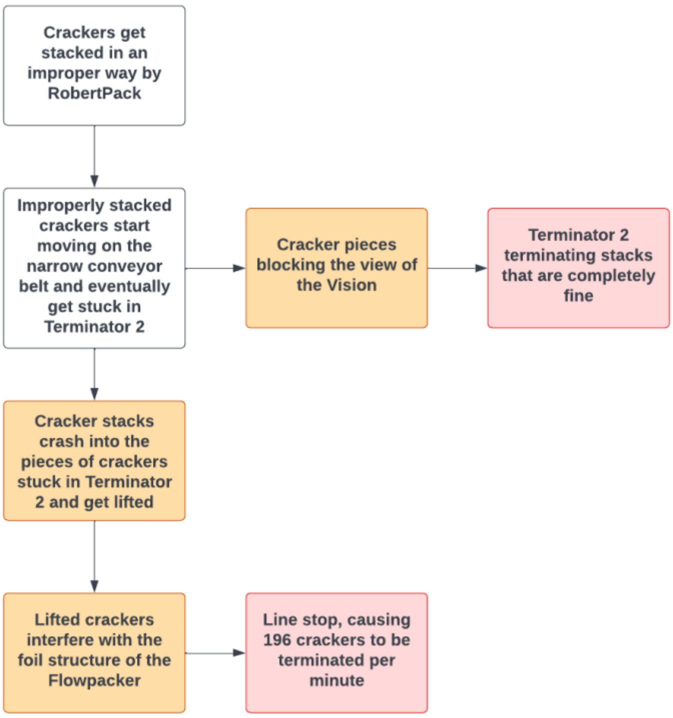

Figure 24 - The process of crackers getting stuck in Terminator 2

4.3 Line stops and Flowpacker errors

In the previous section, *Chapter 4.2,* we have established that waste, errors, and line stops are interrelated: When a line stop occurs, the entire line except for the Conveyor Belt stops. The Conveyor Belt therefore must discard its crackers. Each minute the line stands still, 196 crackers are discarded. A line stop occurs due to an error within the Flowpacker. This results in both a decrease in availability as well as an increase in waste production.

To find out the exact impact of the stops within the Flowpacker, data from *OEEblue* and data generated by the measurements from *Chapter 4.1* will be combined and used. First, the *OEEblue* overview of Line 154 shows that in the span of a year (from 02-01-2023 until 30-12-2023) 2050 errors occurred within the Flowpacker. The total error duration of the Flowpacker is approximately 4323 minutes. Keep in mind, the error duration-data was provided in seconds, but these have been converted those to whole minutes. An error duration of 4323 minutes means the entire line (except for the conveyor belt) had a total line stop duration of 4323 minutes per year, only because of errors within the Flow Packer.

Table 7 - Frequency and total duration of errors within the Flowpacker

Product	Number of times Errors occurred in 2023	Total Error Duration in Minutes
Ontbijtcrackers Spelt	879	1824
Lichte Crackers Spelt	342	749
Ontbijtcrackers Spelt Volkoren	278	503
Lichte Crackers Volkoren	257	700
Ontbijtcrackers Meerzaden	127	221
Ontbijtcrackers Volkoren Meergranen	75	156
Zadencrackers Zonnebloempitten	58	103
Zadencrackers Pompoenpitten	34	68
TOTAL	**2050**	**4323**

The root causes of these errors are not being recorded by *OEEblue*. However, 26 measurements were conducted on the errors within the Flowpacker. Each time an error occurred in the Flowpacker, the distinct cause behind that error and the duration of the error was recorded. That way an estimation could be made on what type of error is most prominent within the Flowpacker.
During these 26 measurements, there were two causes for an error recorded:

(1) The machine has run out of packing foil because the line workers have not placed new rolls on the machine in time.
(2) Crackers crash into the foil structure of the Flowpacker due to cracker pieces getting stuck in Terminator 2 (as depicted in Figure *23*).

The ratio between the number of times each cause takes place is given in *Table 8*.

Table 8 - Measurement type of error and average duration of error within Flowpacker

Errors within the Flow Packer	**Number of times type of error occurred in total**	**Average duration of the error**
Flow Packer has run out of foil	2 times	2 minutes
Crackers crash into the foil-structure of the Flowpacker	24 times	2 minutes and 26 seconds

Approximately 92.3% (24 times of the 26) of the recorded errors are a result of crackers crashing into the foil structure of the Flow Packer due to cracker pieces getting stuck in Terminator 2. Based on the measurement shown in *Table 8*, it can be concluded that the biggest contributor to errors occurring within the Flowpacker is that cracker pieces are getting stuck in Terminator 2 and therefore cause stacks of crackers to crash into the foil structure of the Flowpacker.

As the root causes of the waste per component have been established, the next step is to create solutions that will target the root problems and thus reach the aim of reducing the waste percentage from the current 15.1% to 12% and improving the availability percentage of the line. These solutions will be discussed in *Chapter 5*.

4.4 Chapter Summary

Chapter 4.1 provided an in-depth analysis of waste production in Line 154, focusing on distinct components such as the conveyor belt, RobertPack, and Terminator 2. The study involves five measurements, revealing the waste contributions of each section and addressing specific issues causing waste.
Measurement 1 examines the conveyor belt, highlighting two scenarios leading to waste: malfunctions within the line and misalignment of outer crackers on the conveyor belt. The analysis shows a significant impact of errors on waste production, especially in "Lichte Crackers" recipes.
Measurement 2 focuses on the RobertPack, revealing that it generates less waste than the conveyor belt. The delicate nature of crackers, particularly in "Lichte Crackers" recipes, contributes to breakages during the stacking process, which results in waste.
Measurement 3 investigates Terminator 2, pointing out issues related to misalignment caused by the RobertPack. The Vision mechanism, while enhancing quality, increases waste due to faster termination of cracker stacks.
Measurement 4 assesses the content of a large box storing discarded crackers, finding a significant percentage of intact crackers that could potentially be re-entered in the production line.

In *Chapter 4.2*, a root cause analysis is conducted for each component, identifying issues such as misalignment of crackers, delicate nature of crackers in the RobertPack, and blockages in Terminator 2 causing line stops. The interrelation of waste, errors, and line stops is discussed in *Chapter 4.3*, emphasizing that errors in the Flowpacker, primarily caused by Terminator 2 issues, lead to increased waste and decreased availability. The chapter concludes by highlighting the need for targeted solutions to address root problems and achieve the goal of reducing waste to 12% while improving line availability.

5 Solutions

In *Chapter 4* it has been shown that there are three components within the line in which waste is being discarded: the Conveyor Belt, the RobertPack, and Terminator 2. *Chapter 4* has also shown that these components and their waste production are interrelated in several ways. The next step is to generate solutions that each contribute to solving the knowledge problem stated in *Chapter 1*: <u>The average percentage of waste production of Line 154 is 15.1%, and the aim is to decrease it to a minimum of 12%.</u> The availability percentage of Line 154 currently is 78%, which is too low for Company X. Increasing the availability percentage has been a goal besides solving the action problem, as the low availability percentage of the line is a by-product of waste production. The availability of the line therefore has also been kept in mind when generating suitable solutions.

