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Analyzing Production Efficiency: Recommendations Based on the DMAIC Cycle

Master's thesis in Quality and Operations Management

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Cover:
The logos for Swedish Match and Philip Morris International retrieved from the companies' websites.

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SUMMARY

Lean Six Sigma is a combination of two methodologies that are used globally to develop processes and improve quality. At Swedish Match, Lean and Six Sigma are integrated into daily operations, and they have a well-established team working specifically with it. Therefore, Six Sigma is the methodology that have been used during the project, more specifically, the DMAIC-cycle including five different phases: define, measure, analyze, improve, and control. The purpose of the improvement project is to analyze production efficiency at one of Swedish Match largest production lines and develop clear improvement proposals that can increase productivity, minimize waste, and optimize material flow. In addition to existing data, supplemented information and data was gathered through interviews, observations, and some frequency measurements. Together, this information and data collection developed a comprehensive overview of the problem area and the problem definition. All the problem areas were analyzed in an FMEA, where every input was evaluated and scored based on severity, detectability, and occurrence. Based on the FMEA and the researcher's own analysis, thirteen improvement proposals were developed. These improvement proposals were then evaluated using a Pugh Matrix to compare them and rank them with a weighted score based on the different criteria. This project has already led to implementation of four improvements by the company, while others are planned for the future.

Keywords: Lean Six Sigma, DMAIC, FMEA, Pugh Matrix, Snus Manufacturing.

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Sincerely,

Amanda Lindfors Emma Wiksfors

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Terms and Definitions

A list of abbreviations and field specific words used in the report.

Abbreviations

5M: Material, Method, Manpower, Machine, Measurements

CIP: Cleaning in Process

DMAIC: Define, Measure, Analyze, Improve, Control

DOE: Design of Experiments

FMEA: Failure Mode and Effects Analysis

I-MR: Individual Moving Range

MR: Moving Range

MTBF: Mean Time Between Failure

MTTR: Mean Time to Repair

OEE: Overall equipment Efficiency

PMI: Philip Morris International

QEMS: Quality and Environmental Management System

RQ: Research Question

TPD: Tobacco Product Directive

Glossary

σ: The Greek symbol for “Sigma”. Used to demonstrate standard deviation.

Andon: A visual management tool, usually used with different colored lights.

Mezzanine: A second floor, similar to a loft or terrace. Swedish: *Entresol*.

Power BI: Data visualization software, focusing on business intelligence (BI).

Snus: Pouch containing tobacco (and nicotine), used orally.

1. Introduction

To be a competitive and profitable company today, it is crucial to streamline resources as much as possible (Bergman & Klefsjö, 2010). High efficiency in both processes and personnel is essential for maximum effectiveness. Every industry strives to improve quality and productivity while continuously evolving. This thesis will focus on Swedish Match and one of their largest but least efficient production lines that they want to develop.

In this chapter, a brief overview of the theory used, some information about Swedish Match, and the problem area this report will address are presented. Additionally, the aim and scope of the work will be outlined. Furthermore, the research questions intended to be answered will be introduced, and lastly, the report's structure will be presented.

1.1 Lean Six Sigma

Lean and Six Sigma are two methodologies that effectively complement each other, enhancing an organization's ability to create value (Sörqvist & Bergendahl, 2021). Both are used by companies globally to develop processes and improve quality. Swedish Match has a well-established team specializing in lean and Six Sigma that works continuously with improvements. Therefore, lean and Six Sigma are the methodologies that will be used in this project.

Today is Toyota's groundbreaking system used worldwide to speed up processes, reduce waste, and improve quality (Liker & Meier, 2006). The core idea of lean is to eliminate waste, reduce bottlenecks and focus on value-adding activities (Sörqvist & Bergendahl, 2021; Liker & Meier, 2006). *Waste* refers to anything that neither creates value for the end customer nor is necessary for the business. There are eight (7+1) types of waste: overproduction, inventory, overwork, transportation, waiting, errors and rework, movement, and unused creativity (Sörqvist & Bergendahl, 2021). A *bottleneck* is a process with longer cycle time than others, limiting the total capacity of the flow by having the lowest throughput. This can result in queues before the bottleneck process and unused capacity in following processes. In lean, the goal is to have balanced and uninterrupted flows, with continuous improvements (Sörqvist & Bergendahl, 2021). Since lean production aims to minimize disruptions and to create smooth and continuous processes, it serves as a highly relevant methodology for identifying and addressing

inefficiencies in the assigned production line (Sörqvist & Bergendahl, 2021). However, it is important to mention that lean is much more than a tool. Lean is a philosophy that also includes cultural changes, total transformation of a business and management techniques (Sörqvist & Bergendahl, 2021; Liker & Meier, 2006).

In contrast, *Six Sigma* is centered on strategic problem-solving and reducing variation through a systematic approach known as DMAIC, which includes five phases: define, measure, analyze, improve, and control (Sörqvist & Bergendahl, 2021; Carleton, 2016). During the 2000s, Six Sigma developed into a complete improvement program through a mix of tools such as lean tools (Sörqvist & Bergendahl, 2021). Six Sigma is useful when the solution to a problem is not obvious (Sörqvist & Höglund, 2017). The problem can be related to measurement data and analysis of variation, but it can also be broader. By systematically analyzing the organization's processes and reducing its variation, a process less sensitive to disruptions is achieved (Sörqvist & Höglund, 2017).

Lean Six Sigma is based on the DMAIC approach combined with lean tools (Sörqvist & Bergendahl, 2021). Sörqvist and Bergendahl (2021) describe how a better understanding of the variation in the business can be obtained by identifying critical measures and analyzing them with statistical methods. Together, these methodologies complement each other by addressing strategic challenges, aiming to improve the organization by eliminating errors, waste, and variation while optimizing the production flow (Sörqvist & Bergendahl, 2021).

1.2 About Swedish Match

Swedish Match is a global company with a history going back to the early 1900s, starting with Swedish Tobacco Monopoly and Svenska Tändsticks AB (Swedish Match, 2025). Through various collaborations and mergers, the company has evolved into its current form. In 1996, it adopted the name Swedish Match AB. Since February 2023, Swedish Match has been fully owned by Philip Morris International, an American tobacco firm focusing on offering smoke-free products to its consumers (Philip Morris International, 2025).

In Sweden, Swedish Match has three factories, in Kungälv, Gothenburg, and Gotland. Swedish snus is a product that significantly differs from most other smokeless tobacco products (Swedish Match, 2025). Swedish Match produces high-quality products in the smoke-free,

cigars, and lights segments (Swedish Match, 2025). Their goal is to improve public health by actively promoting a smoke-free future. To ensure the unique quality of the products, Swedish Match has developed a quality standard. The standard is named GOTHIATEK® and is a guarantee that the consumer can always be certain that Swedish Match snus products are controlled and maintain the highest quality at all stages, from tobacco plant to consumer (Swedish Match, 2025).

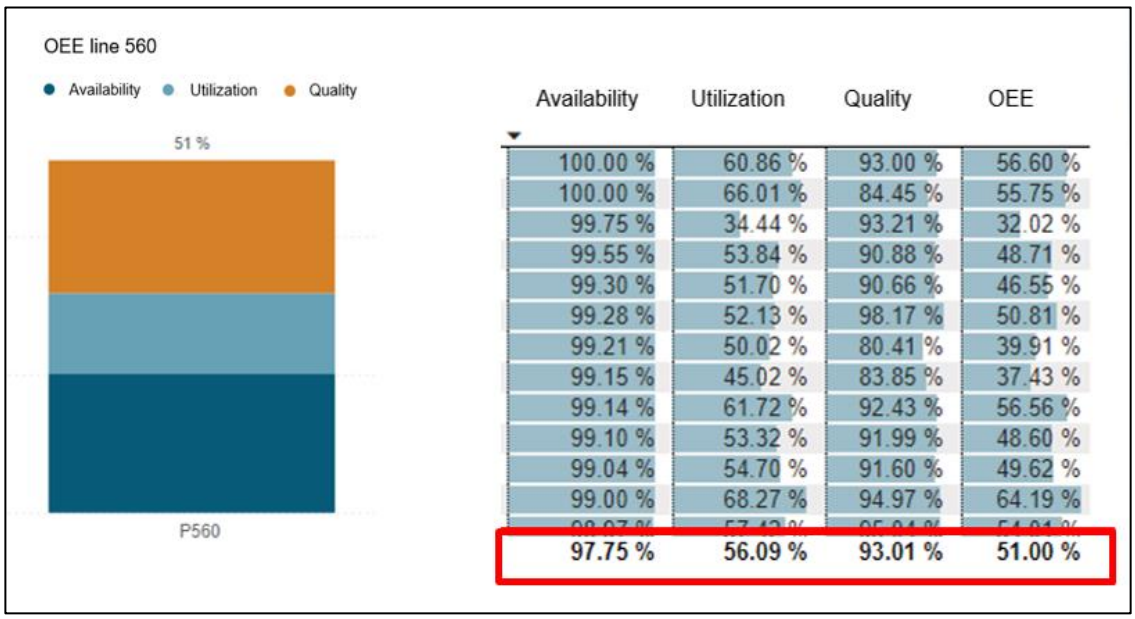
Their product portfolio includes tobacco snus, moist snuff, chewing tobacco, and nicotine pouches. This report will focus on tobacco snus, as the production line discussed in this project exclusively manufactures it. Some of Swedish Match well-known products are ZYN, General, Göteborgs Rapé, Ettan, Onico, Thunder, and Oliver Twist (Swedish Match, 2025).

1.3 About the Production Line

The project will focus on one of the largest production lines at the Kungälv factory. The Kungälv factory, completed in 2003, was the most advanced snus production facility at that time (Swedish Match, 2025). The production line experiences recurring inefficiencies that impact production capacity that limit output and negatively affect the company's delivery capabilities (R. Grosshög, personal communication, Jan 2025). In this report, *production efficiency* refers to how resources are utilized and how uptime and process quality are optimized to maximize output from the production process (Holweg et al., 2018). Numerous measurement values extracted from Power BI support this observation, indicating that the machines are not being used properly and that something is disrupting the process product flow.

Currently, the production line has X number of packing machines where the snus is made into pouches, then arranged in a star shape in the can, and covered with a lid. This process includes several visual and manual quality check steps to ensure all parts meet quality standards. After the packing machines, the next step is the two labeling machines. In the label machine the cans get a side banner, a bottom label, and a top label. If the two label machines are stopped or overloaded, the cans are transported to a buffer, which holds approximately three minutes of full running speed in capacity. If the buffer is full, all the packing machines stop automatically. After labeling, ten cans are bundled together with shrink film, placed into cartons, and moved to a refrigerated warehouse.

Figure 1 shows the line's Overall Equipment Effectiveness (OEE) on packing machine level which is used to provide an overview of how the line operates. OEE is calculated by multiplying availability, utilization, and quality (Sörqvist & Bergendahl, 2021). As the figure shows, the availability of the machines is high, around 98%, and the quality is also high. However, the utilization rate is surprisingly low, 56%. This results in a low value of the OEE, indicating that something is disrupting the process.



Availability	Utilization	Quality	OEE
100.00 %	60.86 %	93.00 %	56.60 %
100.00 %	66.01 %	84.45 %	55.75 %
99.75 %	34.44 %	93.21 %	32.02 %
99.55 %	53.84 %	90.88 %	48.71 %
99.30 %	51.70 %	90.66 %	46.55 %
99.28 %	52.13 %	98.17 %	50.81 %
99.21 %	50.02 %	80.41 %	39.91 %
99.15 %	45.02 %	83.85 %	37.43 %
99.14 %	61.72 %	92.43 %	56.56 %
99.10 %	53.32 %	91.99 %	48.60 %
99.04 %	54.70 %	91.60 %	49.62 %
99.00 %	68.27 %	94.97 %	64.19 %
97.75 %	**56.09 %**	**93.01 %**	**51.00 %**

Figure 1: Measurement of machine availability, utilization, and quality on the production line. Retrieved 20250210 from Power BI.

In May 2024, the Tobacco Products Directive (TPD) was introduced as a legal requirement in the EU. The aim of the TPD is to increase traceability to detect potential fraud and prevent illegal tobacco products (European Commission, 2024). For Swedish Match, this entails ensuring traceability on each can, bundle, and carton to track the product with a scannable QR-code. Unfortunately, the TPD markings have resulted in significant additional work and rework as all TPD codes must be read correctly, otherwise, they are removed from the system and result in rework.

However, the low OEE numbers and the decision to implement an improvement project on this line were made before the TPD was introduced. When going back in time of the data from Power BI, the OEE number in 2024, before introducing TPD, was about 55% compared to 51% in the beginning of 2025. This shows that disruptions in production were already present before

TPD was introduced. However, due to a lack of time and resources, Swedish Match decided to outsource this assignment as a master's thesis project.

Power BI and its data of stoppage reasons for the production line can be analyzed to determine what the low OEE is caused by. Figure 2 is a summary of the most common stoppage reasons in minutes so far in 2025. Every stop cause starts with “A” or “M”, which stands for automatic or manual stops. As the image shows, the most common stoppage is the automatic stop "Queue from line", which means that something after the packing machines has stopped, causing the packing machines to stop. The second highest stoppage is also an automatic stop "Vision 1 – Too many defects in a row", which means that too many pouches in a row are defected, causing the packing machine to stop automatically. The third most common stoppage is the automatic stop "Lid shortage", which means that production is stopped due to a shortage of lids. This can be caused either by a shortage of lids because the warehouse workers have not refilled the containers supplying the production lines with material, or because the lids are stuck somewhere in the pallet turner, turning mechanism or on the conveyor belts.

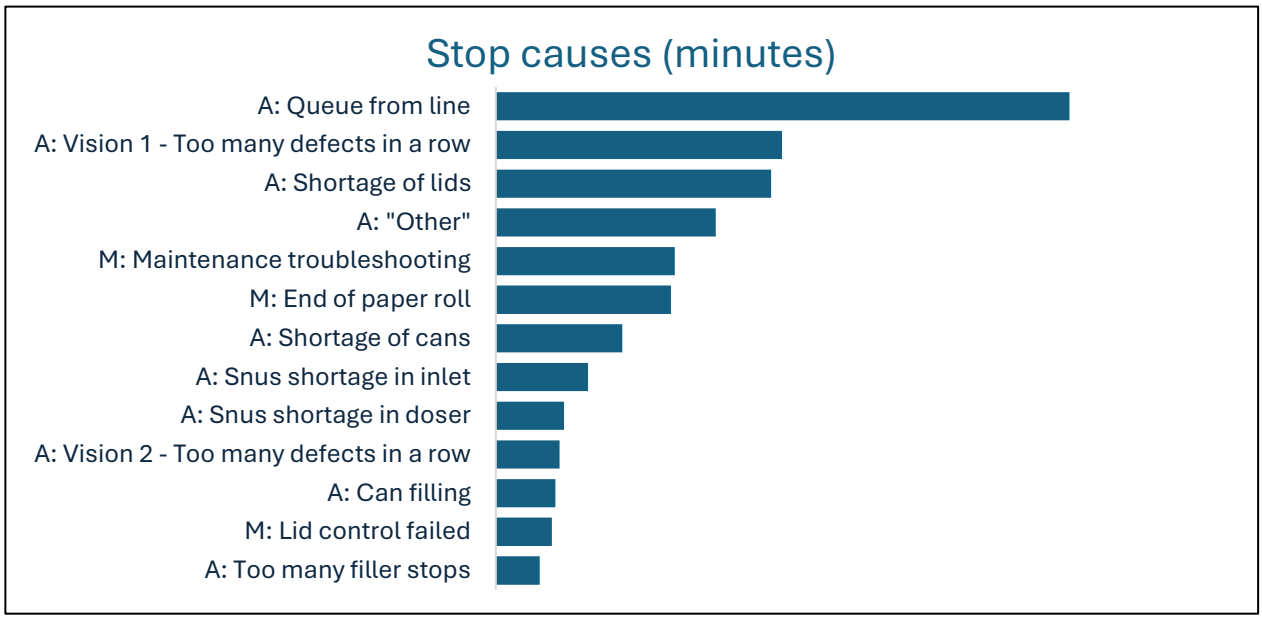


Figure 2: Stop causes in minutes. Adapted from Power BI 14/4-2025.

1.4 Aim

This thesis aims to analyze production efficiency for the production line and develop clearly described improvement proposals that can increase productivity, minimize waste, and optimize material flow when implemented.

1.5 Scope

The production line depends on the supply of cans and lids from the warehouse and snus from the preparation process. The project will include incoming cans and lids, their handling, and the pallet turners in the warehouse. Furthermore, the production line will be examined, with the flow extending all the way to the packed cartons with bundles being sent to the refrigerated warehouse. With that said, the preparation of the raw snus is not included in the scope of this project. Furthermore, suggestions for improvements will also be presented, but not fully evaluated.

Components of a snus can

To be able to understand the product that is produced on the line, the components of the snus can will be presented. A snus can consist of a can and a lid that are assembled during production. Figure 3 illustrates some of the visible components of a snus can. The lid is made up of two parts, the main lid and a disposer lid. The disposer lid is positioned on top of the main lid and is designed to dispose of used pouches. During production, the snus can is labeled with a banner on the side and a label on the bottom and top.

Figure 3: Explanation of snus can components.

1.6 Research Questions (RQ)

To achieve the aim of the report, which is to analyze production efficiency for the production line and develop clearly described improvement proposals that can increase productivity, minimize waste, and optimize material flow, the report will address two research questions. To

gain a clear understanding of the issues in the production line and identify areas for deeper analysis and investigation using the DMAIC-cycle, the first research question is:

- RQ 1: What are the identified possible causes of problems on the production line?