For the solutions, a staircase-structure of three solutions has been made:

(1) Step 1: A solution that demands minimal effort and minimal investment, but that has the least impact on decreasing the waste production by Line 154.
(2) Step 2: A solution that demands effort and investment, but that has a significant impact on decreasing the waste production and increasing the availability percentage of the line.
(3) Step 3: A solution that demands a large amount of effort and investment, but that has the greatest impact on decreasing the waste production by Line 154.

Each solution will be explained below.

5.1 Solution 1 – The Correction of Missing and/or Misaligned Crackers

Implement a system that allows for the correction of misaligned crackers on the conveyor belt before reaching the end, reducing the need for discarding entire rows.

As described previously, Terminator 1 discards two lines of nine crackers whenever one or more <u>outer</u> crackers are missing or not properly aligned. This means that a group of 18 crackers is terminated whenever one outer cracker is missing or misplaced. When we solely look at the Espelta recipe, on average 93 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt, as also mentioned in *Chapter 4.1.1*. Since the Espelta recipe is being produced for 2540.77 hours per year (see *Table 3*), 2540.77 x 90 = 228,669.3 crackers per year are being discarded because of misalignment or missing crackers. One Espelta cracker weighs 20 grams. Therefore, 228,669.3 x 0.02 = 4,573.39 kg Espelta is being discarded by the Conveyor Belt in a year. This amount of waste is 0.35% of the total kilograms of Espelta that is being produced each year.

Table 8 shows the outcomes when I do the same calculation for the other recipes. The calculations can be found in *Appendix B*.

Table 9 - Waste and cost reduction Solution 1, outer crackers

Recipe	Kg waste due to missing outer crackers per year	Costs of waste per year
Ontbijtcrackers Espelta	4573.39	€9146.77
Lichte Crackers Spelt	1457.47	€2914.93
Ontbijtcrackers Spelt Volkoren	973.79	€1947.57
Lichte Crackers Volkoren	2008.56	€4017.13
Ontbijtcrackers Meerzaden	790.14	€1580.28
Ontbijtcrackers Volkoren Meergranen	798.19	€1596.38
TOTAL	**10,601.54 kg**	**€21,203.06**

The discarded crackers are captured by another belt that transports them to a big box (*Figure 22*). In *Chapter 4.1.4*, it has been mentioned that for all recipes except the 'Lichte Crackers' recipes, 94.6% of the crackers captured in the box are still intact. Knowing this, combined with the reason why the Conveyor Belt discards crackers, leads to a solution that would prevent the excessive waste production by the Conveyor Belt in this scenario.

An outer (or inner) cracker is absent because a piece of dough got stuck on the roller in the rolling process before the oven. The dough gets brought back into the dough machine, but an empty spot is left on the conveyor belt. The average speed of the entire conveyor belt leading up to the RobertPack is 5 meters/minute, and the total length of the conveyor belt (from the start of the oven to the RobertPack) is 50 meters. A line operator could thus spot a cracker being missing or misaligned and have 10 minutes to correct it before Terminator 1 sees it. The idea is to place a button just before the oven. Whenever a line worker spots an outer cracker that is misaligned or absent on the conveyor belt in the rolling process, he or she can push this button. The button will send a signal to the line operator station located in the problem area. A red light would start shining and a countdown on a timer will begin. In case of a cracker being misaligned, a line operator working in the problem area could correct the placement of the cracker before it reaches Terminator 1. In case a cracker is missing, a line operator working in the problem area could then take one cracker out of the big box that is used to catch the crackers terminated by Terminator 1 and place it in the empty spot on the conveyor belt. This would prevent Terminator 1 from terminating the 18 crackers that are in the same group as the misplaced or absent cracker.

Regarding the signalling in the problem area following the push of a button, a pole could be installed next to the computer, which would give a red light whenever the button prior to the oven is being pushed. A timer could be installed on the pole as well, giving the line operators insight into how much time they still have left to correct the missing or misaligned crackers. Since it takes 10 minutes for the crackers to get from the start of the oven to the RobertPack and the button is placed at the start of the oven, the timer will start counting down from 10 minutes to 0 as soon as the button gets pushed. Since each machine in Line 154 is equipped with a pole that gives a certain colour of light in certain situations - green when everything is working correctly and red in case of an error - this new pole with a light and timer on it could be easily installed (*Figure 25*).

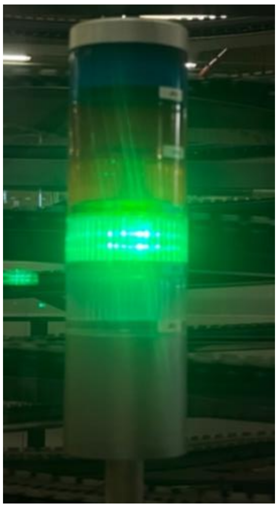

Figure 25 - Light pole

Based on the cost of the light poles that are already installed in the line, the approximate cost of installing this light pole is €500. Together with the instalment of a timer, the cost of this solution would be around €1000.
If this solution were applied for each missing and misaligned outer cracker, which does not cost a lot of manpower, Company X could save up to €21,203.06 - €1000 = €20,203.06 after a year. After that, €21,203.06 worth of dry waste would be saved yearly.

An addition to this solution is that a line operator also places crackers on empty spots whenever an inner cracker is missing or not aligned. Suppose the empty spot of an inner cracker stays empty. Then this leads to the Robert Pack making an incomplete stack. Depending on the recipe, this means that three or two crackers are discarded by Terminator 2 down the line due to it not being a complete stack. For each recipe, the average number of times an inner cracker is missing on the Conveyor Belt, is three times in an hour. Taking again the Espelta recipe as an example; this means 6 crackers are discarded per hour because of inner crackers being missing or being misaligned as a normal stack of Espelta crackers consists of 3 crackers total. Taking again that the total production hours in a year are 2540,77 for Espelta, this means that 6 x 2540,77 = 15,244.62 crackers are discarded each year because of inner crackers being missing or misaligned. This is 15,244.62 x 0.02 ≈ 304.89 kg waste in a year. *Table 9* provides an overview of the number of kilograms that are wasted due to crackers missing in one of the inner spots for each recipe. The costs of the waste are again calculated by multiplying the kilograms with €2, since dry waste costs Company X €2 per kilogram.

Table 10 – Waste and cost reduction Solution 1, inner crackers

Recipe	**Kg waste due to missing inner crackers per year**	**Costs of waste per year**
Ontbijtcrackers Espelta	304.89	€609.78
Lichte Crackers Spelt	80.97	€161.94
Ontbijtcrackers Spelt Volkoren	108.2	€216.40
Lichte Crackers Volkoren	55.22	€110.44
Ontbijtcrackers Meerzaden	55.13	€110.26
Ontbijtcrackers Volkoren Meergranen	48.87	€97.74
TOTAL	**653.28 kg**	**€1306.56**

Summarized, Company X could reduce waste production with around 11,255 kg and save up to approximately €21,510 each year by applying the solution to these two scenarios combined.

5.2 Solution 2 – Preventing crackers from getting stuck in Terminator 2

As the section '*Root Cause Analysis Terminator 2'* has already described, the waste problem in the Terminator 2 component lies in the fact that improperly stacked crackers get stuck in the steel structure of Terminator 2. These crackers can block the view of the Vision and often block the passing way of upcoming stacks of crackers as well. This last scenario regularly leads to line stops as upcoming stacks of crackers crash into these loose crackers. This creates stacks of multiple broken crackers that are moving on the conveyor belt. This can cause errors within the Flowpacker because the crackers get lifted due to the motion and interfere with the foil construction of the Flowpacker (as shown in *Figure 23*). The crackers do not get terminated by the blow system of Terminator 2 as the crash happens after the camera of Terminator 2, causing these stacks with lifted crackers to reach the Flowpacker. The question is now: *How can we prevent crackers from getting caught in the steel structure of Terminator 2?* There is one constraint that needs to be kept in mind when generating a solution: the view of the Vision cannot be narrowed, since the system is very sensitive.

Therefore, the solution implemented is an alteration to the steel structure of Terminator 2, without interfering with the view of the Vision. The improperly stacked crackers get stuck in the steel structure and stay on the flat surface next to the conveyor belt (marked with red in *Figure 26*).

Figure 26 - Flat surface in Terminator 2 that needs to be sloped

If this surface would be sloped instead of flat, crackers would just slide off the structure. This way they would not block the view of the Vision, nor would they block the passing way of upcoming stacks of crackers. This would prevent the scenario in which upcoming crackers crash into the crackers stuck in the steel structure of Terminator 2, resulting in errors in the Flowpacker. The solution of a sloped surface in the structure of Terminator 2 would therefore have a direct impact on the availability percentage and thus the OEE percentage of the line, plus it would impact the amount of waste discarded heavily. The result of a minute line stop is a rejection of 196 crackers by the conveyor belt (as explained in *Measurement 1* in *Chapter 4.1*). As the measurement in *Chapter 4.3 – Line stops and errors* showed, the scenario in which crackers crash into the foil structure of the

Flowpacker because of crackers being stuck in Terminator 2, happens on average two times per hour. Would the surface be sloped instead of flat, this would not happen anymore, since the crackers would slide off the surface immediately and thus would not block any upcoming stacks of crackers. The number of kilograms of waste this will save, together with its accessory cost savings will be calculated below and presented in tables.

Waste and Cost Savings Calculated

Based on the measurements focusing on the Flowpacker given in *Chapter 4.3*, 92.3% of the errors within the Flowpacker are a result of crashing crackers. The average duration of such an error is 2 minutes and 26 seconds (*Table 7*). The total number of errors is 2050 (*Table 7*). 0.923 x 2050 ≈ 1892 errors with an average duration of 2 minutes and 26 seconds (≈ 2.43 minutes).

The conveyor belt discards 196 crackers each minute the line stands still. Thus, because of the errors within the Flowpacker, Line 154 discards 2.43 x 196 ≈ 476 crackers per hour. Line 154 produces crackers for 5623.46 hours total in a year. Therefore, the line discards on average 476 x 5623.46 ≈ 2,678,342 crackers in a year only because of the errors within the Flowpacker that are caused by crackers crashing into each other and interfering with the foil construction.

As the average weight of a cracker produced by Line 154 is 19.53 grams, the amount of waste discarded can be converted to kilograms: 2,678,342 x 0.01953 ≈ 52,308 kilograms discarded in a year. As the costs for dry waste are €2/kg for Company X, this means the errors within the Flowpacker caused by crackers interfering with its foil construction cost Company X approximately €104,616 yearly.

Making the steel structure sloped instead of flat, does demand an investment. In order to alter the steel structure, parts have to be removed and parts have to be inserted. After a rough calculation, the investment of this alteration would be around €2000 for Company X. Implementing this solution would therefore save €104,616 - €2000 = €102,616 after one year. After that, €104,616 worth of dry waste would be saved yearly.

Implementing and Testing Solution 2

As it was not possible to make a slope in the steel surface solely for testing, a simpler solution that had the same effect on the problem scenario of crackers getting stuck on the steel surface was installed. A narrow piece of cardboard was placed within the steel structure of Terminator 2, creating a wall parallel to the narrow conveyor belt (*Figure 27*).

Figure 27 - Testing of Solution 2

The effect of this tiny wall would be similar to making the steel surface sloped because both options prevent crackers from getting stuck in Terminator 2. Installing the narrow piece of cardboard would never be a good permanent option, since it does block the view of the Vision. However, since the Vision is only used when the 'Ontbijtcrackers Espelta' recipe is being produced, the effect of the narrow piece of cardboard could be tested during the production of other cracker recipes.

This solution was tested in one production shift: The cardboard wall was installed the entire shift on Tuesday, January 16th, from 07:00 am until 03:00 pm. During this shift, the 'Lichte Crackers Spelt' recipe was produced. The effect of the tiny cardboard wall could be seen in the availability percentage of that shift. The average availability percentage of Line 154, when the 'Lichte Crackers Spelt' recipe was produced, was on average 79.3% in 2023. The availability percentage of Line 154 during the shift in which the cardboard wall was installed was 93.2%. Both statistics can be found in *Appendix C*. The fact that the Flowpacker is not the only machine contributing to the availability percentage of the line has been taken into account. Although these results are based on samples which are too small to make statistical claims, they do indicate a clear positive effect, which could result in the decrease of waste production and the increase of the availability percentage of the line.

Using the cardboard wall as a real solution (Solution 2b)

Inserting the cardboard wall was initially done with the intention to imitate the effect of a sloped steel structure. As it would block the view of the vision, it did not seem a perfect solution. It is however, a very affordable solution, as the cardboard wall costs nearly nothing to install and can be removed at all times. And after seeing the great impact the implementation had on the waste production as well as the availability percentage of the line during that shift, the cardboard wall seemed like a good solution after all. Since the vision is only used during one of the eight recipes, installing the cardboard wall could be done during the production of the other recipes. The production of the recipes for which the Vision is not being used, takes up 3082.69 hours of the total production capacity. This would mean that the implementation of the cardboard wall when the Vision is not turned on, would prevent 476 x 3082.69 ≈ 1,467,360 crackers from being discarded by the line each year. This is equal to 1,467,360 x 0.01953 ≈ 28,658 kilograms. With this implementation, Company X would save approximately €57,315 each year.

5.3 Solution 3 – Installing a Buffer in between RobertPack and Terminator 2

The last solution does not focus on solving problems within the line but focuses on minimizing the impact of problems occurring in the line. Errors within a production line are only preventable to a certain degree, there are always unpredictable errors happening, such as machine failure or mistakes made by line operators. In addition to this, during my research, the fact that the performance of Line 154 heavily depends on the line operators working the line became very prevalent. To make the waste production of Line 154 less dependable on factors that are not easy to control, installing a buffer between the RobertPack and Terminator 2, would be a valuable option. As has been described in several sections already, the biggest contributor to the waste production of Line 154 is the large conveyor belt leading to the RobertPack. Whenever there is a line stop, the robotic arms within RobertPack stop picking up crackers from the conveyor belt and so the belt discards 196 crackers per minute until the error causing the line stop is resolved.