To not only identify bottlenecks but also propose solutions and address the second part of the aim, which is to present improvement proposals, it is essential to explore potential improvement measures. By analyzing the causes of bottlenecks and how they can be eliminated, the researchers can identify concrete actions to enhance production efficiency. By combining existing measurements with the researchers' own data collection and investigations, a deeper understanding of the issue will be gained, and consequently, well-founded improvement proposals can be presented. Therefore, the second research question is:

- RQ 2: What changes can be made to increase uptime and improve efficiency on the production line?

1.7 Structure of the report

The structure of this master's thesis report is shown in Figure 4.

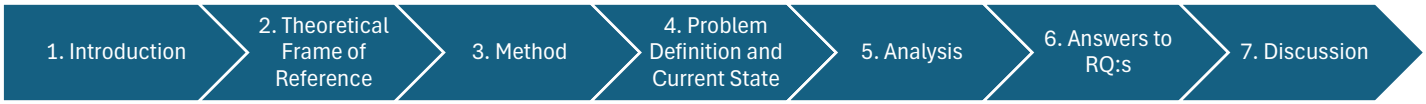


Figure 4: Structure of the report.

Chapter one, the *introduction*, provides background information about the concepts of Lean Six Sigma, the company, the project, and its scope, and lastly the research questions are presented. This is to give the reader all the necessary information to understand the subsequent chapters.

Chapter two, *theoretical frame of reference*, covers the theory of concepts used in the study, for example Lean Production, Six Sigma, Control Charts and Fishbone Diagram. This provides the reader with a deeper understanding of

Chapter three, the *method*, describes how the research was conducted. It describes the research design, data collection, literature analysis and lastly the research quality.

Chapter four, the *problem definition and current state*, firstly provides the reader with the results from the observations and interviews. It is followed by a complementary flowchart of the production line and a capacity diagram. Then, secondary data from the researcher's own measurements are presented.

Chapter five, *analysis*, is based on the concept of 5M:s where the collected data is analyzed through the category's material, method, manpower, machine, and measurements.

Chapter six, the *answers to research questions,* presents the researcher's conclusions and answer to the two research questions. Here, the improvement proposals will be clearly described and connected to the corresponding category of the 5M:s described in chapter five.

Chapter seven, *discussion and conclusion*, discusses the improvement proposals and how they are prioritized. And ends with a conclusion and the researcher's recommendations of future studies to further improve the operations.

2. Theoretical Frame of Reference

In chapter 2, all theories, methods, models, and definitions that the project will include will be presented. This will be used to analyze and investigate the processes and results of the study. Figure 5 shows how the research questions are connected to each phase in the DAMIC cycle and its specific tools.

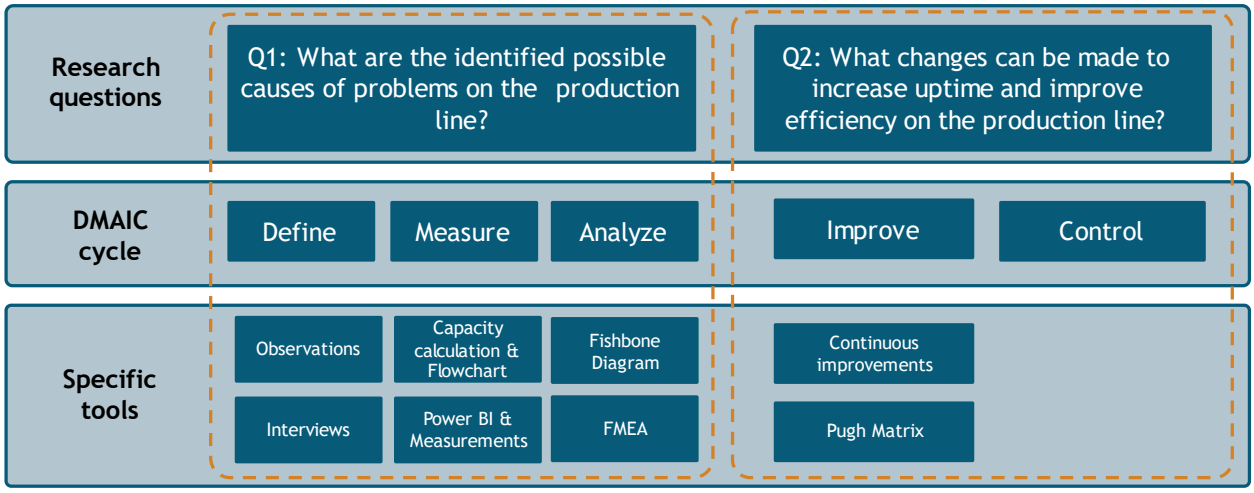


Figure 5: A visual presentation of the connection between each research question and theory.

2.1 Processes

A *process* can be defined as a limited set of coordinated activities that together have a limited purpose (Sörqvist & Bergendahl, 2021). The proportion of resources that contribute to creating value for the customer is often called how efficient a company is with its resources (Holweg et al., 2018). Efficiency is usually measured in productivity, which is defined as the ratio between all resources (inputs) that are put into a process and the proportion of goods or services that are obtained from the process (outputs). Productivity can be increased by either increasing the proportion of output from the process or reducing the proportion of input added to the process (Holweg et al., 2018).

To measure how well the process is performing is quite complex (Holweg et.al., 2018). The two most fundamental categories are effectiveness and efficiency. *Effectiveness* refers to how well the process meets the objectives of those consuming its products and services. *Efficiency*, on the contrary, describes how the process converts resources into outcomes. Additionally, effectiveness can be seen as an external perspective, while efficiency represents an internal view (Holweg et.al., 2018).

2.1.1 Flowchart

A flowchart gives a detailed picture of how a flow, or a process works (Sörqvist & Bergendahl, 2021). It consists of symbols representing different work steps and activities tied together with arrows and creating a flowchart. Typically, a process flow diagram follows the material flow from start to finish of a process (Holweg et al., 2018). It is a useful tool to discover exactly what happens under different circumstances and to find and analyze problems (Sörqvist & Höglund, 2017; Holweg et al., 2018). In Figure 6, all the process map symbols are explained.

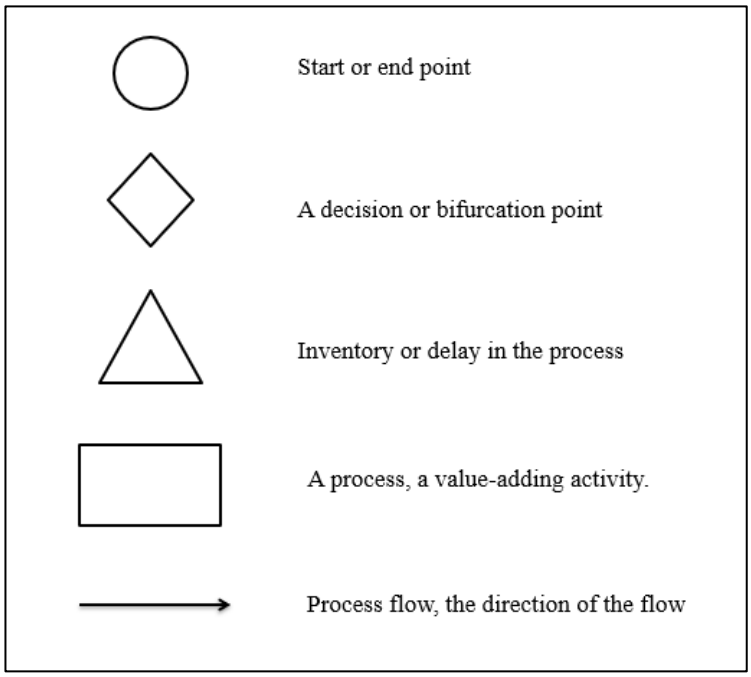


Figure 6: Basic process mapping symbols (Holweg et al., 2018).

2.2 Lean Production

The overall perspectives in lean production are working to create value, improve processes, and reduce waste (Sörqvist & Bergendahl, 2021). Lean is not about quickly implementing a system and expecting immediate results. Instead, it is a long-term journey where lean principles are gradually built into the organization (Liker & Meier, 2006). To succeed, a culture must be created where continuous improvements become a natural part of everyday work. Sörqvist and Bergendahl (2021) argue that this means that change is not about tools and processes, but also about transforming how people collaborate and think about their work.

A prerequisite for a successful implementation of lean is to have knowledge and engagement from both employees and managers, together with a strong leadership (Sörqvist & Bergendahl, 2021). Many mistakes in the implementation of lean often stem from a lack of knowledge and

the misconception that lean is only a tool. Lean is not a tool; lean is a way of leading, viewing, and driving an organization (Sörqvist & Bergendahl, 2021). For managers to succeed in lean management, it is of great importance for them to serve as role models and clearly embody the lean values and principles (Sörqvist & Bergendahl, 2021; Liker & Convis, 2012). It is about creating the right conditions for continuous improvements, where knowledge and trust are improtant parts in fostering an environment where everyone feels involved and committed (Liker & Convis, 2012).

Consequently, Liker J. K. (2004) further emphasizes the importance of applying all theories, philosophies, and principles of lean – rather than selectively applying the tools that best fit the business – despite risking short-term financial losses. As Danielsson and Holgård (2010) describe, lean is not focusing on lifting the roof to reach more advanced heights, but rather to raise the floor which the organization is built upon. This is enabled by increasing the general knowledge within the organization, utilizing common work methods, and ensuring all group members have a broad concept understanding (Danielsson & Holgård, 2010).

In lean, a lot of focus is placed on resource and flow efficiency, but these can sometimes be difficult to distinguish. *Resource efficiency* in lean refers to how available resources, such as people and machines, are utilized (Sörqvist & Bergendahl, 2021). In other words, it concerns how well critical resources in the flow are allocated to work. In contrast, *flow efficiency* refers to the extent to which an individual unit is refined, and value is added in relation to its total lead time in the process. However, it is not possible to achieve maximum resource and flow efficiency simultaneously, as there are inherent trade-offs between them.

2.2.1 Waste

In lean production, the goal is to eliminate waste (Muda) (Liker, 2004). This refers to anything that neither creates value for the end customer nor is necessary for the business (Sörqvist & Bergendahl, 2021). To achieve an efficient flow, it is essential to eliminate different types of waste (Liker & Meier, 2006). Lean can also be used to radically reduce the non-value-adding work, which also brings environmental and sustainability benefits (Sörqvist & Bergendahl, 2021). By increasing efficiency and optimizing flows in the workplace, numerous advantages can be achieved (Liker & Meier, 2006). The time required for work tasks can be reduced by eliminating unnecessary steps and movements in the process. Thus, reducing time leads to

increased production and improved workflow. Creating an efficient flow minimizes the need for intermediate storage, thereby reducing associated costs. Additionally, by optimizing the placement of materials and workstations, unnecessary movements can be minimized, increasing productivity (Liker & Meier, 2006).

2.2.2 Continuous Improvements and Standardized Work Methods

Continuous improvements (kaizen) are a core principle in lean (Sörqvist & Bergendahl, 2021). Kaizen means "continuous improvement to the better" on Japanese and includes a variety of improvement works. In an organization working with continuous improvements, flows and processes are continuously analyzed and challenged with the intent to improve and develop them (Berger, 1997; Sörqvist & Bergendahl, 2021). First of all, understanding the process is the important part, not only focusing on the result (Berger, 1997). Employee involvement and engagement trough out all divisions of the organization are considered incredibly valuable and positive in this context and are a prerequisite for successful improvement work (Berger, 1997; Sörqvist & Bergendahl, 2021). Standardization together with stable and consistent processes is a fundamental component to be able to achieve overall stability and enable continuous improvements (Berger, 1997; Liker & Meier, 2006). The aim is to standardize best practices to strengthen effective ways of working, ensure clarity and consistency in processes, and reduce unnecessary variation in how tasks are carried out (Sörqvist & Bergendahl, 2021).

To be able to implement all these improvements, a standard is needed. This entails that a standardized way of working creates the conditions required for systematic work (Berger, 1997; Sörqvist & Bergendahl, 2021). This ensures that all employees perform the work in the same way, enabling an uninterrupted flow. One way to create these standards is through 5S, which consists of five steps: sorting, setting in order, shining, standardizing, and sustaining (Sörqvist & Bergendahl, 2021). Today, 5S is seen as a fundamental requirement for an organization to work on process development and create efficient flows.

Standardization, continuous learning and employees' skills and training are important for a company's development (Berger, 1997; Sörqvist & Bergendahl, 2021). A standardized training process is essential to ensure that new employees achieve the desired competence, which in turn will contribute to the company's long-term profitability (Hasanbegovic & Merhawi, 2019). Furthermore, communication and collaboration are central factors in building teams and

improving performance (Bui, et al., 2019). To increase trust and understanding within a group, openness and regular communication is important. It helps to coordinate tasks and resources, but also a resource to creates stronger and more successful teams (Bui, et al., 2019).

2.2.3 Capacity Analysis

Bottleneck analysis is a method used to identify a process that slows down the system (Anderson, 2023). Since the system can only operate as fast as its slowest process, managing bottlenecks is crucial for optimizing production efficiency (Sörqvist & Bergendahl, 2021). To conduct a bottleneck analysis, the first step is to examine the cycle times of each process and compare them to one another (Salunkhe, 2022). Additionally, it is essential to determine the maximum cycle time required to meet the production target. By analyzing both the differences in cycle times and the required maximum cycle time, inefficiencies such as unused capacity or process misalignment are discovered (Salunkhe, 2022).

Bottlenecks will determine the maximum throughput a system can theoretically achieve (Holweg et al., 2018). However, there are variations in what goes into the bottleneck and in how efficiently the bottleneck processes this input. These variations mean that the actual throughput of the system will always be less than the bottleneck's theoretical capacity. In simple terms, even if a bottleneck can manage a certain amount of work under ideal conditions, the actual amount of work that passes through the system will be less because of these variations (Holweg et al., 2018).

2.3 Six Sigma

Six Sigma is used for continuous improvements for processes and products (Sörqvist & Höglund, 2017). It is a powerful tool that employs fact-based analysis and systematic problem-solving. Six Sigma's primary focus is to understand and reduce variation. By identifying the critical measures of a process, measuring, and analyzing data using statistical methods, one can gain a good understanding of the business and the variations that occur (Sörqvist & Höglund, 2017).

Six Sigma refers to six standard deviations and in statistics the measure of standard deviation is giving the symbol sigma (σ), see Figure 7 (Aartsengel & Kurtoglu, 2013). The normal distribution is symmetric, which means that 50% of the observations are in the left part of the average and 50% to the right. The spread of the data is controlled by the standard deviation σ. The smaller the σ, the more concentrated the data is around the mean. The larger the σ, the more spread out the values become. In Six Sigma the focus is to minimize deviations and ensure that almost all values fall inside ±6σ. In any distribution, the numbers of items outside six standard deviations from mean is vanishing small (Aartsengel & Kurtoglu, 2013).

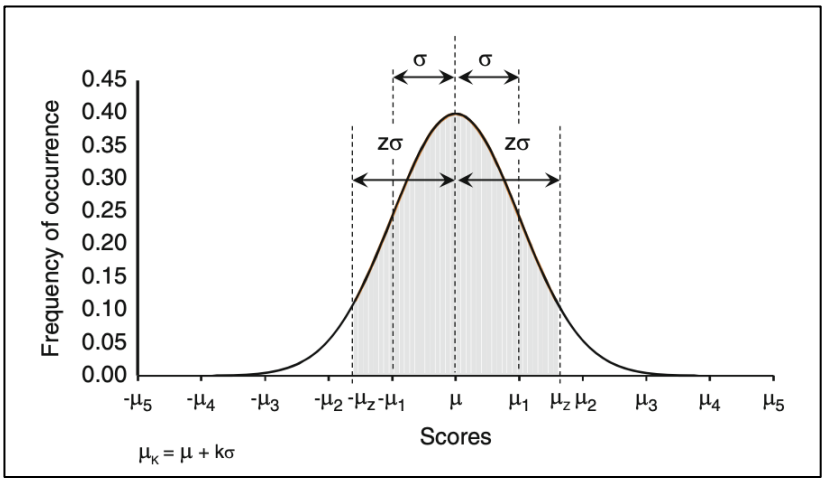


Figure 7: A plot of the normal distribution (Aartsengel & Kurtoglu, 2013).

2.3.1 Variation and Control Charts

Understanding variation is crucial not only for identifying areas needing improvement but also for ensuring that processes remain stable and capable of producing consistent results (Wheeler, 2000). There are two types of variation in all processes: special and common cause (Gitlow & Gitlow, 1987). Special cause variation arises from specific events, while common cause variation is natural cause and present in all parts of a process and is a system problem that management has. This is connected to rule number 5 of Deming's 14 points of management (Gitlow & Gitlow, 1987).

Figure 8 illustrates three different processes and their types of variation over time (Bergman, Personal Communication BB2.1, 2024). The process on the left is unstable, showing several types of variation, which means the results fluctuate significantly due to specific causes, making the process unpredictable. The process in the middle is stable but has a wide range of

variation, indicating that while the process is predictable over time, the results vary within a large interval. The process on the right is both stable and capable, meaning the results are consistent and fall within a narrow range, making the process efficient and reliable (Bergman, Personal Communication BB2.1, 2024).