Explanation of the buffer

The narrow belt conveying stacks of crackers out of the RobertPack through Terminator 2 has a length of approximately 2 meters. This narrow belt could be changed into a dynamic U-shape buffer. A dynamic U-shape buffer is a narrow belt, carrying the crackers the same way as the current narrow belt is doing, but can elongate whenever needed. In case of a line stop, the dynamic U-shape buffer would elongate the belt, creating more time for crackers to be conveyed from RobertPack through Terminator 2 to the Flowpacker. The stacks of crackers would thus still be led to Terminator 2 but must travel a longer distance for it. This buys time and so this way the robotic arms within RobertPack could proceed to pick up crackers from the conveyor belt, which would result in fewer crackers being terminated off the conveyor belt. The buffer elongates as long as a line stop lasts. Suppose the maximum length of this buffer is enough to keep crackers for five minutes total: Would the line stop last longer than five minutes, then the dynamic U-shape buffer would stop as well. When the error gets resolved and the line starts working again, the buffer makes itself shorter again, which prevents crackers from taking too long to get to Terminator 2 when the line starts working again. The entire situation is drawn in *Figure 28*. This figure is taken from a video made by Improsy B.V. that builds different types of dynamic flow regulators, explaining the workings of a dynamic U-shape buffer in a production line (Innovative Production Systems, 2021).

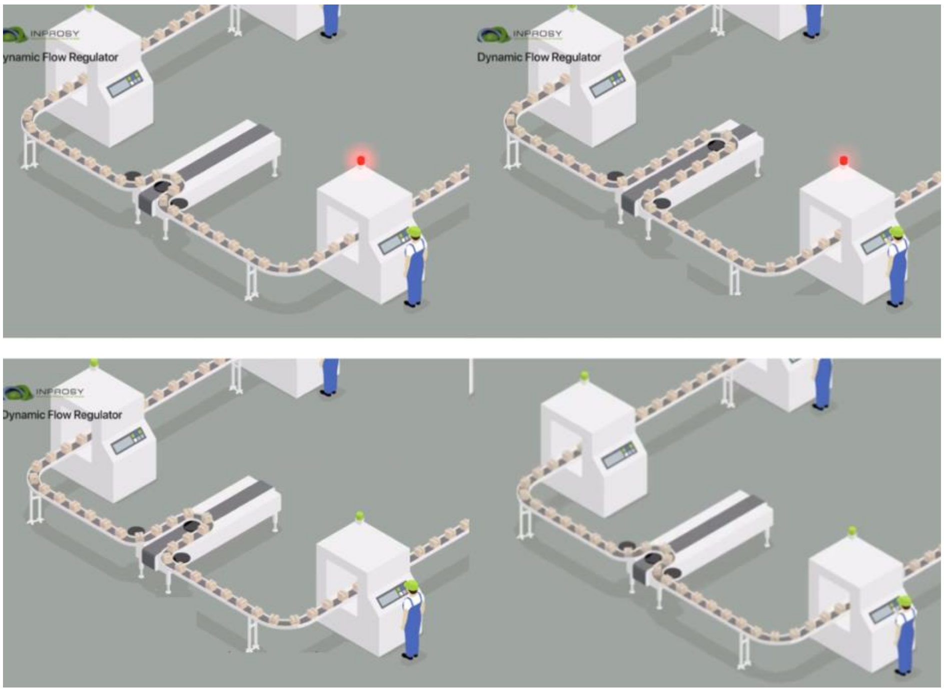

Figure 28 – “Dynamic U-shaped buffer,” Innovative Production Systems, 2021.

The only problem left to solve is how the buffer can shrink without hindering the supply of cracker stacks by the RobertPack. The solution is to speed up the line a to a certain speed so that it can catch up to the upcoming supply after an error.

The current speed of the Flowpacker is 141 flowpacks (stacks of crackers) per minute. Suppose an error of exactly four minutes has occurred and the buffer is expanded to its maximum, which means the buffer contains 564 flowpacks (as the line produces 141 flowpacks per minute). The error is resolved, and the crackers can continue to flow through Terminator 2 to the Flowpacker. The speed of the Flowpacker that is still good to use, and which does not cause accumulation down the line, is 146 ppm. If we would speed up the Flowpacker from 141 flowpacks per minute to 146 flowpacks per minute (an increase of approximately 3.6%), it would take 3 minutes and 51 seconds to move all crackers that are in the buffer through the Flowpacker and have the buffer back at its starting point. Increasing the speed of the Flowpacker from 141 to 146 flowpacks per minute for 3 minutes and 51 seconds after an error of four minutes would thus be the solution for this problem. *Table 11* shows the duration of bringing flowpacks out of the buffer back into the line and retrieving the buffer for different types of error-duration. The calculations can be found in *Appendix B*.

Table 11 - Duration of bringing flowpacks out of the buffer back into the line for different error durations

Error duration	Duration of bringing flowpacks back into the line
≥4 minutes	3 minutes and 51 seconds
3 minutes	2 minutes and 54 seconds
2 minutes	1 minute and 56 seconds
1 minute	58 seconds

Waste and Cost Savings Calculated

Assuming the buffer has a capacity of four minutes, this would prevent 196 x 4 = 784 crackers per four-minute line stop. If a line stop lasts longer than four minutes, the buffer stops working until the error causing the line stop has been resolved. However, still, in this situation, four minutes of the conveyor belt discarding crackers has been prevented.

The results of the Flowpacker measurements and the short-stop information from the periodic report of the period 02-01-2023 until 30-12-2023 from *Chapter 4.3*, are combined and displayed in *Table 11*. The table shows that Line 154 stood still for 14,119 minutes in a year solely because of the Flowpacker, and short stops occurring down the line. Only because of this, the conveyor belt discarded 14,119 x 196 = 2,767,324 crackers in that year. Converted into kilograms, this is 2,767,324 x 0.01953 ≈ 54,046 kilograms of dry waste, costing Company X approximately €108,092 in a year.

Table 12 - Total number and duration of line stops and errors within Flowpacker

Component	Total number of errors/short stops	Total duration of downtime	Average duration of downtime
Short stop	13654 times	9796 minutes	43 seconds
Flowpacker	2050 errors	4323 minutes	2 minutes, 21 seconds

Taking the fact that the average duration of the errors in each component is significantly less than four minutes, a buffer with a capacity of four minutes would prevent a lot of waste from being discarded. The duration of short stops is always less than one minute. The four-minute buffer would therefore always cover this type of line stop. Regarding errors in the Flowpacker: There are no records of outliers of the error duration of the Flowpacker, which means it is not certain whether the error duration of the Flowpacker always lasts less than four minutes. However, Company X stated that the chances of downtime within the Flowpacker being longer than four minutes are extremely small. Since the data on outliers is not available, every error within the Flowpacker is assumed to last shorter than four minutes with a margin error of 2.5%, to compensate for the assumption.

Suppose Company X has installed a dynamic U-shape buffer with the capacity of four minutes. The cost savings would then be as follows:

(1) **Short stops.** 9796 minutes of short stops would be covered by the dynamic U-shape buffer, preventing 9796 x 196 = 1,920,016 crackers from being discarded. This is equal to 1,920,016 x 0.01953 ≈ 37,498 kg dry waste. Company X would save with this approximately €74,995.83 every year.

(2) **Errors Flowpacker.** 4323 x 0.975 (error margin) ≈ 4215 minutes of errors within the Flowpacker would be covered by the dynamic U-shape buffer, preventing 4215 x 196 = 826,140 crackers from being discarded. This is equal to 826,140 x 0.01953 ≈ 16,135 kg dry waste. Company X would save with this approximately €32,269.03 every year.