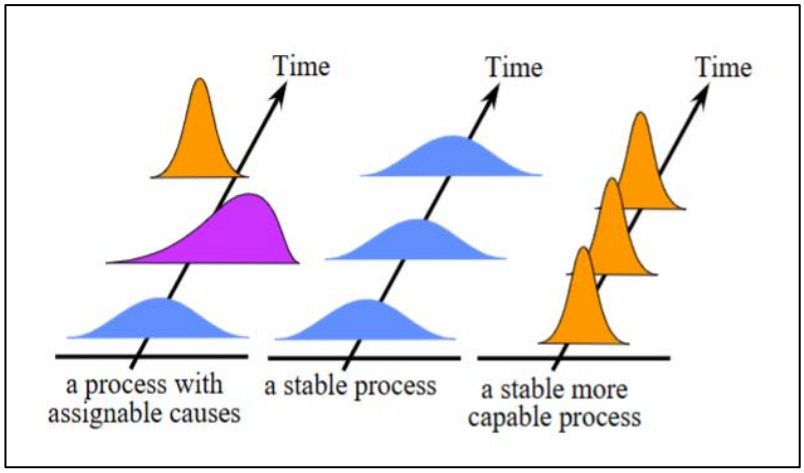


Figure 8: Different types of variation and processes stability (Bergman, Personal Communication BB2.1, 2024).

A stable process mainly consists of random variation and is stable and predictable over time (Sörqvist & Höglund, 2017). When working on improvements in a process, one aims to identify any systematic variations, after which their cause is eliminated or controlled. A valuable tool to use is control charts.

A control chart is a tool used to visualize and analyze variations in a process over time (Wheeler, Chapter 15, 2009). Customers usually have specific quality standards, so-called specification limits, that the production quality must fall within (Montgomery, 2009). To ensure these standards are met, companies set control limits for their products. Figure 9 represents an example of a control chart where there is a center line representing the mean, and an upper control limit (UCL) and lower control limit (LCL). The upper and lower control limits are determined by the variation of the data points. The bigger the variation, the wider the control limits and the smaller the variation, the narrower the control limits. A stable and predictable process stays within these control limits, known as natural variation, while points outside the control limits results in a process that is out of control and investigations and corrective actions need to be taken (Montgomery, 2009). If product quality falls outside these limits, it results in waste and rework.

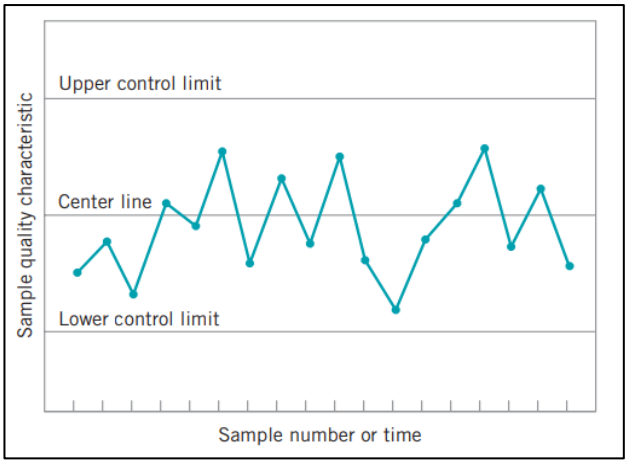


Figure 9: Example of a Control Chart (Montgomery, 2009).

There are different types of control charts used to analyze variation in processes over time. One type is called Individual Moving Range (I-MR) chart, which consists of a combination of two charts: Individual chart (I-chart) that shows the individual measured points and Moving Range chart (MR-chart) that shows the variation between these measurements (Montgomery, 2009). When entering the data, it is crucial that the data is in sequential order due to an MR-chart plotting the difference between each data point. What is special about the I-MR chart is that the data does not need to be normally distributed, Minitab automatically uses 3-sigma limits to examine the variation (Wheeler, Chapter 7, 2009). These 3-sigma limits are sufficiently general to work with all types of data, regardless of distribution.

Since workers should not be responsible for system problems, managers must know how to identify special and common cause variation to know when to act (Gitlow & Gitlow, 1987). A control chart tells the user when a change has occurred, but not specifically what has happened (Wheeler, 2000). When a sample value falls outside the control limits, or if trends and other systematic patterns are present, the variation is probably special cause (Gitlow & Gitlow, 1987). Once management has identified and eliminated all assignable causes of variation in a process, it becomes stable and considered in statistical control. If all data points lie within the control limits and no systematic patterns or trends are observed, the variation is likely common cause. Once statistical control is achieved, managers can improve the system by shifting the process average closer to the desired level or by reducing the amount of common variation (Gitlow & Gitlow, 1987).

Arvidsson and Gremyr (2007) describes Robust Design as a method to handle *noise factors* in a process. Noise factors are referred to sources of variation (natural variation) that might be expensive, difficult, or impossible to control (Arvidsson & Gremyr, 2007). These are divided up into three categories by the authors: external noise, internal noise and unit-to-unit noise (Arvidsson & Gremyr, 2007). The main principle of robust design is not to fully eliminate the sources of noise, but rather designing a process that is insensitive to them (Hasenkamp et al., 2008; Arvidsson & Gremyr, 2007). Hasenkramp et al. (2008) complements the research Arvidsson and Gremyr (2007) presents, with a practical applications of robust design.

The first principle of robust design is to establish an awareness of variation in the business or process (Hasenkamp et al., 2008). Hasenkamp et al. (2008) recommends starting from focusing on the customer, followed by identifying and understanding the noise factors. The second princple concerns the process' insensitivity to noise factors (Hasenkamp et al., 2008). In this step nonlinearities and interactions are found through, for example, a DOE (Design of Experiments) or simulations. The results from this step is then used to redesign the process to handle insensitivity to the found noise factors (Hasenkamp et al., 2008). Lastly, establishing a continuous applicability rooted in the business is recommended to ensure an organizational integrations of robust design (Hasenkamp et al., 2008).

2.4 Fishbone Diagram

A fishbone diagram, also known as a *cause-and-effect* diagram, is used to identify, explore, and graphically display potential causes of a problem or condition to discover its root cause (Carleton, 2016). It is used to analyze the possible root causes of the process variation or problem. To construct a fishbone diagram, place the problem statement in a box on the right side of the writing surface. Then, draw a straight horizontal line representing the backbone. According to Carleton (2016) the key elements of production processes typically include machines (equipment), methods (how work is done), materials (components and raw materials), people (human resources), and occasionally measurements (calibration and data collection). There is no perfect set or number of categories, instead, choose those that best fit the project. These five categories are also called the 5M:s and are commonly used (Hessing, 2017). Next, draw major cause categories branching off the backbone, creating different main causes (Carleton, 2016). For each main cause, add more specific causes that contribute to it. To generate ideas and causes, conduct brainstorming sessions with the team. This collaborative

approach helps in identifying a comprehensive list of potential causes. Once the diagram is complete, analyze the potential causes to identify the most likely root cause of the problem. By systematically breaking down the problem into its contributing factors, a fishbone diagram helps teams to focus their investigation and problem-solving efforts more effectively (Carleton, 2016).

2.5 FMEA

Failure Mode and Effects Analysis (FMEA) is a tool for evaluating the risk to customers if a certain activity input were to fail (Carleton, 2016). FMEA application is not limited to single processes, but also for design, systems, and products. The FMEA is usually initiated in the measure phase of DMAIC but could be continued into both analyzing and improve phases, depending on the type of process. Along with the risk analysis, FMEA also includes recommended and implemented remedies to minimize the identified risks. Inputs can come from process maps, Cause and Effect matrix, brainstorming sessions, or existing data. The inputs are then evaluated through the aspects: severity, occurrence, and detection. Every time the process is changed, the FMEA must be updated (Carleton, 2016).

2.6 Pugh Matrix

Pugh matrix is a type of decision matrix where different options are compared with a set of different criteria (Sörqvist, 2004). The matrix allows teams to compare alternative improvement opportunities quickly and easily against each other to identify the design solutions that best meet the customer's needs. Here is a single-point scale used to evaluate the different options. Each option is given a score based on how well it performs for the set criteria. The different criteria have a weighted score depending on how important they are for the problem definition aimed to solve. The total score of each option is the sum of all individual values for the criteria, multiplied by the weight of the criteria. The option with the highest total score will therefore represent the most suitable option for solving the problem (Sörqvist, 2004).

3. Method

In this chapter, the research design, research method, and research quality will be presented. It also includes a summarizing table on the interview respondents and how information and data were collected.

Before initiating an investigation of the current situation at Swedish Match, the philosophical aspects of research must be considered. *Ontology* is the philosophy of understanding and the assumption of reality and can be divided into two different views - objectivism and constructionism. In this case, where data is regarded as something that exists objectively, the view of objectivism is most appropriate. *Epistemology* is the study of what can be known and how knowledge can be obtained and could, similarly to ontology, be divided into two different views - positivism and interpretivism. When assuming an objectivist ontological position it is common to apply a positivist approach to the research. Positivism advocates, according to Bell et al. (2019), the use of scientific methods to study social reality in an objective manner and generate hypotheses to test. For Swedish Match's case, having a positivist approach and analyzing objective data seems the most appropriate. However, some parts of the research must be analyzed through an interpretivist approach, for example interviews, where the focus is to understand the human factor within production.

3.1 Research Design

When selecting an appropriate research design, it is essential to consider factors such as the research scope and data availability, as these directly influence the choice of methodology. In the case of Swedish Match, the study is confined to a single production line, resulting in a clearly defined and limited research scope. All relevant parameters for evaluation are related to the machinery and organizational processes, making the researched areas unique to this company. Bell et al. (2019) describes different research designs and their ability to result in generating general statements regardless of time and place. The selected research design is a case study, as it enables a detailed examination of unique operational interactions and dependencies between machines and processes. According to Bell et al. (2019), this study qualifies as an intrinsic case study, focusing on the specific characteristics of the production line rather than seeking to generalize findings to other contexts.

In case studies qualitative, quantitative, or mixed research methods can be used, but the most common one is qualitative methods (Bell et al, 2019). This study will primarily focus on numerical data, utilizing both historical records and new measurements to analyze the current state of the production line. To further enhance the analysis, qualitative data will also be collected through employee interviews and on-site observations. This approach not only validates the quantitative findings but also provides a broader contextual understanding. According to Bell et al. (2019), this methodology aligns with an explanatory sequential design, where qualitative data serves to further interpret and clarify the quantitative results.

3.2.1 Six Sigma Methodology

This research will follow an iterative process in line with the DMAIC cycle, starting with a bottom-up approach where collected data is revised by going back and forth between the theory and data. Bell et al. (2019) describes this linear process as having an inductive approach to your research.

In the DMAIC cycle all five phases must be completed in chronological order (Carleton, 2016). Shortly explained, during the defining phase the aim is to define the problem while giving it a reasonable limitation (Sörqvist & Bergendahl, 2021). This can be achieved through observations, interviews, and effective scoping. In the measure phase the processes' current state is measured to better understand where the problem is. The data collected in the measure phase is then used to analyze the root causes of the problems in the analyze phase. One useful tool in these phases is, for example, a fishbone diagram. In the improvement phase selected actions to solve the problem should be implemented. In the control phase, the changes made should be maintained to achieve effect over time and verify the successes in results (Sörqvist & Bergendahl, 2021).

3.2 Data Collection

The data collection process incorporated both qualitative and quantitative methods. Quantitative data consisted of numerical measurements, including both existing data and newly collected data (Bell, et al., 2019). Qualitative data was gathered through observations and interviews, providing additional context and deeper insights into the findings. Some of the data

collection methods were both qualitative and quantitative and will be presented under mixed methods.

3.2.1 Qualitative

Bell et al. (2019) describes qualitative research methods as a focus on trying to understand events through an analysis of human experiences and social contexts via non-numerical data.

Initial observations and interviews

To get an understanding of the production and how everything worked, qualitative observations were conducted on the production line. These will be described in detail in subchapter 3.2.3. Additionally, semi-structured interviews were carried out with operators, line mechanics, and people with other important and relevant roles, as seen in Table 1. The interviews complemented the evaluation of organizational and work method-related aspects, to properly examine if improvements to the organizational structure and work methods could be made. Therefore, it was interesting to ask the operators questions regarding both their work tasks, and their perspective and perception of production efficiency.

Table 1: Summary of the interview respondents.

Department	Respondent	Date	Duration (minutes)
Technology	One person responsible for the implementation of TPD	6/2-2025	25
Production	Operator 1 - day shift	18/2-2025	15
	Operator 2 - day shift	18/2-2025	15
	Operator 3 - day shift	18/2-2025	15
Maintenance	Electrician	19/2-2025	15
Production	Line mechanic - day shift	19/2-2025	20
	Line mechanic - evening shift	19/2-2025	15
Raw snus manufacturing	Raw snus manufacturing worker	25/2-2025	25
Warehousing	Warehouse worker	27/2-2025	20
Production	Operator 4 - evening shift	27/2-2025	15
	Operator 5 - evening shift	27/2-2025	15
Purchasing	Purchasing department	7/3-2025	15

Before collecting data, the *sample size* must be considered. For this case study a representative sample was used for the qualitative data, specifically for interviews. The representative sample included operators, maintenance staff, technicians (such as the employees responsible for the TPD implementation) and the purchasing department to get a holistic view of how a single operation can affect the whole organization. This sample was purposely chosen to ensure that diverse roles with experiences directly connected to the production line were represented in the data collection. One method to ensure representativeness is to use what Bell et al. (2019) refer to as "stratified random sampling", where the sample is distributed the same as the population in terms of the criteria chosen. Here, the criteria will be based on which department the employee belongs to.

3.2.2 Quantitative

Bell et al. (2019) describes quantitative research methods as an objective assessment of events through statistical and mathematical analyses, mainly focusing on numerical data.

Existing data analysis

Swedish Match has already collected a substantial amount of data in Power BI, including metrics such as OEE, downtime causes, stop causes, and production times for each line and packing machine. This existing data provides valuable insights for the project. However, to ensure a comprehensive analysis, it has been supplemented with additional measurements where it was needed.

The data analysis began with compiling numerical data, such as the standard deviation of downtime, using descriptive statistics. However, more data was collected to complement the existing data. The current data was mainly based on the packing machines but lacked data from the rest of the flow. Therefore, measurements on the remaining part of the flow were supplemented. This quantitative data was then further examined by integrating it with interview and observational data to identify anomalies or patterns linked to specific events or preceding process steps contributing to downtime. This phase involved inferential statistical analysis, potentially utilizing software such as Minitab to determine the statistical significance of observed variables.

3.2.3 Mixed Methods

Mixed methods is a combination of qualitative and quantitative methods that gives a comprehensive understanding of the research problem (Bell et al., 2019). It uses numerical data together with other valuable insights, allowing for robust analysis. It helps to capture more complex phenomena, offering a balanced perspective that leverages the strengths of both qualitative and quantitative data.

Observations

The qualitative data collection was made by conducting observations during different times and days to understand the production and way of working. To understand how everything worked, was connected, and influenced each other, observations were conducted on both shifts. Furthermore, more observations of a quantitative nature were conducted to collect numerical data, for example, counting and registering the number of times the production line experienced downtime. It was important for the researchers to design the data collection for standardized collection to facilitate comparisons and quantitative analysis. The observations were a suitable starting point to get an understanding of the work process and to gather firsthand data on workflow, bottlenecks, and downtime occurrences. For the initial observations, the researchers undertook a role of what Bell et al. (2019) described as "participant-as-observer". Here, the production operators were aware that research was being made on their work at the same time as the researchers were shadowing the operators and played an active role in the production line. This role was crucial to get an understanding of the workload, stress level, and critical points for a smooth production flow. The two researchers conducted this type of observation at different times and compared their different experiences with each other to find common patterns or differences in the work methods of the operators.

Later in the study, the researchers decided to do a second type of observation when all the basic information about the production line was known. This time the researchers undertook a role of what Bell et al. (2019) describes as "observer-as-participant". This role was passive and limited to analyzing the product flow, stop times for the machines and reaction time of the operators. The aim was to collect secondary data to complement the missing data from the organizational documents (e.g., Power BI), both on the production line and in the warehouse. The strategy was that one researcher was placed on the production line and the other was situated in the warehouse and contact between them was established through SMS text to alert

the other about potential disturbances. To ensure reliability of the data collection, the same researcher was placed in the same location each time data was collected. Notes were taken during the shifts, and the two researchers decided to follow the operators' schedule, including splitting up during breaks to ensure that data could be collected at all times, even when half of the operators had lunch, since more problems might arise when there is a shortage of staff on the production line.

Conducting structured observations enable a qualitative and a quantitative approach. Bell et al. (2019) describes various strategies for behavioral observations, such as recording incidents and continuous recording. For this research project incident recording is quite useful to analyze consequences of incidents in production. Incidents were recorded by being at the production site and noting every time the machines had downtime, how much time was spent on repairing the machine as well as the operators' reaction time. All the collected data from the observations were compiled in an Excel-file to further code the different incidents and consequences to enable analysis at a later phase.

Video recordings

Continuous observations were conducted through setting up cameras in areas along conveyor belts where problems usually arise. This quantitative data collection complemented the remaining observations with both reaction times, mean time to repair and root cause of problems. The recordings were up to several hours long and were analyzed at the end of the day. The aim was to capture the causes of collisions on the conveyor belts without having to spend hours of observing, and risk missing problems during break times. Another advantage of recording the collisions was the ability to replay the videos in slow motion, allowing for detailed analysis of how the issues occurred, the employees' reaction times, and the repair durations. This also validated the reliability of the existing data in Power BI and helped assess whether the data corresponded with the employees' statements from the interviews.