In total, with the implementation of a dynamic U-shape buffer with a capacity of four minutes, Company X would reduce the waste production of Line 154 by approximately 53,633 kg. This would make Company X save approximately €107,266 every year.

The costs of implementing the dynamic U-shaped buffer are hard to estimate but judging from the costs of the instalment of the buffer down the line, a reasonable estimation would be a total cost of €350,000. This is a huge investment. However, knowing that the buffer would prevent €107,266 worth of dry waste from being discarded each year, the investment would be paid off in 3 years and 4 months.

5.4 Solution Summary

To gain a clear understanding of the potential waste and cost savings achievable through the three solutions, *Table 13* provides a detailed overview of each solution and its associated reductions in waste and costs.

Table 13 - Solution Summary: Waste reduction and cost savings

Solution	Waste reduction in kg	Cost of Solution in €	Cost saving in €
1: The correction of missing and/or misaligned crackers	11,255 kg	€1000	€22,510
2a: Preventing crackers from getting stuck in Terminator 2 with Sloped Iron Structure	52,308 kg	€2000	€104,616
2b: Preventing crackers from getting stuck in Terminator 2 with Cardboard Wall	28,658 kg	€0	€57,315
3: Installing a buffer in between RobertPack and Terminator 2	54,046 kg	€350,000	€107,266 worth of waste is being saved each year. The investment of the buffer would be 'paid off' in 3.5 years.
TOTAL	117,609 kg	€354,000	€235,218

Aside from the waste reduction and cost savings Solution 2 would realize, this solution would also improve the availability percentage of Line 154 significantly, as became clear in the test – mentioned in *Chapter 5.2*.

In *Chapter 1.3*, the primary goal of the research was stated:
<u>The average percentage of waste production of Line 154 is 15.1%, and the aim is to decrease it to a minimum of 12%.</u>
This action problem meant that the aim is to decrease waste production of Line 154 from 15.1% to 12%. Converted into kilograms, this is a reduction from 386,316 kilograms of dry waste in a year to 307,520 kilograms of dry waste in a year.

(1) Would Company X only implement Solution 1, the waste percentage would decrease to approximately 14.7%.
(2) Would Company X only implement Solution 2, the waste percentage would decrease to approximately 13.1%.
(3) Would Company X only implement Solution 3, the waste percentage would decrease to
(4) Would Company X implement both Solution 2 and 3, the waste percentage would decrease to approximately 11%.
(5) Would Company X implement all three solutions, the waste percentage would decrease to approximately 10.5%.

With the implementation of all three solutions, or only Solution 2 and 3, the aim of the stated action problem would be reached.

6 Managerial Recommendations

During the research on Line 154, the main focus was on the machinery and its workings within the line to solve the action problem stated in *Chapter 1.3*. However, during the research, several managerial issues were noticed that decreased the performance of the line as well, causing more waste production by Line 154. For clarity, the hierarchy between positions in the production branch of Company X is displayed in *Figure 29*. As can be seen in the figure, the Operator Cs are responsible for two lines and Operator Bs work together at one line. The Team Leader is responsible for both types of Operators in multiple production lines.

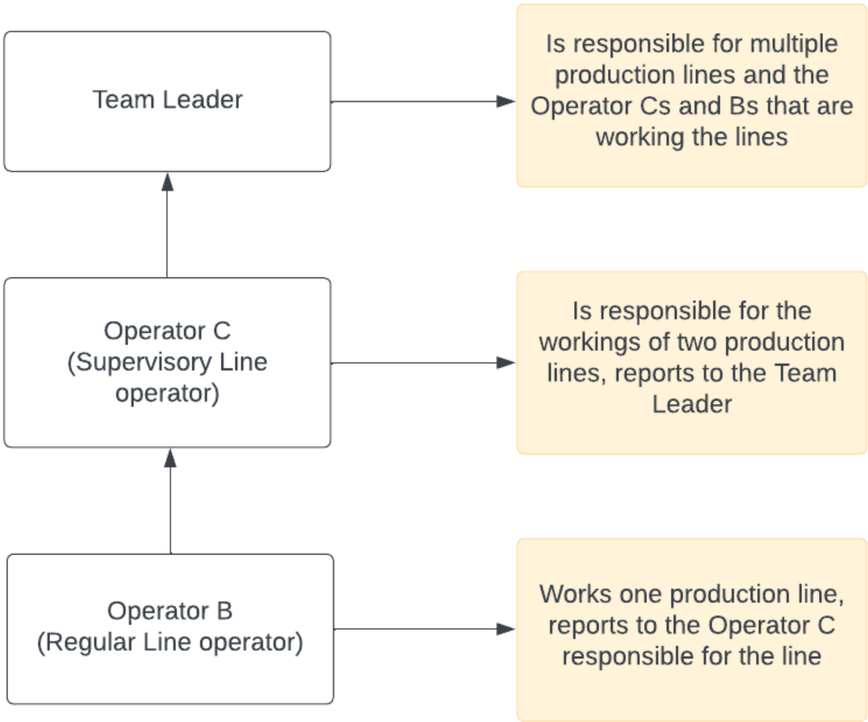

Figure 29 - Hierarchical structure Management of Company X

The primary managerial challenge faced by Company X's Line 154 revolves around a high rate of personnel turnover. This problem is connected to the waste problem I have been researching as the expertise of line operators is very important to prevent excessive waste production: unskilled line operators often make mistakes resulting in errors, or line stops last longer than necessary due to line operators being incapable of fixing the error causing it.

Many line operators start working at the line but leave the company after a relatively short time. New line workers often find the workload heavy; they must be constantly alert when working in the line. In addition to this, adapting to the irregular and demanding hours – ranging from night shifts to early morning and late evening shifts – is hard. As it takes a lot of dedication for new line operators to adapt to the way of working, it is Company X's mission to make the work enjoyable. The current high rate of personnel turnover is detrimental since new line operators do intensive training in the first period of working at Company X. A lot of energy is put into teaching them the necessary skills, which gets lost when they leave Company X during or shortly after the training. The question arises: '*How could new line operators be motivated to stay within the company?*'

To find answers to this question, the survey "*The 7 Key Trends Impacting Today's Workplace"* was used. In this survey the Employee Engagement firm *TINYpulse* surveyed over 200,000 employees in more than 500 organizations. The research explored several management topics, under which 'motivation'. The question in the survey concerning 'motivation' was *"What motivates you to excel and go the extra mile at your organization?"* (TINYpulse, 2014). There were three answers to this question that came out on top, and these would be useful for Company X as well. *Table 14* provides an overview of the results from the survey together with accessory applications that could be useful for Company X. These points will be elaborated on below.

Table 14 - Ideas for Company X's Operations Management

Results from the 'Motivation' question	**Applications done by Company X**
Feeling encouraged and recognized	- Instruct Operator Cs to motivate Operator Bs: focus on their talents instead of their shortcomings. - Give line operators their time to shine, post them on social media, or hang pictures of them in the factory.
Having a real impact as an employee	- Set quarterly meetings with Managers responsible for the line, Team leaders, Operator Cs, and Operator Bs in which improvement ideas for the line can be discussed. - Have the Operations Management team show all Operators that something is being done with their feedback. Implement small (or big) changes after these quarterly meetings.
Growing professionally	- Classify positions differently: Trainee, Line Operator, Trainer, Line Expert (All Operator C), and then Operator B and Team Leader. - Create certificates for certain accomplishments.