3.4 Literature

To get deeper understanding of the scientific findings in the Six Sigma area, a literature study was performed. The literature study was done to get the theoretical background of the methods of Six Sigma, and to examine what type of research that already had been made. As a first step, the researcher's course literature was reviewed, mainly from the courses *Sigma Black Belt,*

Lean Production, Quality and Operations Management, Quality and Reliability Control, and *Research Methodology*. As a second step other student's master's thesis works have been reviewed, as well as additional research projects searched for on Google Scholar and Chalmer's Library. Some keywords that were used to gather relevant research were: "*Six Sigma", "DMAIC Method", "Control Charts", "Lean Production" and "Robust Design"*. The keywords have been chosen based on their relevance to the project's aim.

3.5 Research Quality

Research quality is an essential aspect of ensuring reliable results in the study. It includes assessing a study's reliability, validity, and replicability. These are more closely associated with quantitative studies, but Bell et al. (2019) adds the aspects of trustworthiness to further assess a qualitative study. Since this research has a mixed-method approach, it is of interest to also include the aspects of credibility, transferability, dependability, and confirmability (Bell et al., 2019). Lastly, the ethical considerations of the research study are stated.

3.5.1 Reliability

Bell et al. (2019) describes reliability in terms of quality criteria in research methodology as being able to trust the consistency of the measurements and whether the results of the research are repeatable. Aspects considered within a study's reliability include stability, internal reliability, and inter-observer consistency. Bell et al. (2019) describes stability as ensuring the results would be the same if the measures were performed later, regardless of the variations in the measurements. It is therefore important to collect data over time to include the normal variations of the phenomena studied. Internal reliability is related to the coherence between different measurement scales. Inter-observer consistency is explained as the coherence between how data is categorized when there are several observers involved in the data collection (Bell et al., 2019).

To increase the reliability of this study, the researchers have taken some strategic actions. Firstly, the researchers have ensured that the data will represent reality by collecting data at several random occasions over a four-week period, thus ensuring that the data is stable. Secondly, the researchers have collected the measurements of the production line jointly to ensure that no events were missed. They have followed the same structure to collect the data;

reporting the time of the event, what happened during the event, and how the event might have affected the rest of the production line. For example, during a standard roll change in the labelling machines the researchers noted the time the roll was empty, the reaction time of the operators, the time to change the roll of labels and if the roll changes caused stops in the packing machines. This collectively ensured that the collected data was representative of reality.

3.5.3 Validity

While reliability tells the reader about the consistency of the measurements, validity tells the reader about the accuracy of the measurements. Both are equally crucial to ensure high-quality study.

There are four main types of validity; measurement validity, internal validity, external validity, and ecological validity (Bell et al., 2019). Measurement validity will assess whether the measurement captures the intended phenomena. Internal validity concerns if the relationship between two factors found during data collection incorporates a causal relationship, and if the researchers can be sure that there is not anything else that might affect the cause. External validity will tell the reader if the results from the study can be generalized. Ecological validity concerns if the findings are applicable in a naturally occurring setting, not only in a controlled environment.

For this research project, internal validity has been ensured by having a broad starting point when the data collection was initiated. After some observations, the researchers listed all possible causes to the observed problems in the production line, however small or non-significant they seemed in the beginning. After more data collection points, the researchers could confidently discard the causal relationships that were hypothesized in the beginning and further investigate the remaining relationships until a certain conclusion could be made. Regarding the external validity of the study, the aim was not to generalize the results. However, the same method could be used for other types of research. More importantly, the results could easily be generalized for other production lines in the factory and therefore be highly valuable for the company. The ecological validity is not relevant for this study since all measurements have been made in a natural setting, thus not being controlled.

3.5.4 Replicability

To enable other researchers to criticize the quality of a study, replicability has become an increasingly more important criteria when assessing the research quality of a study (Bell et al., 2019). To enable replication of this case study the researchers have ensured that every step of the research has been documented, including interview questions that have been asked during the interviews, methodology of data collection and the literature that has been used to form a theoretical reference. To enable replicability of the study it is important for the case company to make sure they can apply the same method to other parts of the operations, for example other production lines.

3.5.5 Trustworthiness

Trustworthiness of a qualitative study consists of the aspects of credibility, transferability, dependability, and confirmability (Bell et al., 2019). Regarding the credibility of a study Bell et al. (2019) mentions *respondent validation*. This is described as the researcher providing the participants of the study with the result of their findings. The researchers of this study have invited participants of the interviews and data collection points to a presentation of the conclusions drawn based on the interviews and observations, thus enabling them to object to the findings if there is a lack of coherence.

3.5.6 Ethics

In this improvement project, the ethical aspect must be included. While there are numerous ethical aspects to consider, three key points have been identified that are considered the most important. Firstly, the quality and safety for both the products and the workers involved must be prioritized (Bell et al., 2019). One way to achieve safety for the employees is to emphasize the importance of confidentiality and informed consent. To achieve the safety of the products, the researchers have ensured to follow the required standards of production in the factory, such as wearing a hair net and gloves to not contaminate the products. Secondly, any enhancements should be rooted in long-term financial sustainability. Lastly, the process shall not affect the health or safety of the workers. In conclusion, it is important to build on safety and quality and not challenge that aspect for the sake of both employees and the product.

Another relevant aspect regarding ethics in thesis writing is the use of AI tools. In this report AI tools such as Microsoft Co-Pilot and ChatGPT has only been used in linguistic purposes, i.e., to find synonyms and translate text.

4. Problem Definition and Current State

In the following chapter, a description of the current state will be presented using various methods and tools. This includes observations, interviews, flowcharts, capacity diagrams, training and onboarding processes, secondary data, and frequency measurements. These elements constitute a significant portion of the report's value, forming part of the define and measure phases, and serve as the foundation for the entire improvement section.

4.1 Observations

Observations were conducted to develop an understanding of the work processes, how production is conducted, and how the external functions that supply materials to production interact and operate. This is a part of the define phase to establish the current state. On the production line, there are two shifts: day and evening. Consequently, observations were made during both the day shift and the evening shift to gain the best understanding. The production process consists of a section where the pouches are made and another where it is labeled and packaged, referred to as the end of line. Therefore, during the observations, both areas were observed to understand their operations and interaction effects.

During the observations, many valuable aspects were noted. Both how the machines and the flow work, how important the surrounding factors are, but also how the human factor affects it. How the flow and the machines work will be presented later in chapters 4.3 and 4.4. Additionally, the importance of surrounding factors was observed, such as ensuring the timely and quality of supply of materials for production. Surrounding factors in this case are the supply of cans and lids, the supply of snus, but also other materials such as labels, pouch paper, plastic for the oven, and tape for the carton filler.

Furthermore, the human factor was observed. The production line has the highest speed in the entire facility, which makes the human factor and ensuring a smooth flow extra important. Both how people cooperate, communicate, work with rework, preventive work, etc., become more critical. Rework, preventive work, and reaction time were particularly interesting aspects the researchers noted. Additionally, there is a single operator who manages the entire end of line, including two label machines, oven, carton filler, rework, and quality-checks. The rest of the operators are responsible for the packing machines.

4.2 Interviews

To gain a comprehensive understanding of the operations and accurately define the current state, several interviews have been conducted to complement the observations made. The supervisor from Swedish Match recommended potential respondents that then were contacted through Microsoft Teams. A unique interview structure was created for each type of respondent, but those who had the same type of position received the same questions. The interviewers followed a semi-structured approach where pre-determined questions were mixed with follow-up questions based on the interviewee's responses. Below, a brief summary of the interviews will be presented. A full interview guide will be provided in Appendix 1.

Operators

The operators described their responsibilities as ensuring that the production flow is running smoothly, assessing stops on the conveyor belt, quality check-ups and ensuring that all components in the packing machine are working correctly. Almost all operators mentioned that the TPD work and getting cans and lids to the production line were the biggest daily challenges. Some of the operators also explained that there has been increased pressure from the management team to produce more with an optimistic production schedule. Considering this, together with a lot of production issues with TPD, the labeling machines and the oven, the operators are experiencing higher stress levels. Something that was brought up recurringly by the operators was that they would wish for one more person working in the end of line. As mentioned before, one employee is responsible for the end of line, and having an extra person would minimize the stress level at the same time as ensuring that all packing machines are still running.

Electrician

The electrician explained some of the changes that had been made to increase efficiency recently. One example is the implementation of a sidetrack for the cans from the buffer to pass through to the labeling machines in a parallel flow to the cans that go directly from the packing machines to the labeling machines. Before, both flows were merged, but now they get fed into two conveyor belts to two different labeling machines. A problem that occurred after this implementation was that the electric switches got overloaded and accidentally let too many cans through, causing collisions around the switches. These problems are generally not noticed

by the operators until the cans cause a queue long enough to stop the packing machines or when both the labeling machines do not receive cans and stand still.

Line mechanics

The line mechanics are responsible for helping the operators with more complicated changes in the different machines on the production line, for example changing properties of the packing machines, speed of the labeling attachment or analyzing a reoccurring problem to assess the root cause. However, their experience is that the operators call them for help even if there is a remedy that the operators can do themselves, resulting in the line mechanics doing unnecessary tasks. The reason for this, according to the line mechanics, is that the operators are not given enough training to know that some issues can be resolved easily, without having to call the line mechanics and wait until they are available.

Warehouse worker

In the warehouse two people are responsible for supplying all the production lines with cans and lids. The workers have to put pallets in the pallet turner for the production line multiple times every hour, making it the line with the highest demand for supplies. When the pallets are placed in the pallet turner, they are emptied into a container with a conveyor belt. If the container is getting empty, the pallet turner will empty a new pallet of cans or lids, provided that the warehouse employees have placed a new pallet in the turner. If this has not been prepared, the machine will call for a new pallet through an Andon-system. When the signal has started, the warehouse employees have an adequate amount of time to prepare a new pallet. The lead time from the pallet turner to the production line is 3-4 minutes when the packing machines are running at full capacity.

The employees in the warehouse also described how manual handling of cans and lids work. When the production line changes the orders to produce another kind of snus with another color of cans and lids, the warehouse workers have to empty the containers with a type of vacuum cleaner. The leftover cans and lids were then placed in plastic bags on the floor, to be used in a maximum of three days when the color is being used in production again. This process could cause the disposer lid to detach from the main lid due to extra movement and pressure on the lids. When the bags of leftover lids are emptied into the containers at a later point, these lids with missing disposers or single disposer lids are likely to get stuck, either in the pallet turner, turning mechanism, or on the conveyor belts. This will cause collisions that require manual

handling, often including disassembling parts of the conveyor belts to release the stuck lids. There are no signal systems to alert the warehouse workers that such collision has happened, and since the conveyor belts are not visible from the warehouse floor, the production line workers usually notice them first when the line is no longer supplied with lids.

The pallet turner for lids is equipped with a type of the turning mechanism that separates the lids with the correct side turned up, from the lids that are turned incorrectly, and then a conveyor belt will turn them facing the correct side up before merging. In the turning mechanism, lids with a partially opened disposer lid tend to get stuck and block other lids from passing. If the turning mechanism is overloaded, it will start passing through lids that are turned the incorrect way into the conveyor belt, supplying the production line with lids that cannot be attached correctly. This causes other problems on the production line, such as failure in the lid application.

The interviewee explained how they have experienced different problems with cans and lids of different colors. The colors have different added colored granulates causing a variation in the experienced softness. This causes certain colors to bend and deform much easier. Additionally, when there have been collisions on the conveyor belts lids get piled up due to extra pressure, resulting in that the defective lids risk falling down from the belts located straight above the pallet turner back into the container. As a consequence, these lids could lead to additional collisions or lids getting stuck in the turning mechanism.

Raw snus manufacturing worker

The production of raw snus is a process of between 6 to 12 hours where the tobacco is heated, cooled, mixed, salted and gets flavor mix-ins. Depending on the moistness level of the snus it has different times for mixing in the blenders. Samples are taken at different times during the process to analyze the pH-level and moistness, and corrections are made thereafter. The raw snus is prepared in containers (shown in Figure 10) that hold approximately 350 kg of snus and are emptied in pipes from the fifth factory floor to the second factory floor where the production lines are located. Every container has an attached traceable batch number.

The raw snus needs to rest for at least 24 hours to await clearance from the quality department before production. During the storage, the moistness level changes, and the production workers prefer a snus that is not too sticky. This type of snus is difficult to make into pouches.

Cleaning of the pipes is done by the production line workers, and cleaning of the containers is done by the raw snus manufacturing workers. Changing between different types of snus requires different cleaning procedures depending on the flavor add-ins and strength of the tobacco and nicotine.

Figure 10: Picture from the raw snus manufacturing showing the containers.

Purchasing department

During the researcher's visit to the factory, problems caused by the cans and lids have become increasingly apparent. To get answers to questions regarding what specifications of cans and lids look like, the researchers invited the head of supplier quality to an interview. The interview started with the respondent describing the specifications of cans and lids. Firstly, there are some basic specifications, such as measurement of the cans, and specifications regarding the deformation and concavity. Additionally, there are some functional specifications on the newer cans and lids, such as opening force, closing force and torque of the disposer lid. Some anomalies are also specified from the injection molding process, for example, flash (Protolabs, 2024).

The interviewee explained how the tools and designs are different between the two suppliers (Supplier A and Supplier B) that produce cans and lids used at the production line. When Supplier A was hired, they made slight design adjustments after initial testing. However, this design was not set as the new "standard". When they hired Supplier B a few years later, they decided to design the tools based on the original unadjusted design. This has resulted in

Supplier A producing cans and lids that are outside specifications, but work well in production, and Supplier B producing cans and lids within the specifications, but they do not function perfectly in production. Another factor in the differences in quality between the two suppliers is the age of the tools being used when producing cans and lids. However, this is under development, and during April 2025 Supplier B will start using new tools based on the best concepts from the designs of both suppliers. Supplier A will undergo maintenance of its tools to ensure that both suppliers can produce products as similar as possible, to minimize problems in the production in the factory.

The polymer granulates that are added to mix different colors in injection moulding will affect the measurements and weight of the product, especially for darker colored granulates. Today, both suppliers produce all different colors of cans and lids with the same tools, which will result in small visual and functional differences, as mentioned. If these anomalies are not acceptable, the only solution is to have separate tools for each color produced, which is an expensive investment.

The respondent continued explaining the deviation report process and how it is unsatisfactory. The reasons for this are that they have a lack of resources where only the biggest and most critical issues are addressed, and even then, some of them are missed. Another reason is that it has been difficult to specify what the issue is with the cans and lids, which makes it almost impossible to report it to the supplier. It is not sufficient to only tell the supplier that *something* is wrong. Additionally, it is difficult for the supplier quality team to determine whether it is a manufacturing problem from the supplier or a problem due to incorrect handling. Incorrect handling could be, for example, when the leftover cans and lids are stored in plastic bags on the floor, resulting in the disposer lids falling of the lids, or when the pallets have been stacked on top of each other in the warehouse, causing deformations.

During the interview, the researchers asked questions about the labels to understand their purchasing process. The labels do not have as many specifications as what the cans and lids have, but there are several problems that the supplier quality team has identified. Firstly, approximately 80% of the problems regarding the banners are connected to the paper on the back of the banners. When the banner is applied to the can, the breakage usually happens on the residual paper, and not on the adhesive side.

4.3 Flowchart

Through observations and interviews, the flow of the packaging process has been mapped, see Figure 11. At the start, incoming cans and lids from the warehouse arrive transported on conveyor belts, and snus transported down in pipes from the raw snus manufacturing. These are transported to the packing machines, where the pouches are produced, quality checked and placed into the cans in a star shape. Several quality checks are then performed before the lid is put on.

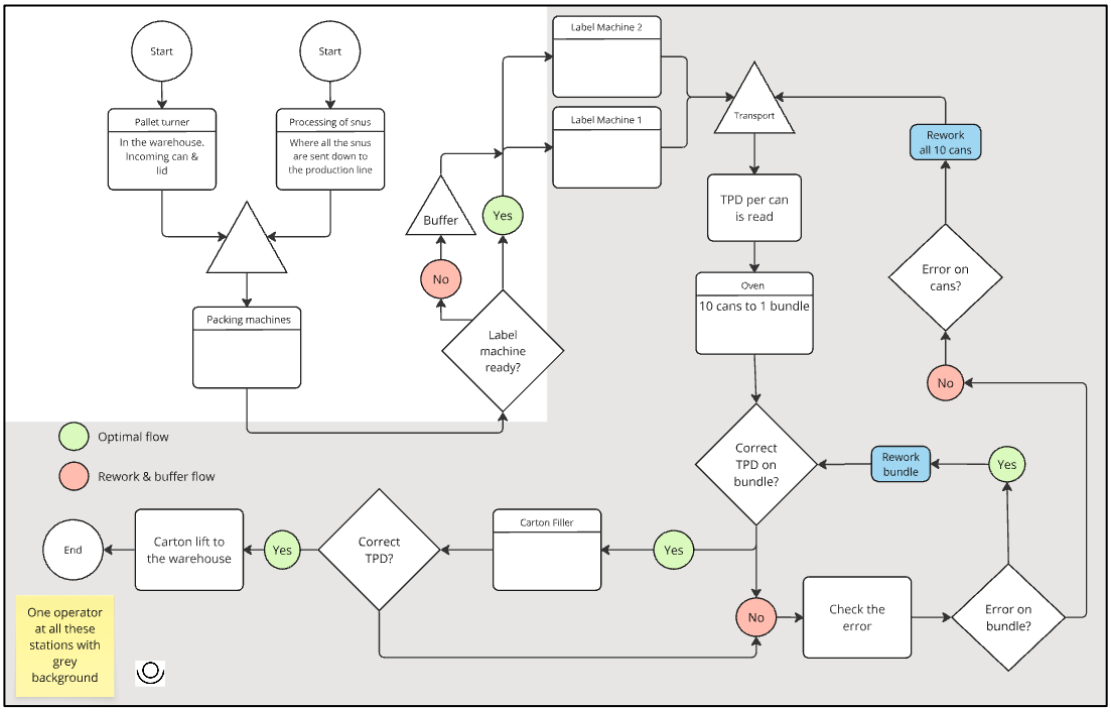


Figure 11: Flowchart, from incoming materials to finished product.