Feeling encouraged and recognized
The role of a line operator is challenging, particularly when relying solely on intrinsic motivation, especially if the tasks are physically and mentally demanding. Line operators often require external motivation, which can range from small gifts to compliments, to provide them with a sense of recognition. Company X excels in this aspect by consistently providing each employee with a bag of Company X products every month. While this is a thoughtful gesture, it lacks a personal touch, as every employee receives the same bag of products. Employees often crave more personalized recognition than what is currently offered (Brun & Dugas, 2008). A potential solution could involve instructing Team Leaders to acknowledge Operator Cs and Bs and encouraging Operator Cs to commend Operator Bs. There seems to be an imbalance in the management focus, with more attention given to addressing issues rather than acknowledging successes in the production line and

recognizing those responsible. In particular, Line 154 has demonstrated a notable 'Gerrit Effect' in the OEE percentages of the line. Whenever line operator Gerrit is on duty, the OEE percentage is consistently higher than when other teams are working. While the operations management team is aware of this and acknowledges Gerrit's contribution, Gerrit himself occasionally feels a lack of recognition. Although he is content with the situation, increased acknowledgment of his exceptional performance would undoubtedly boost his confidence.

To further motivate line operators, it might be beneficial to engage Company X's PR team. Directing attention to line operators through social media platforms such as Instagram or LinkedIn, where a 'shoutout' or highlighting the 'best team of the month' could be featured, would provide especially younger line workers with the opportunity to share their achievements with their own social circle. This approach would not only boost the morale of individual operators but also showcase Company X's pride in having such dedicated line operators within the company.

Having a real impact as an employee

Something that is in line with feeling encouraged and recognized, is having a real impact as an employee. Several highly motivated line workers of Line 154 would love to work on improving the line. One of them, Yvar Bredewold, was thrilled to support my research and was eager to contribute to it. He expressed to me that thinking about making improvements on the line gives him energy. He would be thrilled if he could share his findings with the Operations Management team, or even with the Team Leaders. Unfortunately, these departments, understandably, are already occupied with various tasks and cannot thoroughly investigate every improvement suggestion put forth by line operators. Nevertheless, line operators, having an intimate knowledge of the line from their eight-hour daily observations, can pinpoint bottlenecks and suggest valuable improvements.

A practical solution would be to organize quarterly meetings per line involving all operators. This approach serves a dual purpose: firstly, it empowers line operators to feel they can truly make a difference, and secondly, it allows Team Leaders to instruct line operators with new suggestions to document and prepare them for the meeting instead of addressing them immediately, which can be time-consuming. The subsequent step involves keeping line operators updated on the implementations resulting from their feedback. While seemingly minor, this last task is undeniably crucial in maintaining open communication and fostering a collaborative work environment.

Growing professionally

Every employee desire professional growth, particularly those with ambitious aspirations who derive confidence from advancing in their positions. Currently, the leap from Operator B to Operator C is very big. Introducing new positions and restructuring the hierarchy could address this issue:

(1) Trainees: New employees would undergo training before assuming the role of a Line Operator. This clear distinction between Trainees and Line Operators creates a sense of accomplishment and encourages individuals to work towards their titles.
(2) Line Operators (Operator B): Line Operators should accumulate experience before taking on the responsibility of training others. This isn't to diminish the skills of Line Operators but to allow them the opportunity to master their role. Many Line Operators I've spoken to find it challenging to train others and simultaneously manage the entire production line.

(3) Trainers (Operator B): Trainers would be seasoned Line Operators with a passion for teaching. Designating this as a distinct title establishes clear boundaries for responsibilities.
(4) Line Experts (Operator B): A Line Expert would be someone who has been a Trainer but is now solely focusing on the workings line. Since he taught others how the line works, he knows all the ins and outs. He will be the one who steps in when there is a crisis.
(5) Operator C: Line Experts who have the ambition to grow could become an Operator C. A Line Expert becoming an Operator C would be great: this person knows everything about the line and knows the other Line Operators on a personal level.

To clearly differentiate these positions, certificates could be introduced. Trainees could earn certificates in various skills, such as fixing specific errors, performing changeovers, and cleaning. Upgrading from Line Operator to Trainer could be achieved by obtaining a Trainer certificate. The promotion to Line Expert could then be determined, for example, by an Operator C or a Team Leader.

Implementing this solution has the potential to significantly boost the motivation of every Line Operator by providing a structured path for professional development.

7 Conclusions and Recommendations

In this chapter, the conclusions following from the research done on Line 154 are discussed. In addition to this, recommendations for Company X based on this research are being provided.

7.1 Conclusions

Company X is facing a problem with too much dry waste being produced on Line 154. This is causing the company to spend more money than necessary and is affecting the availability and overall equipment effectiveness (OEE) of the line. Currently, the waste percentage is 15.1%, which is higher than the acceptable norm of 7.5%. The goal is to reduce this waste percentage to at least 12%.

To tackle this issue, the research was divided into different phases. In Phase I, an overview of the components of the problem area was created. This helped in understanding the layout of the line, how the machines work, and their interrelationships. Measurements were taken for each component, including the conveyor belt, RobertPack, Terminator 2, and Flowpacker, to identify their individual contributions to waste production.

Moving on to Phase II, a detailed root cause analysis was conducted. This analysis provided insights into the specific reasons behind different types of waste production and clarified the connection between waste and line stops. The conveyor belt emerged as the major contributor to waste production during errors. While the RobertPack and Terminator 2 didn't individually contribute significantly to waste, they played crucial roles in causing errors.

This analysis laid the foundation for Phase III, where solutions were generated. Three solutions were proposed: the first involved efforts from line operators to correct missing and misaligned crackers on the conveyor belt. The second suggested a minor adjustment to Terminator 2 to prevent crackers from getting stuck, thereby avoiding errors in the Flowpacker. The third solution required an investment and proposed the implementation of a dynamic U-shaped buffer between the RobertPack and Terminator 2. This buffer would keep the line running during Flowpacker errors, preventing the conveyor belt from producing excessive waste.

The quick personnel changeover at Company X contributes to the excessive waste production as well: errors occur more frequently due to mistakes made by unskilled line operators and line stops last longer than necessary. By creating a more engaging and supporting work environment, Company X would slow down the personnel changeover, which eventually would lead to more skilled line operators.

In essence, the research presented a clear roadmap for Company X to address the waste issue on Line 154, offering viable solutions tailored to the specific components and processes involved. Implementation of these solutions is poised to bring about a substantial reduction in waste, contributing to cost savings and improved operational performance for the company.