After the packing machines, the cans are moved along conveyor belts, where they are marked on the bottom with the packing machine's number. This marking allows the cans to be traced back to the respective packing machine. They are then transported to the two labeling machines. Cans from half of the packing machines are merged onto one conveyor belt, while cans from the other half of the packing machines are transported on another. The two conveyor belts merge into one through a switch that gradually releases cans from both lines.

In an optimal scenario, the cans go directly into the labeling machines, where they receive a side banner, bottom label, and a top label. To prevent the packing machines from stopping due to disruptions further down the flow, there is a buffer before the label machines. The buffer has a capacity of approximately three minutes of full production.

The bottom label contains a TPD code, which is checked to ensure readability. Cans with unreadable codes are discarded. During this process, a visual inspection of the label placement is also performed where cans with misaligned or incorrectly placed labels are removed. There are three rejection points during the labeling process for cans that fail quality control. After labeling, the cans are transported on a conveyor belt to the oven. Here, two conveyor belts merge into one through a switch that gradually feeds the cans forward.

At the oven, ten cans are grouped into a bundle using shrink films. During this process, the TPD codes on all cans are scanned, allowing each bundle to be traced back to its specific cans. After passing through the oven, the bundles roll onto a new conveyor belt, where they receive a label. The TPD code on this label specifies exactly which cans are included in the bundle. Bundles with incorrect or unreadable codes are discarded, but under good circumstances, they proceed to the carton filler.

In the carton filler, a TPD code check is conducted before a robot places six bundles at a time into four layers in a carton. Once all twenty-four bundles are packaged, the carton is automatically sealed and given a final label. This label is also inspected. If any issues are detected, the carton is rejected, otherwise, it is sent to fridge warehouse.

To explain TPD codes in a simple way, they can be compared to a family tree:

- Each individual can receive a unique code, called a *child*.
- When ten cans are packaged into a bundle, the bundle receives a new TPD code, referred to as *parent*.
- When twenty-four bundles are placed in a carton, the carton receives a label with an overarching TPD code, called *family*.

With these codes, every can is able to be traced back to a specific packing machine.

Throughout the process, rework loops occur, as illustrated in Figure 11. The amount of rework increased in May 2024, when TPD codes were introduced. One of the biggest challenges is that the codes must be scanned and registered in the cloud before the next camera in the process scans the product. If this does not work, adjustments and rework are required. Even before TPD codes were introduced, rework was necessary, for example, due to misaligned labels or other deviations. However, the new traceability requirements have further increased the workload to ensure that all cans and bundles are correctly labeled and traceable throughout the entire chain.

4.4 Capacity Diagram

To investigate potential bottlenecks in the production process, a capacity calculation was conducted on all main processes in the flow. In this case the processes' capacity was analyzed to determine if the current machine capacity can meet the production goal.

As illustrated in Figure 12, all four processes have a capacity exceeding the production goal. The production goal is represented by the dark blue bars, while the additional capacity for each machine is represented by the light blue bars. The packing machine has an additional capacity of 54 %. On the production line, there are two label machines, and the yellow line in Figure 12 represents one label machine's capacity. The total additional capacity of the two label machines is 145 %. The oven has an additional capacity of 92 %, and the carton filler has an additional capacity of 122 %.

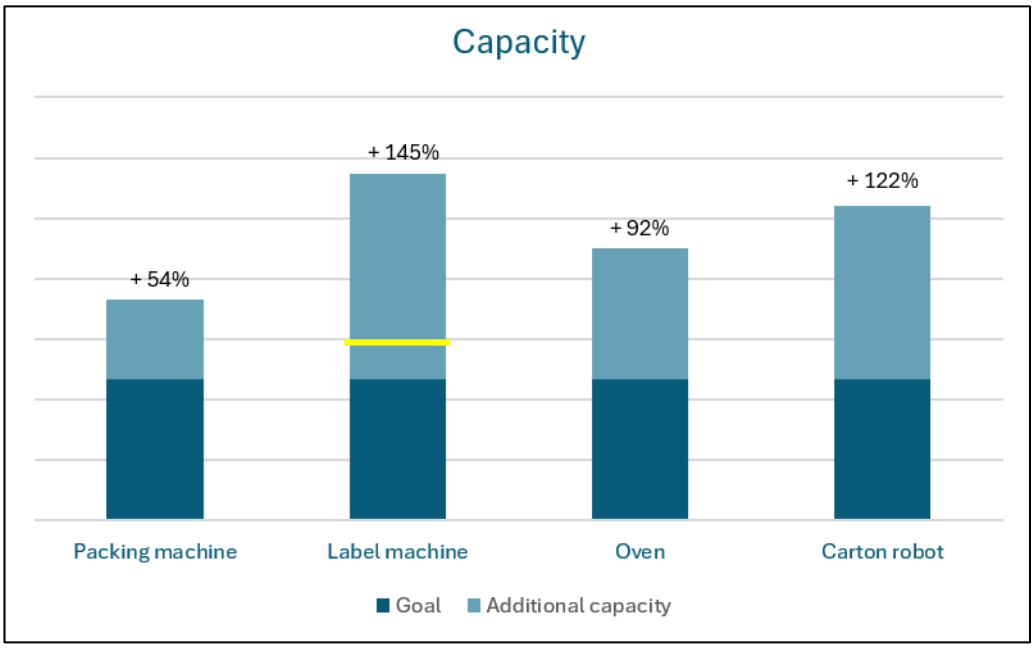


Figure 12: Capacity diagram of the machines in the production line.

4.5 Secondary Data

Swedish Match had a lot of data collected in Power BI for each production line for each day, including everything from reasons for stoppages, production quantities, snus shortages, lid and can shortages, etc. With that data, it was possible to assess how the line was performing and

determine what needed further investigation. Additionally, there were also numerous documents with routines and educational material on the intranet.

4.5.1 Production Time

The existing data included information on the total daily operating hours for the packing machines. However, to determine the actual available production time, setup times for product and order changes must be subtracted. To assess the packing machines' performance compared to the available production time, the researchers examined three months of production, focusing on five days each month to calculate an average.

Table 2 summarizes the three months and the operating hours during these five days of available production time. For each month's five days, an average of the production hours was calculated and summed up. Setup times were calculated by reviewing the production schedule and planned order changes. Then the percentage of available production time was calculated by taking the average operating hours per day minus the setup time for each day divided by available production time. An average value for each month was then derived from these calculations. As Table 2 shows, the percentage of available production time is between 62 % - 70 %. During the remaining 30 % - 38 % there is something that is disrupting the production flow, which will be presented further in subchapter 4.5.2.

Table 2: Percent of available production time on the production line.

Month	% of available production time
November 2024	62%
January 2025	70%
February 2025	70%

Regarding setup time, it varies depending on whether it is a product change or an order change, as well as the types of snus being switched. During an order change, only a reset of production and often a label change are carried out, for example changing Swedish labels into Norwegian labels.

At the end of the day or between changes in what type of snus is being produced, it is required to perform a cleaning of the whole line, pipes, and raw snus containers. This cleaning process is called “CIP” (Cleaning in Process) and can be performed in three different sequences: start CIP, medium CIP, and total CIP, depending on which type of snus is being changed. The start CIP is used when there is a small difference in the snus change. The start CIP includes draining the pipes and containers with hot water and then a drying session. This type of cleaning program takes 15 minutes to do. The medium CIP sequence includes draining the pipes with hot water and *lye* (a concentrated solution of sodium hydroxide used for cleaning), resulting in a process time of 30 minutes. The total CIP is used for the daily cleaning in the morning (or in the night, depending on schedule) and when there is a change of snus with a strong added flavor to a neutral flavor, for example, Kapten Mint X-Strong to Kapten Original. This cleaning process includes the same as medium CIP but will also add an acid rinse at the end of the process, resulting in a 45-minute-long cleaning sequence.

Normally, the production schedule is planned to avoid major cleanings during the day. However, there are several things that affect the production during the day that might prevent the completion of an order. This causes the production schedule to be delayed and might result in a major CIP in the middle of the day. These obstacles could be a changed plan of what snus is produced, or the raw snus not being finished in time for production. This is, of course, not optimal, but there is not much that can be done about it.

4.5.2 Training and Onboarding

Training and onboarding are incredibly important for learning the tasks and acquiring the skills expected by the workplace (Bui, et al., 2019). Tasks and instructions how to perform them correctly are clearly described on Swedish Match internal site, QEMS: Quality and Environmental Management System. Swedish Match’s QEMS works as a portal with important documents on how activities and processes in the organization should be planned and controlled. The aim of gathering all critical documents in QEMS is to easily ensure that the desired quality of products and environmental goals are met in every part of the operations, from product research to export logistics. The QEMS site is divided up by the different main processes, such as *Research*, *Manufacturing* and *Logistics*, with support activities such as *Laws and Requirements* and *Quality Assurance*, and sub-categories such as *Engineering, Purchasing* and *TPD*, to name a few.

However, some issues of the training process have been identified. There are several instructors responsible for teaching in different production lines. However, gaps have been noticed in verifying the instructors' skills and the training set-up. Currently, a four-page checklist is used to ensure all areas are covered. This would work if the instructors' competence and the standards they teach were ensured. Furthermore, training lacks strategy and guidance on how to think and collaborate on the production line. Working on a production line might seem like a solitary job, but it is quite the opposite. Communication, collaboration, and preparatory work is needed for everything to function as smoothly as possible.

4.6 Current State with Secondary Data

In Power BI, there is a collection of both automatic and manual stoppages, see Figure 13. As shown in the figure, the stop cause “Queue from line” is by far the most common cause of stoppages so far in 2025. Queue stoppages from the line mean that something after the packing machines is disrupting the production. This causes the buffer to fill up and the packing machines to stop. To understand this issue more deeply, independent measurements were conducted. Analyses of the different stoppage causes were conducted, along with more in-depth observations and frequency measurements.

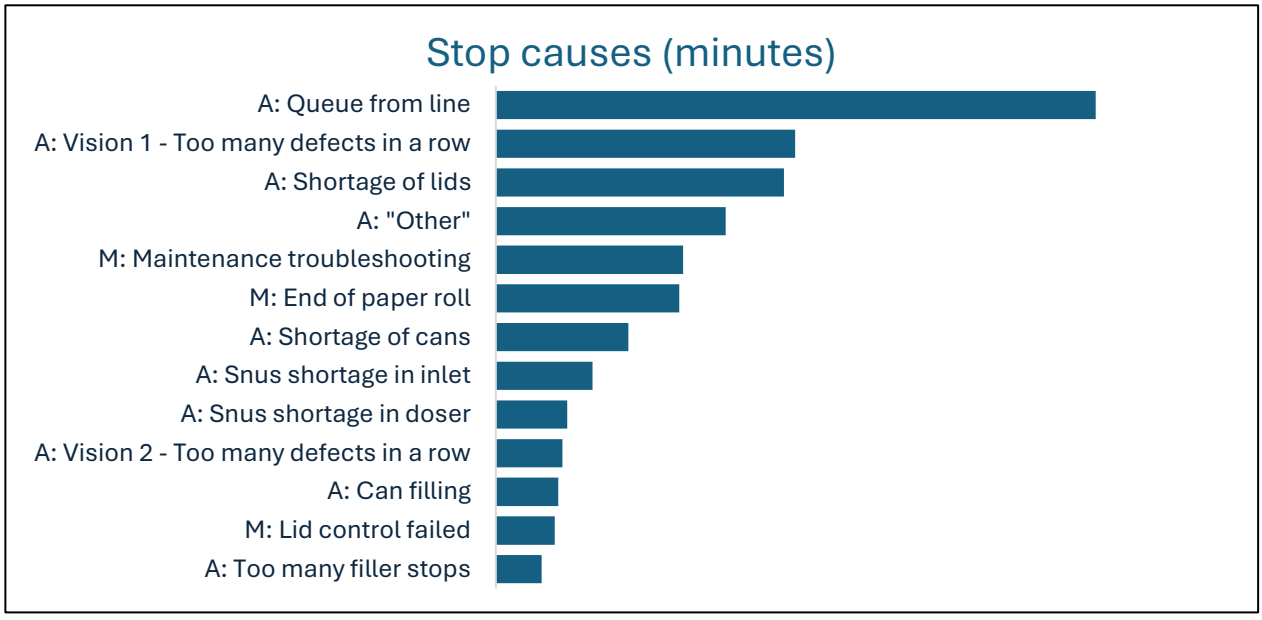


Figure 13: The most common stoppage causes from 2025.

4.6.1 Frequency Measurements

To complement the existing data in Power BI, the researchers decided to conduct frequency measurements of stops on the conveyor belts, collisions of lids and how often there is a shortage of lids delivered to the production line. The chosen areas to conduct frequency measurements in were based on what the researchers considered as critical points based on their observations.

Conveyor belt stops

To gather data regarding the conveyor belt stops and collisions the researchers started off by registering all the stops manually in their diaries during the observations. However, this was not considered to be sufficient since stops during the evening shift could not be registered. To overcome this problem, the researchers put up lists next to the point of the conveyor belts where most stops occurred and asked the operators to fill it in every time they had to intervene and correct the collision, see Appendix 2. The two most frequent stop locations; the conveyor belts between the packing machines and label machines, and the conveyor belts between label machines and oven. This data collection put a lot of responsibility on the operators, but the researchers were very attentive to explain the aim of the data collection and how a potential improvement of the number of collisions could benefit the operator's workload.

Figure 14 and Figure 15 show a summary of the frequency measurements, where the dark blue bars represent the number of stoppages on that day and the light blue bars represent the estimated number of minutes the label machines stopped due to a lack of materials. Several stoppages occur daily without any signal or alarm, requiring an operator to go upstairs to fix the issue. The only way to detect the stoppage is when the packing machines stop because the cans cannot move forward, or when the label machines do not receive any cans.

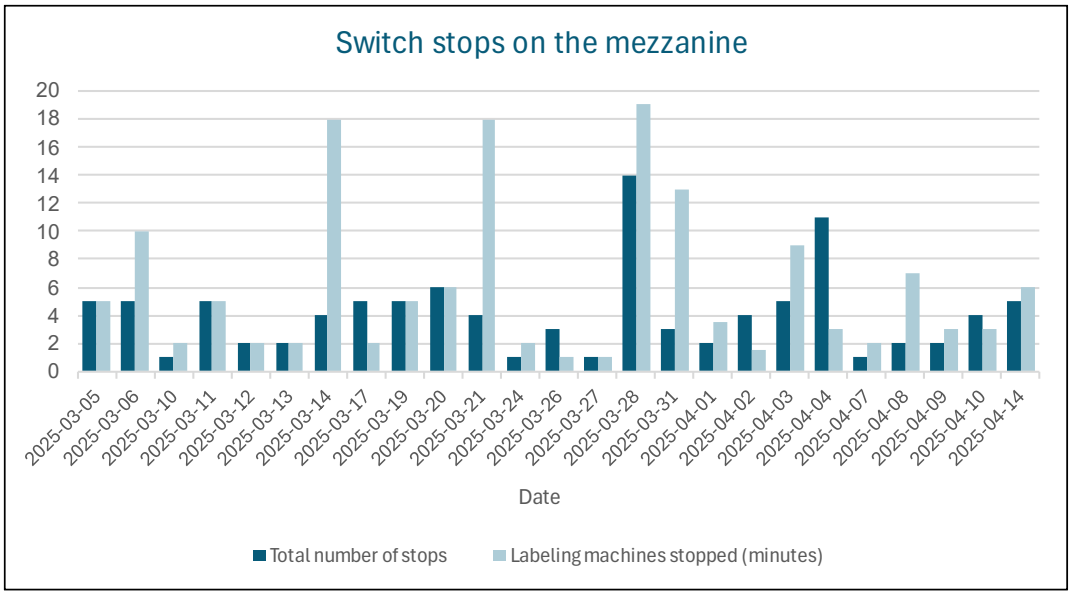


Figure 14: Mezzanine conveyor belt stops.

Figure 15 shows stoppages on the conveyor belt where the two label machines' conveyor belts merge into one and then go towards the oven. Here, there are also no alarms or signals, and the stoppages are detected when the label machines stop due to a conveyor belt to the oven or when the oven does not receive cans. To resolve this issue, one operator must climb a ladder and reach up to remove the cans that have collided.