7.2 Recommendations

Based on the findings of this research, the following recommendations are given to Company X:

First, to prevent the conveyor belt from discarding crackers whenever outer crackers are missing or misaligned, a mechanism should be installed that gives line operators enough time to correct missing or misaligned crackers and prevent other crackers from being discarded. Whenever a line operator working in the dough-making area sees that a piece of dough has stuck to the rollers, leaving an empty spot on the conveyor belt, this line operator should push a button, located directly before the oven. In the problem area, a light would turn on and a timer of 10 minutes would start, to indicate line operators working in the problem area that they have to correct missing or misaligned crackers and how much time they have left.
Second, to make sure crackers do not get stuck in the steel structure of Terminator 2, the flat surface of the steel structure needs to be sloped. This way, crackers ending up off the conveyor belt, do not stay in the steel structure, risking crashing with incoming stacks of crackers, but slide off simultaneously. This with the goal to prevent 'crashed' crackers from interfering with the fragile foil structure of the Flowpacker.
Third, to implement a U-shaped buffer in the line between the RobertPack and Terminator 2, to prevent a line stop from happening. Line stops cause the conveyor belt to terminate 196 crackers each minute the line stands still. With the implementation of a buffer with a capacity of four minutes, the line would be able to keep moving for four minutes of error. As almost all errors last shorter than four minutes, this buffer would cover almost all line stops.

Company X's Line 154 deals with a substantial challenge in personnel turnover, particularly among new line operators. The lack of killed line operators has a negative effect on the waste production of Line 154. To solve this problem, Company X needs to keep their personnel motivated within the company. A few recommendations are given for this:
First, Instruct Team Leaders to acknowledge Operator Cs and Bs, and encourage Operator Cs to commend Operator Bs. Recognize outstanding performers more prominently, and acknowledge their exceptional contributions. Collaborate with Company X's PR team to highlight line operators on social media platforms. A monthly 'shoutout' or featuring the 'best team of the month' on platforms like Instagram or LinkedIn can provide individual recognition and showcase company pride.

To make line operators feel like they have an impact on the organization, Company X can organize quarterly meetings involving all line operators, Team Leaders, Operator Cs, and Operator Bs. This provides a platform for operators to share improvement ideas and allows management to show commitment by implementing changes resulting from these discussions. Team Leaders should be instructed to show follow-up on the progress of implemented changes to maintain open communication.

Growing professionally is motivating for employees. Implementing a system in which line operators can grow in position would create the feeling of excelling. Company X should introduce clear distinctions between job positions: Trainees, Line Operators, Trainers, Line Experts, and then Operator B and Team Leader. Recognize Line Experts as those with the expertise to handle crises, and the other Operators C as those with a deep understanding of the line and a personal connection with other Line Operators. Introduce certificates for Trainees and Line Operators, highlighting specific skills and achievements, and provide a clear path for professional development, with promotions from Line Operator to Trainer and Line Expert based on achieving specific certificates.

By implementing these recommendations, Company X can create a more supportive and engaging work environment, addressing the primary challenge of personnel turnover.

7.3 Future Research

In this chapter, we extend our exploration beyond the conclusions and recommendations drawn from the current research. We look at areas that need more investigation to make Company X's operations work better and create less waste on Line 154.

7.3.1 Improving Suggested Solutions

The proposed U-shaped buffer, designed to mitigate line stops, could benefit from additional research to refine its design and assess its performance in various error scenarios. Consideration should be given to dynamic adjustments based on real-time error data, possibly incorporating machine learning algorithms for predictive maintenance.
In addition to this, conducting a more comprehensive cost-benefit analysis of implementing the proposed solutions is imperative. This analysis should evaluate the financial impact of suggested changes against potential savings resulting from reduced waste, increased operational efficiency, and decreased personnel turnover.
As the solutions did not include solving things within the RobertPack it would be a good idea for Company X to look into the technical workings of RobertPack, to see whether improvements could be made there as well.
Implementing a real-time monitoring system to track the performance of proposed solutions is crucial. By establishing a feedback loop involving line operators, team leaders, and management, it will become possible to address emerging issues and continuously improve the operational efficiency of Line 154.

7.3.2 Investigating Long-term Effects on Suggested Solutions

Understanding the impact of suggested changes in the work environment on the overall performance and job satisfaction of line operators is crucial. Gathering qualitative data through surveys or interviews will provide insights into how these measures influence operators' experiences, uncovering any unforeseen challenges or benefits. Besides this, investigating the long-term effects of creating a more engaging work environment on personnel changeover rates is essential. Tracking the development of skills among line operators and understanding how a supportive workplace culture influences the retention of skilled personnel over an extended period will yield valuable insights.
Doing comparative studies is recommended to assess the effectiveness of the implemented solutions against alternative strategies used in similar manufacturing environments or used in similar lines within Company X. Identifying best practices from other industries or companies facing comparable challenges will further optimize Company X's approach to waste reduction and operational improvements.

7.3.3 Training and Skill Development Programs

Developing structured training programs for line operators, emphasizing the skills required to address specific challenges identified in the research, is recommended. Regular updates to these programs will ensure alignment with evolving industry standards and technological advancements. Last, establishing formal employee recognition programs to acknowledge and reward outstanding performers is essential. Regularly celebrating achievements and contributions will foster a positive work culture, motivating employees to excel in their roles.

By addressing these further research areas and implementing the future recommendations, Company X can not only resolve the current challenges on Line 154 but also position itself as a forward-thinking and sustainable player in the manufacturing industry.

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Appendices

Appendix A – Data Measurements

Exact records of measurements for Measurement 1, 2, and 3

Ontbijtcrackers Meerzaden	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
18/10/2023	80	1012	92	503	10
20/10/2023	91	1049	136	470	17
23/10/2023	73	1083	123	489	12
25/10/2023	95	1077	95	511	19
26/10/2023	91	1079	124	472	17

Ontbijtcrackers Espelta	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
24/10/2023	143	1923	96	543	27
14/11/2023	36	1332	132	492	33
15/11/2023	72	902	93	502	10
20/11/2023	121	1883	140	537	14
21/11/2023	93	1685	179	531	36

Ontbijtcrackers Spelt Volkoren	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
03/11/2023	52	306	122	478	18
16/11/2023	58	843	86	502	11
17/11/2023	69	674	90	488	20
22/11/2023	43	592	150	510	6
23/11/2023	48	615	162	512	20

Ontbijtcrackers Volkoren Meergranen	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
06/11/2023	85	1327	89	433	15
14/11/2023	103	1648	107	419	5
15/11/2023	99	1499	67	402	11
21/11/2023	71	1185	133	456	3
22/11/2023	122	1606	109	405	11

Lichte Crackers Spelt	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
27/10/2023	151	2003	180	467	2
30/10/2023	126	1857	175	434	8
07/11/2023	147	1992	133	489	14
08/11/2023	139	1904	210	403	10
08/11/2023	157	1959	182	462	6

Lichte Crackers Volkoren	Conveyor Belt Alignment	Conveyor Belt Error	RobertPack	Terminator 2 Terminated	Terminator 2 Broken but still let through
25/10/2023	310	2243	163	481	0
31/10/2023	275	1845	149	450	0
01/11/2023	299	1979	126	474	0
02/11/2023	289	2160	185	468	0
09/11/2023	282	2338	147	457	0

Average records of measurements for Measurement 1, 2, 3, and 4

Measurement 1	Ontbijtcrackers Meerzaden	Ontbijcrackers Espelta	Ontbijtcrackers Spelt Volkoren	Ontbijtcrackers Volkoren Meergranen	Lichte Crackers Spelt	Lichte Crackers Volkoren
Error	1060	1545	606	1453	1943	2113
Outer cracker not aligned or missing	86	93	54	98	144	291
Total	1146	1638	660	1551	2087	2404