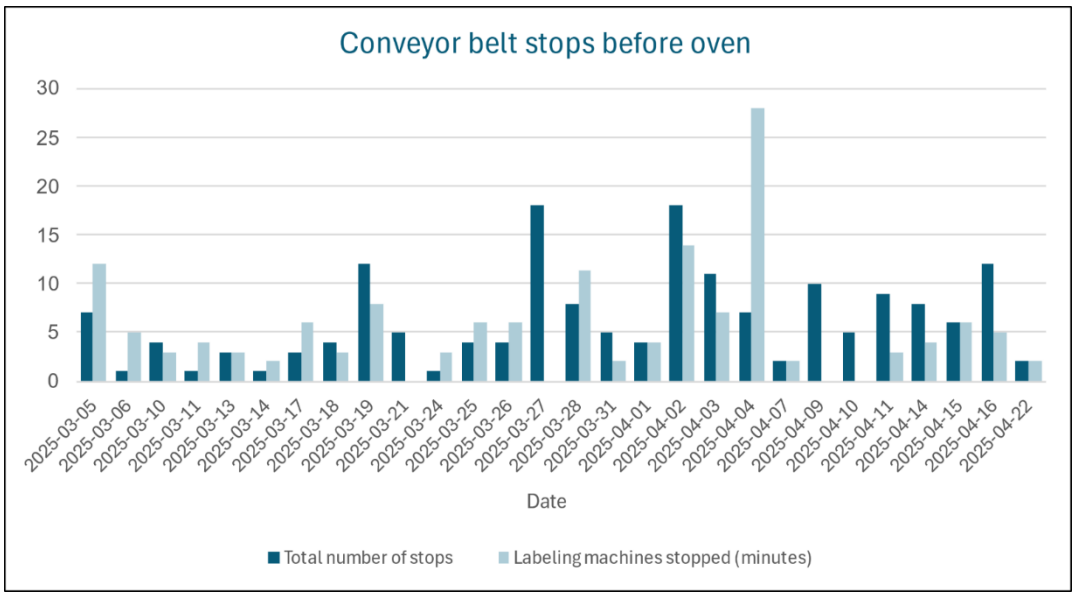


Figure 15: Conveyor belt stops before oven.

As shown in the figures, the number of stops and the total minutes of stops varies a lot. During the observations, it was noted that not all employees filled in the information correctly or did not know how long the label machines had stopped due to collisions on the conveyor belts.

However, these frequency measurements show that it occurs several times, leading to additional work and stoppages in the flow or packing machines, which could be minimized and increase the flow.

Collision of lids

In the warehouse similar lists were put up. A list was put up by the pallet turner for warehouse workers to fill in if lids got stuck in the turning mechanism or in the pallet turner itself. These locations were chosen to make filling in the lists easier for employees to ensure as many stops as possible were recorded. The list included aspects such as where and why the stop has happened, color of the cans or lids to see if there was a difference in occurrence based on the color, and the time to solve the collision/stop, see Appendix 3. A summarizing table of all the stop causes and time are shown in Figure 16. The superior stop cause is collisions on the mezzanine. Furthermore, the two second most frequent stop causes are stop after turning mechanism and then stop due to lids stuck in the door.

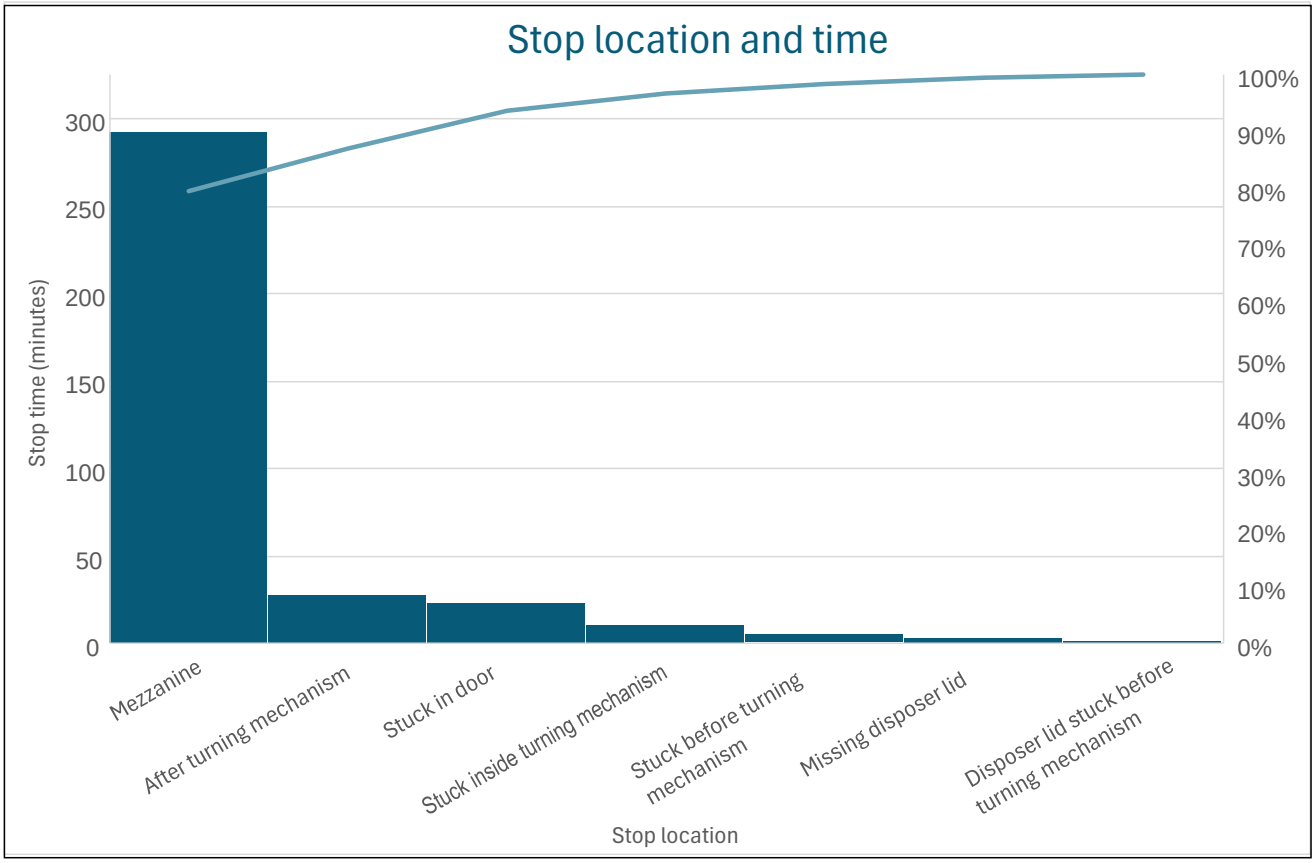


Figure 16: Stop location and time for collisions in the warehouse.

Shortage of lids

To cross-reference the data collected in the warehouse, operators on the production line were encouraged to document the shortage of lids supplied to production. The researchers prepared a list where the operators could fill in the time of the shortage, how long it lasted and whether or not the shortage came from an issue in the warehouse or from a collision on the conveyor belts closer to the production line, see Appendix 4. This list was compared to the list in the warehouse to determine the credibility of the data collected in both departments. If a shortage of lids was recorded at the production line but not in the warehouse, three possible conclusions could be drawn: first, the warehouse failed to supply the pallet turner with material in time to transport to the production line; second, the warehouse workers failed to identify where a collision might have happened; and third, the warehouse workers failed to fill in the form due to a lack of time.

4.6.2 Queue from line

To understand the stop cause "Queue from line", extensive observations were carried out on the production line. The aim was to determine why this stop cause is so common and why the packing machines are not reaching their full capacity. Observations were conducted for several hours over four different days, during which the researchers documented all events with some more focus on the end of line. This included stoppages on the line, all label changes or stoppages in the label machines, stoppages in the carton filler, the time packing machines were stopped, among others. Both reaction time and time to resolve the issue were included to investigate the causes more deeply.

During the observations it was clear how sensitive the production line is to prolonged or repeated stoppages at the end of the line. If everything runs smoothly and only simple label changes occur as planned, the line operates well. Given the high flow rate of this line, it is crucial to address stoppages as quickly as possible, including both reaction time and the time to repair or fix the problem.

Label machines

During the observations, it was noted that the label machines experienced significantly more stoppages than the usual label changes. To investigate this further, all stoppages related to the

label machines were summarized. Figure 17 shows the mean time to repair for all the types of stops without reaction time. The stoppages with the longest repair time are “banner adhesive stuck around pole”, “collision” and “banner breaks”. However, the collected data shows that regular banner and label changes are not a problem for the line's flow. These banner changes are columns 4, 5, and 6 in the table regarding mean time to repair. When looking closer, the label change without reaction time takes around 90 seconds which is reasonable.

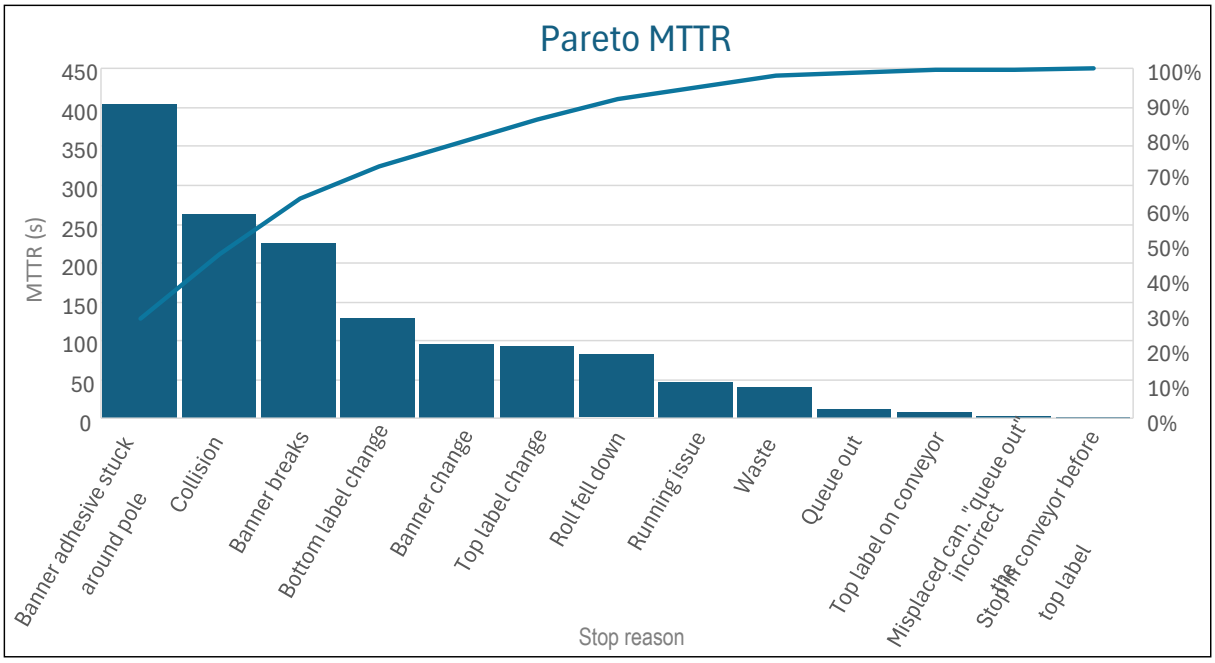


Figure 17: MTTR for the different stop reasons for the label machine, without reaction time.

Furthermore, it is interesting to examine the reaction times for the various stoppages to see how they affect the line. The reaction times can be analyzed using an I-MR chart, which is well-suited for this type of data (Montgomery, 2009). Figure 18 displays the I-MR chart along with the observed variation where every blue and red dot represents an observed reaction time. When summarizing the reaction times for stoppages on the label machines, a large variation in reaction times can be observed. The average reaction time is 48.3 seconds, represented by the green centerline, while the red lines represent the upper and lower control limits.

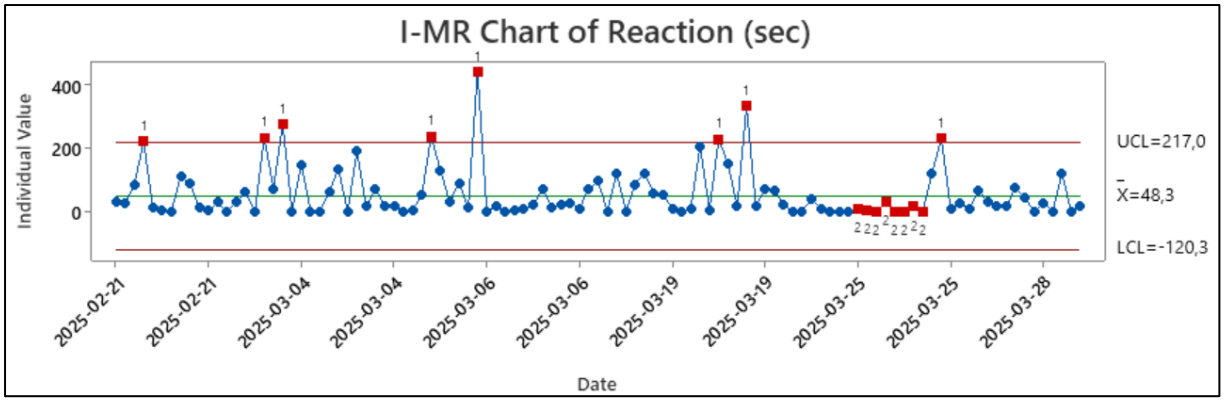


Figure 18: I-MR chart of reaction time (seconds).

Data points that fall within the control limits represent normal variation (Montgomery, 2009). However, there are several red data points above the upper control limit having reaction times that are significantly longer than usual, so-called outliers. When data points fall outside the control limits, it may indicate that something unusual has occurred or a deviation that should be examined further (Montgomery, 2009). In such cases, each data point is investigated by going back in the data and investigate why the reaction time for this specific point is unusually high. However, when these outliers were investigated, nothing unusual was found. One of the outliers corresponded to a label change for the bottom label, something that is done several times a day. The other outliers were associated with unplanned stops that occur without any warning but occur every day.

Furthermore, there are a row of red dots in the lower right corner of Figure 18. An I-MR chart signals when nine points in a row fall on the same side of the mean indicating a deviation. In this case, it is a positive indication as the aim is for the lowest possible reaction time.

To explore this further, the observations were broken down by date to examine the variation between different days more clearly. As shown in Figure 19, there is significant variation in the average reaction times across the dates, which are based on the overall variation in the data. March 25th stands out as a particularly positive example, with an average reaction time of only 25 seconds, while other dates show average reaction times more than twice as long. This highlights the potential for achieving lower reaction times when there is clear oversight, proper preparation for label changes, and effective collaboration and communication between operators.

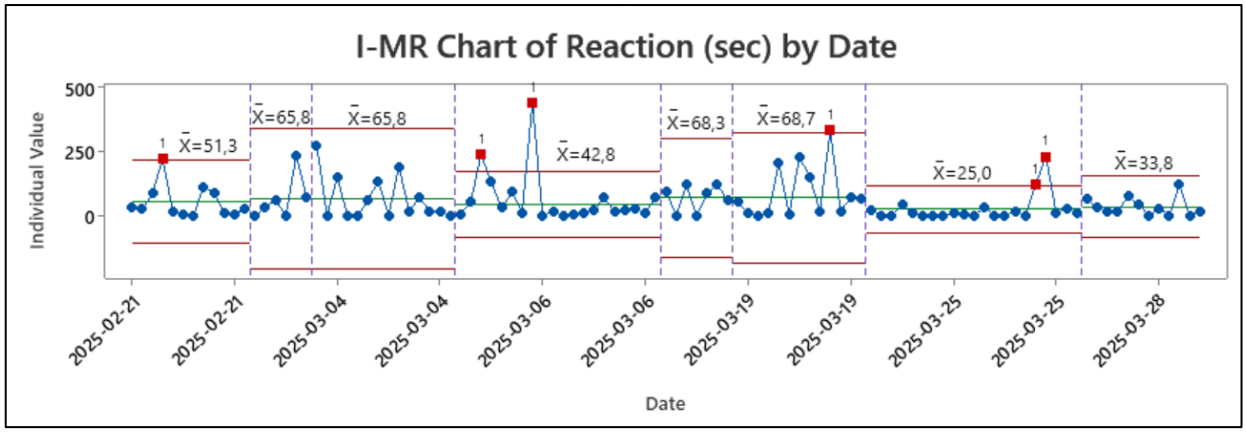


Figure 19: I-MR chart of reaction time, every date separately.

Furthermore, the different stop causes and their corresponding variation in reaction times can be analyzed. To do this, an Individual Value Plot was used, which displays all recorded reaction times for each specific stop cause, see Figure 20. Each grey dot represents an observed reaction time.

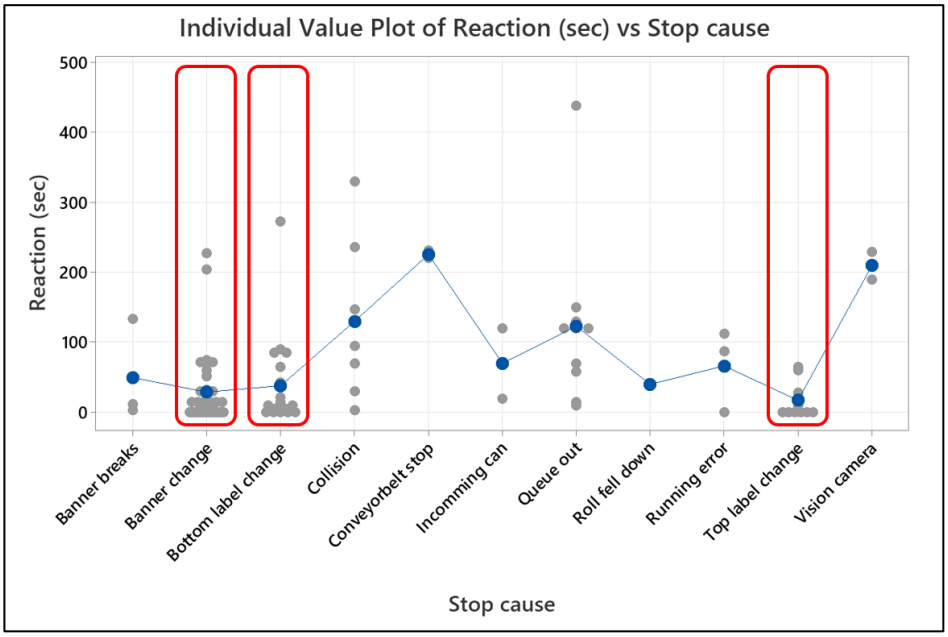


Figure 20: Individual Value Plot of reaction time vs stop cause.

As seen in Figure 20, the three different types of banner and label changes have many data points with low reaction times, which is positive since these are the most frequent occurrences. These stop causes are also supported by an Andon-system that first gives a warning when the roll is about to run out and then turns red when it is time to change it. The remaining stop causes also have an Andon-signal, but in those cases, the light turns red immediately when something happens.

5. Analysis

In the following chapter, the findings will be analyzed and discussed based on the 5M:s (material, method, manpower, machine, and measurements). In Figure 21, ideas and potential causes are visualized in a fishbone diagram. The fishbone diagram has been used to gradually analyze and break the problem into its contributing factors (Carleton, 2016).

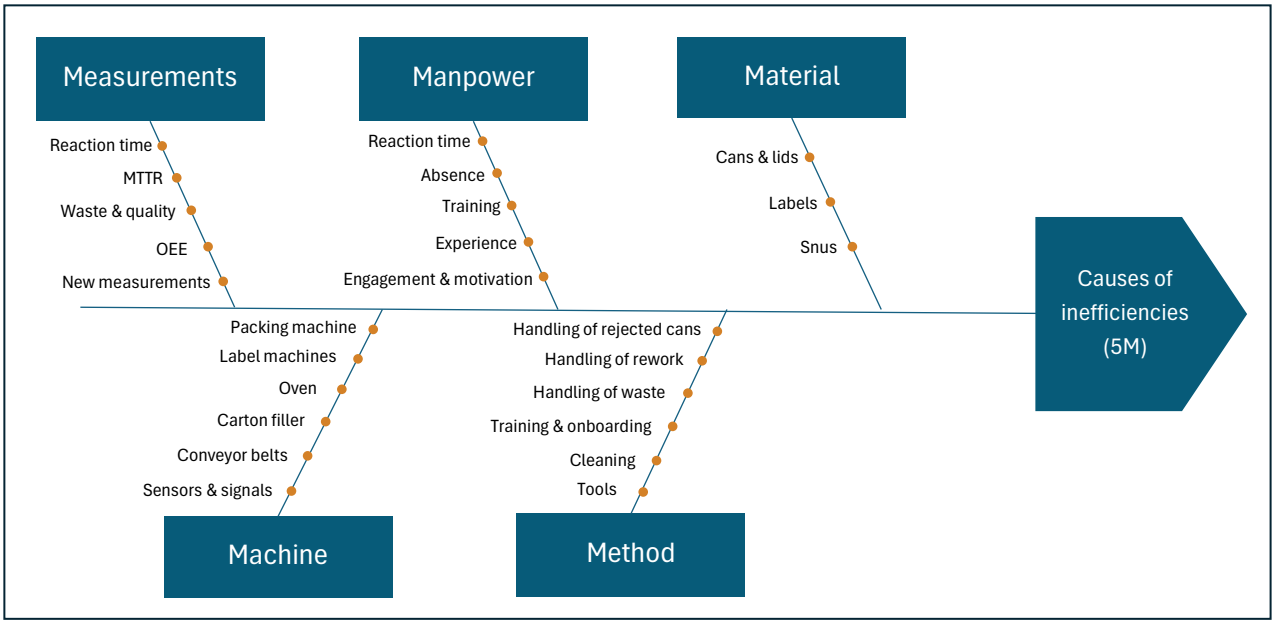


Figure 21: 5M diagram showing different causes of inefficiencies.

5.1 Materials

During the interviews and the structured observations, it became clear that the quality of incoming material significantly affected the production output. Firstly, the researchers will analyze how the incoming cans and lids affect the production including the quality of cans and lids, transportation, storage, and handling of the material. Secondly the quality of labels will be presented, as well as an assessment of the specifications for both the labels, cans, and lids for the suppliers. Lastly, disturbances in the material flow will be presented.

5.1.1 Quality and Handling of Cans and Lids

Firstly, the stop causes on the production line were analyzed. As seen in Figure 13 (in subchapter 4.6), can shortage is the seventh most frequent cause of stoppages, and lid shortage is the third most frequent cause of stoppages in terms of total minutes of downtime.

When analyzing the shortages of lids and cans there are a few possible causes as to why this might happen. The first cause is that the warehouse workers have simply not prepared a new pallet to be put in the pallet turner, and thus, no cans or lids are supplied to the production line. The other possible cause is that there is a stop or collision either in the pallet turner itself, or somewhere on the conveyor belts between the pallet turner and the production line. During the observations, it was evident that the number of cans and lids supplied rarely was the problem as to why there were no cans and lids supplied to the production line. The workers were quick to respond to the signals of preparing a new pallet, and often even had spare pallets already prepared for a more efficient change.

Stop locations

It was of great interest to the researchers to investigate the location of stops in the warehouse and the conveyor belts to be able to analyze the root causes of the stops. The researchers used the frequency measurements the warehouse workers had filled in for one month to determine the most common stop locations and stop times to identify which locations affect the production outcome the most. The summarized data from the warehouse workers can be seen in Figure 16.

Mezzanine

Figure 16 shows that stops on the mezzanine constitutes for the longest stop time. Based on the collected data combined with the researcher's own observations, stops on the mezzanine take a long time (approximately 20-60 minutes) to resolve for several reasons. Firstly, the reaction time is quite long since the stop location is placed where the warehouse workers do not have a good overview. Secondly, since there is no sensor to detect the stop, the pallet turner keeps sending lids on the conveyor belt, not indicating to the warehouse workers that there is an issue further up along the line. When the pallet turner keeps feeding the conveyor belts with more lids, despite it being something already blocking the flow, it results in a pile-up of lids on the conveyor belt. Since the conveyor belt is designed to only hold one lid in height, the extra lids will cause the bar holding the lids down to raise, like in Figure 22.

Figure 22: Showing a lid pile-up on the mezzanine.

As a result of this type of pile-up, several lids will start to fall down on the floor or back into the container of lids by the pallet turner, since there is no room for them on the conveyor belt. The lids falling back into the container are most likely deformed in some way because of the pressure build-up, causing defective lids to get back into the process.

A third reason to why these types of stops take a long time to resolve is that the lids are stuck tightly between the conveyor belts and bar. This results in either the worker having to pull the lids out with pliers, possibly damaging the rails, conveyor belts and lids. The other option is to call for a line mechanic to help them to disassemble parts of the rail, bar, and conveyor belt. Both options are very time-consuming and will eventually lead to a lot of damage to the conveyor belts, considering how often these types of stops occur.

To find a possible root cause of these stops, the researchers set up cameras to be able to capture exactly what happened to result in a stop. When analyzing these videos, the researchers identified one cause; two lids overlapping each other at a location where the bar holding the lids down was placed lower than the rest of the conveyor belt. This conclusion raised two questions; 1. *Why is the bar placed lower here than in other parts?* And 2. *Why do the lids overlap?* The answer to the first question could be either that the bar was placed lower at random, or that the bar has been disassembled to fix the stops so many times that it is now placed at the wrong height. When measuring the differences in height along the conveyor belts the researchers found that the average height was 1,2 cm, but right after the pallet turner it was measured to 1,6 cm and on the mezzanine the height was 1 cm. Considering this, it shows that there is a variation in height of the bar along the conveyor belts where overlapping lids might get stuck. The height of the bars is adjustable, but the question regarding why the lids overlap remains.

To investigate *why* the lids are overlapping, the researchers moved the cameras to after the turning mechanism of the pallet turner. Based on the videos the researchers could see that single disposer lids were sent to the conveyor belts, and since they are not as high as regular lids, they can more easily overlap during higher pressure. Furthermore, it was observed that some lids began to overlap already as they come out from the turning mechanism. This does not affect something in the beginning of the conveyor belts, but causes a stoppage further along, where the bar is much lower than the rest of the bars before.

Door and the turning mechanism

As seen in Figure 16, stops on the mezzanine have the longest accumulated stop time, but is not the most common. The most common stop location is when the lids get stuck in the door of the pallet turner, as shown in Figure 23, and the rest of the most common stop locations are connected to the turning mechanism of the pallet turner or concerning the disposer lids.

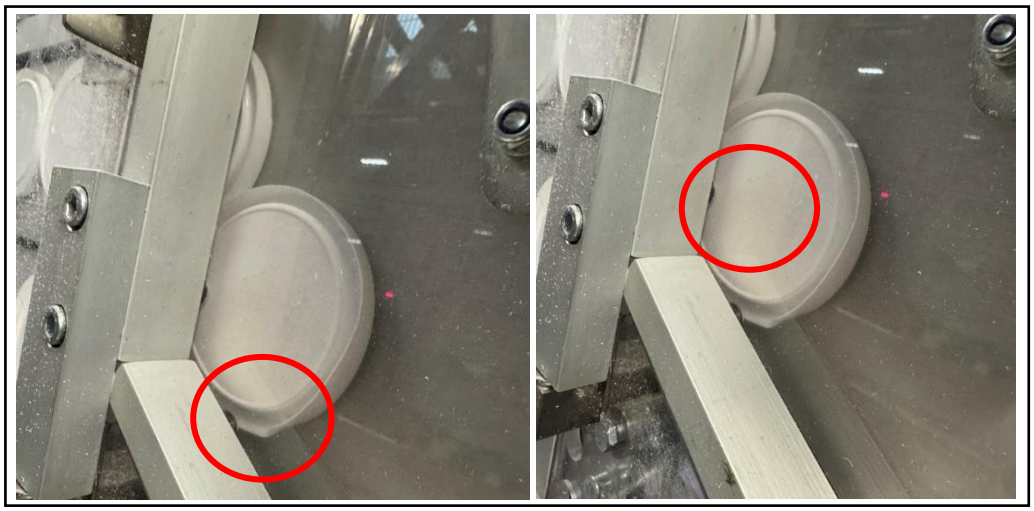


Figure 23: Showing deformed lids that have caused a stop in the pallet turner door.

To further analyze the causes as to why there are stops in these locations, the researchers put up cameras to collect video recordings. The results showed that there are three common causes; deformed lids getting stuck in tight areas, two lids overlapping each other causing a collision after the turning mechanism, and single disposer lids that have detached from the main lid causing collisions on the conveyor belts (Figure 24).

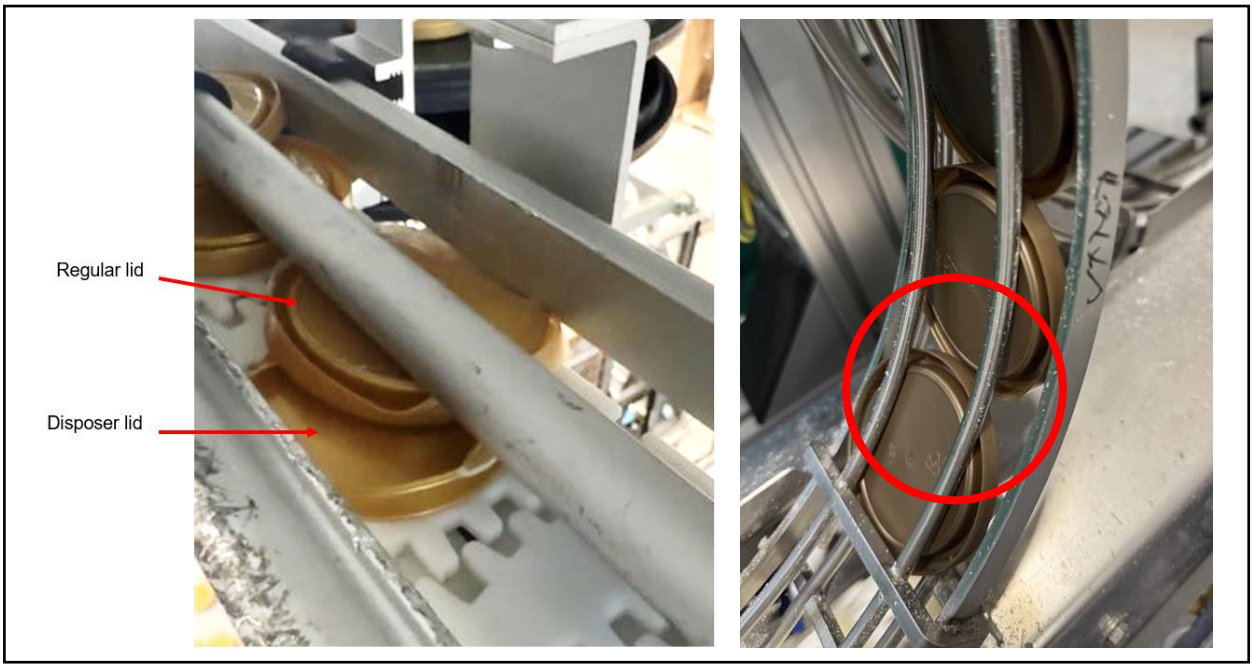


Figure 24: Showing two different types of overlapping of lids.

As a first step to assess the deformed lids the researchers decided to inspect one pallet of lids in the warehouse to determine if the lids were deformed in the pallet turner, or if they were already damaged on the pallet.

Quality of incoming lids

Figure 25 displays some of the lids found on a pallet ready to be placed in the pallet turner. As seen, some lids have crush injuries due to an incorrect placement on the pallet, where the lids are overlapping, combined with a heavy weight placed on top when the pallets are stacked. There are also examples of disposer lids missing and single disposer lids. It is important to note that only the lids on the edges of the pallet are visible. The findings were not made explicit to the warehouse workers to determine if they would perform their own quality assessment of the pallet, which they did not do, but instead used the pallet for production.

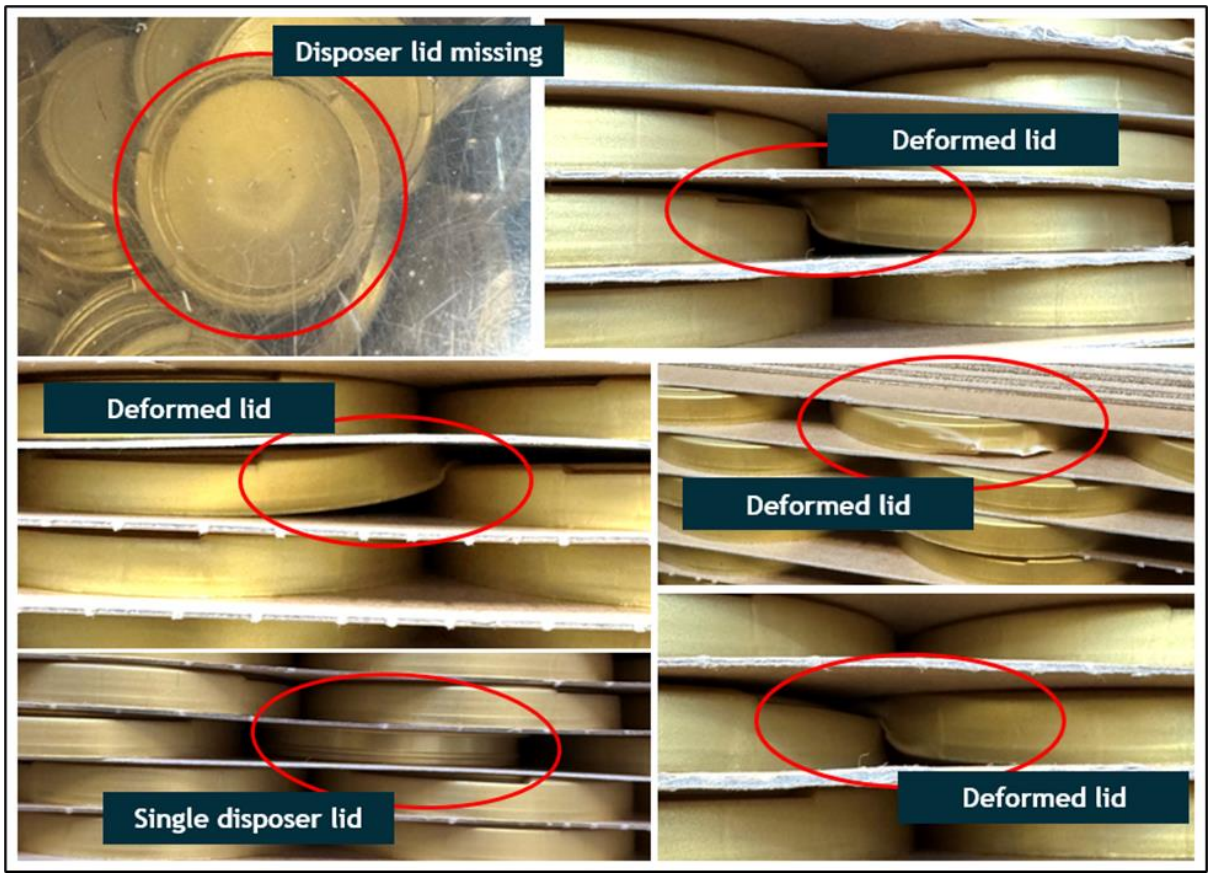


Figure 25: Photos showing lids with a quality deviation.