Measurement 2	Ontbijtcrackers Meerzaden	Ontbijcrackers Espelta	Ontbijtcrackers Spelt Volkoren	Ontbijtcrackers Volkoren Meergranen	Lichte Crackers Spelt	Lichte Crackers Volkoren
Broken by RobertPack arms	114	128	122	101	176	154

Measurement 3	Ontbijtcrackers Meerzaden	Ontbijcrackers Espelta	Ontbijtcrackers Spelt Volkoren	Ontbijtcrackers Volkoren Meergranen	Lichte Crackers Spelt	Lichte Crackers Volkoren
Number of Crackers Terminated	489	521	498	423	451	466
Broken but still let through	15	24	15	9	8	0

Measurement 4	Ontbijtcrackers Meerzaden	Ontbijcrackers Espelta	Ontbijtcrackers Spelt Volkoren	Ontbijtcrackers Volkoren Meergranen	Lichte Crackers Spelt	Lichte Crackers Volkoren
Intact	474	378	451	476	375	348
Broken	13	22	14	23	81	91
Total	487	400	465	499	456	439

Appendix B – Calculations Solutions

Solution 1 – Calculation impact correcting missing and/or misaligned crackers on the conveyor belt

Espelta

On average 93 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.

The Espelta recipe is being produced for 2540.77 hours per year (see *Table 3*)

2540.77 x 90 = 228,669.3 crackers per year are being discarded because of misalignment or missing crackers.

One Espelta cracker weighs 20 grams.

228,669.3 x 0.02 ≈ 4,573.39 kg Espelta is being discarded by the Conveyor Belt in a year.

Lichte Crackers Spelt

On average 144 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.

The Lichte Crackers Spelt recipe is being produced for 851.96 hours per year (see *Table 3*)

851.96 x 144 = 122,682.24 crackers per year are being discarded because of misalignment or missing crackers.

One Lichte Crackers Spelt cracker weighs 11.88 grams.

122,682.24 x 0.01188 ≈ 1,457.47 kg Lichte Crackers Spelt is being discarded by the Conveyor Belt in a year.

Ontbijtcrackers Spelt Volkoren

On average 54 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.

The Ontbijtcrackers Spelt Volkoren recipe is being produced for 801.47 hours per year (see *Table 3*)

801.47 x 54 = 43,279.38 crackers per year are being discarded because of misalignment or missing crackers.

One Ontbijtcrackers Spelt Volkoren cracker weighs 22.5 grams.

43,279.38 x 0.0225 ≈ 973.79 kg Ontbijtcrackers Spelt Volkoren is being discarded by the Conveyor Belt in a year.

Lichte Crackers Volkoren

On average 291 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.

The Lichte Crackers Volkoren recipe is being produced for 581 hours per year (see *Table 3*)

581 x 291 = 169,071 crackers per year are being discarded because of misalignment or missing crackers.

One Lichte Crackers Volkoren cracker weighs 11.88 grams.

168,071 x 0.01188 ≈ 2,008.56 kg Ontbijtcrackers Spelt Volkoren is being discarded by the Conveyor Belt in a year.

Ontbijtcrackers Meerzaden

On average 86 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.

The Ontbijtcrackers Meerzaden recipe is being produced for 408.34 hours per year (see *Table 3*)

408.34 x 86 = 35,117.24 crackers per year are being discarded because of misalignment or missing crackers.

One Ontbijtcrackers Meerzaden cracker weighs 22.5 grams.

35,117.24 x 0.0225 ≈ 790.14 kg Ontbijtcrackers Spelt Volkoren is being discarded by the Conveyor Belt in a year.

Onbijtcrackers Volkoren Meergranen

On average 98 crackers are discarded per hour because of missing and/or misaligned crackers on the conveyor belt.
The Ontbijtcrackers Volkoren Meergranen recipe is being produced for 361.99 hours per year (see *Table 3*)

361.99 x 98 = 35,475.02 crackers per year are being discarded because of misalignment or missing crackers.

One Ontbijtcrackers Volkoren Meergranen cracker weighs 22.5 grams.

35,475.02 x 0.0225 ≈ 798.19 kg Ontbijtcrackers Spelt Volkoren is being discarded by the Conveyor Belt in a year.

Solution 3 – Time before Buffer is back into original shape after error of x minutes
Line 154 produces 141 flowpacks per minute. The current speed of the conveyor belt is 141 ppm.
Increase from 141 ppm to 146 ppm = $\frac{146-141}{141} \cdot 100 \approx 3.5\%$ increase.

Error of 4 Minutes
A buffer with the capacity of 4 minutes and a speed of 146 ppm contains 584 flowpacks.
4 minutes = 240 seconds.
3.5% speed increase results into $0.964539 \cdot 240 = 231.48936$ seconds.
231.48936 seconds can be converted into approximately 3 minutes and 51 seconds.
It takes the buffer 3 minutes and 51 seconds to get back into original shape after an error of 4 minutes when the speed of the conveyor belt is increased to 146 ppm.

Error of 3 Minutes
A buffer expanded during an error of 3 minutes with a speed of 146 ppm contains 438 flowpacks.
3 minutes = 180 seconds.
3.5% speed increase results into $0.964539 \cdot 180 = 173.61702$ seconds.
173.61702 seconds can be converted into approximately 2 minutes and 54 seconds.
It takes the buffer 2 minutes and 54 seconds to get back into original shape after an error of 3 minutes when the speed of the conveyor belt is increased to 146 ppm.

Error of 2 Minutes
A buffer expanded during an error of 2 minutes with a speed of 146 ppm contains 292 flowpacks.
2 minutes = 120 seconds.
3.5% speed increase results into $0.964539 \cdot 120 = 115.74468$ seconds.
115.74468 seconds can be converted into approximately 1 minute and 56 seconds.
It takes the buffer 1 minute and 56 seconds to get back into original shape after an error of 2 minutes when the speed of the conveyor belt is increased to 146 ppm.

Error of 1 Minute
A buffer expanded during an error of 1 minute with a speed of 146 ppm contains 146 flowpacks.
1 minutes = 60 seconds.
3.5% speed increase results into $0.964539 \cdot 60 \approx 58$ seconds.
It takes the buffer 58 seconds to get back into original shape after an error of 1 minute when the speed of the conveyor belt is increased to 146 ppm.

Appendix C – Solution 2 Availability Percentages

This table has been retrieved from the *OEEblue* database and is the yearly average of the availability percentage of Line 154, per recipe.

Product	Average Yearly Availability Percentage
Lichte Crackers Spelt	79.27%
Lichte Crackers Volkoren	77.08%
Ontbijtcrackers Meerzaden	73.44%
Ontbijtcrackers Spelt Volkoren	75.68%
Ontbijtcrackers Volkoren Meergranen	72.04%
Onbijtcrackers Espelta	81.90%
Zadencrackers Pompoenpitten	65.00%
Zadencrackers Zonnebloempitten	64.33%

This is the OEEblue overview of the availability, performance, and quality percentages from the shift on Tuesday, January 16th from 07:00 am until 03:00 pm.