To further analyze the quality of incoming lids, the researchers decided to inspect all lids on four different pallets in the warehouse, all from the same supplier. The first pallet contained golden lids where 20 lids were defective or crushed. The second pallet contained silver lids with 53 deviations, 37 of them were crushed, 3 were single disposer lids without the main lid, and the remaining 13 were missing from the pallet. The third pallet contained white lids where 3 were crushed and 15 were missing. Finally, the fourth pallet contained golden lids with zero defects.

In total there were 91 deviations that were found, a deviation rate of 0,1 %, which might not seem like a high yield. However, according to the data shown in Figure 16, every defect on the lids can cause a stop lasting for 2-60 minutes, thus risking affecting the production a lot. This variation in quality, ranging from zero deviations to 53 deviations on pallets from the same supplier, might indicate that the process could be unstable (Bergman, Personal Communication BB2.1, 2024).

Differences in color of lids

To further investigate the quality of lids, the researchers analyzed pallets based on the information retrieved from the interview with the supplier quality department combined with the information given by the interview with warehouse workers (see subchapter 4.2). Both respondents informed the researchers about differences in perceived quality based on the color of the cans and lids, but this was not confirmed by any existing data. To evaluate this theory, all stops connected to cans and lids were summarized in Power BI comparing the article numbers to each other with the corresponding color. The result is shown in Figure 26. The figure shows, for example, that article number A has a shortage of lids around 3 % of the time.

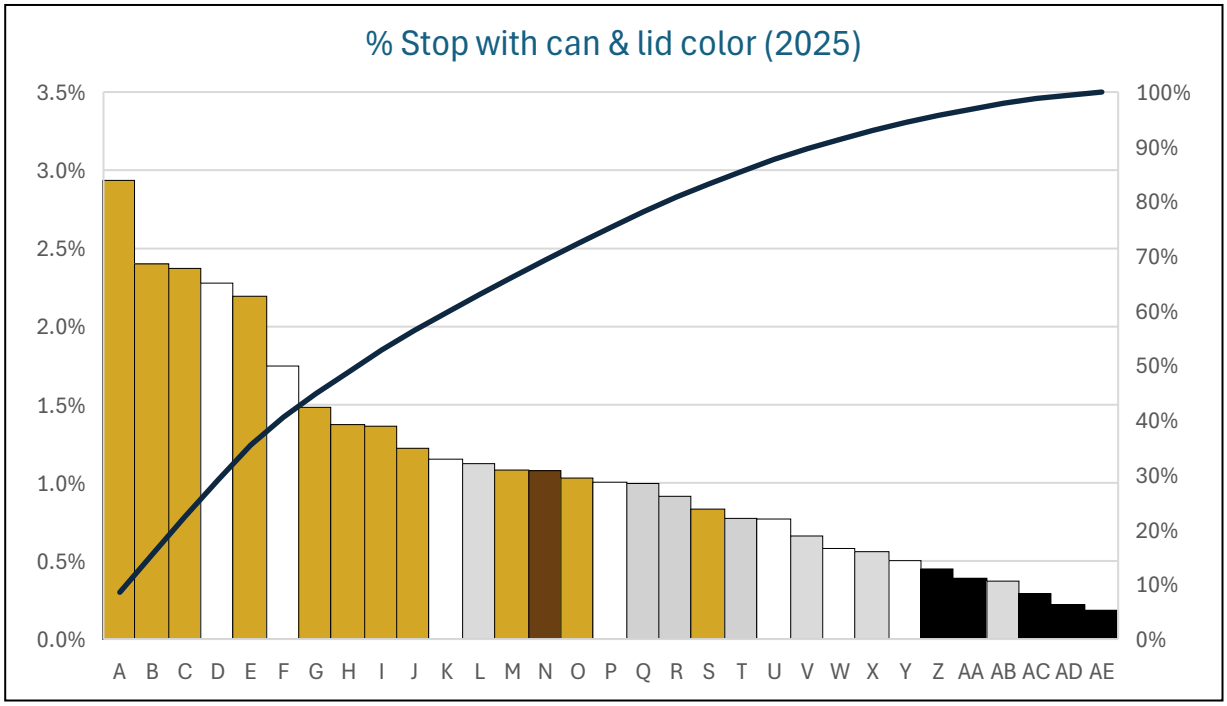


Figure 26: Pareto chart of all stops connected to cans and lids categorized by article number.

As Figure 26 shows, the color seems to be significant for the amount of stoppages they represent. The article numbers using golden cans and lids seem to have the most stoppages, and one might suggest that those article numbers are produced more often than the others. To explore this theory the researchers compiled data of all produced goods during the same time period.

As seen in Table 3, the produced number of cans with a golden color constitutes for 37 % of the total production, closely followed by white cans constituting 30 % of the products. Considering this and hypothesizing that a can's color does not impact the number of stops, the

golden and white cans should have similar percentages of stops. However, as Figure 26 suggests, the golden cans have a clear majority of the stops, indicating that the color is significant for the amount of stops.

Table 3:Number of produced cans categorized by color.

Color	% of total
Black	1%
Gold	37%
Green	8%
Silver	24%
White	30%
Grand Total	**100%**

The consequences of damaged lids are not only limited to a disruption in the material flow in terms of a shortage of lids being delivered to the production line, but also concerning the lid application in the packing machine. When the lids are not attached correctly to the can it risks opening during the transportation on conveyor belts, causing extra cleaning and unnecessary stops in the production. Furthermore, the researchers have seen that cans with poorly attached lids that make it through the quality control also risk causing collisions in the labeling machines. As shown in Figure 17, collisions in the labeling machines have a long repair time since it requires vacuuming up all the loose snus pouches that fall out due to the opened lid.

Additionally, another potential cause of quality deviations for cans and lids found by the researchers was the way pallets were secured with tension bands. Supplier A and B (the suppliers for the production line the researchers are working with) use one type of tension bands for their pallets and were considered to not secured the pallets tight enough according to the warehouse workers. These pallets were compared to the pallets of Supplier C, who rarely delivered skewed pallets. The difference between the suppliers was that Supplier C used thicker, wider, and tighter tension bands than Supplier A and B.

5.1.2 Quality of Labels

During the researcher's observations on the production line, it became evident that the incoming quality of labels were highly relevant for the production output. As seen in Figure

17, banner adhesive getting stuck around the poles of the labeling machine and banner breaks are two events that has a significantly long mean time to repair (MTTR). When the banner adhesive gets stuck around the poles in the labeling machine, the operator is required to peel of the adhesive residue, which is a very tedious task. This results in time taken away from resolving other issues in the end of line production, such as changing rolls of labels in the other labeling machine or doing rework.

5.1.3 Specifications

As presented in chapter 4.2, an interview was conducted with the purchasing department to take part of information about the specifications which are sent to the suppliers for both the cans and lids and the labels. Regarding the cans and lids there seemed to be quite many specifications, but they are not standardized. This caused problems when new suppliers were hired, since new specifications had to be made. However, the supplier has set some specifications on how pallets should be stored and handled to ensure the expected quality level. Firstly, they have recommended that a maximum of two pallets should be stacked on each other. Currently the warehouse is not equipped with storage racks or shelves, requiring the warehouse workers to stack the pallets on top of each other. The researchers have seen that up to four pallets have been stacked in the warehouse at the same time, which might result in the correct quality level cannot be ensured.

Regarding the labels, there are no specifications at all. This makes claim processes difficult since there is nothing to compare the deviations to. If there are no specifications set as a baseline, making improvements becomes seemingly impossible. A central idea within lean production is *continuous improvements* - an initiative to standardize best practices to create a stable process without unnecessary variation (Sörqvist & Bergendahl, 2021). Considering this, it is crucial for the company to standardize the specifications to be able to make improvements in the future.

5.1.4 Flow of Materials

When the researchers observed the flow of materials, one location of the conveyor belts stood out. On the conveyor belts between the warehouse's pallet turner and the production was an area neither operators nor warehouse workers had visualized of. Here, cans tended to get stuck, caused by an uneven bar not fully aligning with a sharp edge, see Figure 27. When comparing

this bar to other bars transporting cans to other production lines, the others seemed to have an additional component to hold the bar in the correct place.

Figure 27: Shows the edge where cans could get stuck.

5.2 Method & Manpower

Method and Manpower are connected to each other as both are involved in how the work is performed and the people performing the work. To develop an organization and make improvements, a standard is required (Hasanbegovic & Merhawi, 2019). This includes a standardized way of working and a standardized training process, ensuring that instructors have the necessary knowledge. During the observations, it was cleared that operators work in slightly different ways. For example, some need to pause the oven for about 1-2 minutes to change the oven's plastic, while others do it while the oven is running, and some add rework bundles on the go, while others stop the oven to add them. These different methods result in varying practices across the workplace. If the method is not standardized, each operator will do it their own way and if the operators are not trained in the same way or lack a common understanding, the methods will not be followed consistently.

A standardized way of working and a standardized training process are key (Hasanbegovic & Merhawi, 2019). In a lot of places at the production line the operators can analyze the rejected cans to see what settings of the machines need to be changed to improve the quality. One of the areas where the operators can analyze rejected cans is by the packing machines. For example, if the star filling is incorrect and a pouch often stands upright, the machine can be stopped to clean the star fillers, and also the waste level of the rejected pouches. Another area to analyze is by the labeling machines. Here cans with misplaced labels or missing TPD codes are rejected, and after analyzing, the settings can be changes to correct the machines and reduce the rework and waste.

Around the same time as this research started, another initiative began to review training and its standards. Therefore, this will not be pursued further in the project, other than noting that a standard is required to create a standardized way of working and ensure the most efficient way to make improvements. Strategy, communication, and collaboration are three crucial points emphasized as prerequisites for successful work on the line. On the production line, the pace is very high, and every stop must be resolved as quickly and smoothly as possible to avoid larger stops later on. Working according to a common strategy, collaborating, and communicating is key to solving all problems that arise in a timely manner and thus delivering what is expected.

Regarding strategy, communication, and collaboration, some observations have been made about the cleaning structure. Cleaning should be done successively throughout the day, which the operators do. However, it has been observed that half an hour before the shift change, an overall cleaning of both the packing machines and the production hall is carried out to leave it clean for the next shift. Leaving a clean workplace is indisputable. However, it has been noted that cleaning at the packing machine level is also carried out when there is a change of snus sort close to the shift change. This results in the packing machines standing still for a few minutes while the operators clean the machines before the shift changes, and then the entire line stops due to the change of snus sort just a few minutes later. With a better strategy throughout the day, along with improved communication and collaboration, the packing machines could be kept running while the packing hall is being cleaned. Subsequently, the packing machines could then be handed over to the evening shift operators, who need to clean the machines during the change of snus anyway. With continuous cleaning, which the packing machines require regardless, this would not be a problem. This is a type of waste that could be minimized with better communication and strategy.

Distribution of operators

When looking at the operator's workload and various types of tasks, it was observed that the operator responsible for the end of line has a particularly stressful job. The end of line is arranged in an L-shape, making it challenging to monitor both ends simultaneously and see all the signals. Additionally, this operator must oversee four machines along with conveyor belts. In contrast, the packing machines each have a responsible operator. To manage the end of line

effectively, the machine operators assist the end flow when it is needed, and when they see the stops.

However, another aspect of this issue needs to be highlighted. Observations and interviews have consistently indicated that the end of line is sensitive and prone to stoppages, which in turn causes the packing machines to stop. This raises the question: why is there only one operator at this critical station? Is the number of personnel adequate for such a high-speed line? Can you, as the only operator responsible for the end of line, really rely on getting support from your colleagues when needed? To investigate this further, the issue has been discussed while considering the comments from operators and the production manager. It has been concluded that the distribution of tasks along the line needs to be checked. This will be further discussed in Chapter 6.

5.3 Machine

In this subchapter, the focus will be on the packing machines, label machines, and conveyor belts, and how they affect the production flow.

The capacity of the machines has been assessed as sufficient. However, the overall capacity of the production line is limited by its weakest link (Sörqvist & Bergendahl, 2021; Holweg et al., 2018). This means that the machine with the lowest capacity reduces the overall throughput. Additionally, the variation in the input to the machines plays a crucial role (Holweg et al., 2018). Each machine's output is dependent on its input. Even if a machine is ready to produce, other machines on the line might prevent it from receiving the necessary materials. Therefore, the more consistently all processes run and the more even the flow of materials, the less variation there will be in the input for different machines. This underscores the importance of maintaining a steady flow and keeping the production line running smoothly.

Packing machines

The packing machines have an automatic stop and start functions for certain stoppage causes. Regarding "queue stoppages from the line," automatic stops and starts were introduced on the production line some time ago. During the observations, a lot of unnecessary start and stops were observed, leading to significant waste as each packing machines spill about twenty pouches each startup. When the buffer is full and the packing machines stop, they all usually

start up simultaneously, which almost always leads to such high pressure of cans that the packing machines stop at least once more due to signals indicating a queue stoppage from the line again. The cans on the line conveyors and the buffer hardly move before the packing machines start up and push even more cans forward.

Further discussions with the line mechanics revealed increased maintenance needs and problems with rotating parts in the packing machine, which can be derived from the increased number of start and stops. To maintain the benefits of automatic start and stops, a correction is needed in the timing of the packing machines' startups, with some starting earlier than others depending on the location of the packing machines.

Label machines

As previously shown, all machines have the capacity to meet the production target. During the observations, the label machines had a lot more stops compared to other parts at the end of line. During the project, the speed of the label machines has been adjusted, and the line mechanics have collectively reduced the speed of the label machines by ten cans per minute. This has reduced label breakages while still allowing the label machines to meet the production target by a margin and result in better quality and less stops.

Conveyor belts

There are a lot of conveyor belts on the production line that cans travel on. As mentioned earlier, there are frequent collisions on these conveyor belts where two belts merge into one, primary on two locations. To investigate this problem, frequency measurements were set up on these two locations to determine how often this occurred. To identify the root cause of the problem, observations were made, and cameras were installed to capture what caused the collisions.

After reviewing the video with the electricians, it was clear that the sensors that controlling the opening and closing sometimes close directly on a can. This causes the sensor to pulse to let a lone can pass so it can close completely. Consequently, the lone can being sent through may collide with the cans from the other sensor, which released its cans immediately when it thought the first sensor had closed. Sometimes nothing happens, but sometimes the cans collide. This primarily occurs at two locations on the conveyor belts but can happen at any point where two conveyor belts merge into one, which is at several different locations.

5.4 Measurements

The primary metric used by Swedish Match has been OEE, which is now being developed further. When this project was received, the new production metrics were already updated on some lines, which is very positive. While OEE can be a useful overall metric, it does not provide detailed insights into where disruptions occur in the process. Therefore, extensive observations on the production floor had to be conducted to measure the various machines and identify where the process disruptions were occurring.

One observation was that order changes are registered in the Power BI data system as "queue stop from line." This is because, during an order change, only the banners and labels are changed, not the snus. So, the operator stops the label machines and lets the packing machines continue running until the buffer is full and they stop automatically with the stop reason "queue stop from line." This misclassification accounts for approximately 15 minutes of incorrect stoppage reasons, multiple times every week, instead of having a function named “order change”.

In addition, incorrectly registered manual stoppage reasons were observed, mostly due to lack of understanding of the importance of selecting the correct one and also because the correct stop reason does not exist. When the packing machine is manually stopped and then restarted, an image of the entire packing machine appears, requiring the operator to click on the reason for the stoppage. The reason is thus only at the packing machine level and nothing else. This results in incorrect stoppage minutes being recorded in Power BI, which improvement work is based on. A clear example of this is the button for pouch paper, which is the largest and nearest button on the screen for the operator to select. In Power BI, the stoppage reason for pouch paper is very high, but upon further investigation, almost no one experiences problems with it.

6. Answer to Research Questions

In this chapter, answers to the research questions will be presented. The structure will follow the 5M:s like in the previous chapter. The two research questions are:

RQ1: What are the identified possible causes of problems on the production line?
RQ2: What changes can be made to increase uptime and improve efficiency on the production line?

To initiate the improvement proposal process, the researchers started by defining each process step's potential failure mode in a FMEA (Failure Mode and Effects Analysis). The failure modes were then given scores based on their potential severity, occurrence, and detection possibility. The FMEA resulted in a list of the potential failure modes that were the most critical to resolve for an optimal production output, see Appendix 5. The potential failure modes were assigned recommended actions with a corresponding person responsible for managing the action and the potential consequences of each failure mode to further analyze the impact on production.

As a next step, the recommended actions were assessed in a Pugh Matrix where each action was given a score based on five criteria; possibility to implement (yes/no), cost of implementation, time-to-benefit, how effectively the action solves the issue, and effect on the daily operations, see Figure 28. The Pugh Matrix resulted in a prioritization of the different recommended action or improvement proposals based on the selected weighted criteria, with several high priority proposals and a few long-term options for the company to consider.

	Net above the mezzanine	Robust design pallet turner	Updated signal system pallet turner	Tighter tension bands on pallets	New specifications for incoming material	Extra holder for rail on conveyor belt	Standardized training guidelines	Extra operator for end of line	Delayed start of packing machines	Lower speed of banner machine	Updated signal times on conveyor belts	Updated packing machine options	New measurement values
Possible to implement? (yes/no)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cost of implement ation 5	6	4	8	8	1	4	6	9	8	10	8	7	2
Time-to-benefit 5	3	5	4	4	1	6	3	7	8	10	7	5	3
How effective is it? 10	2	8	5	3	2	3	6	5	7	7	8	2	2
Affect on the daily operations? 8	3	7	5	3	1	3	7	5	8	9	8	5	5
Total	89	182	151	115	39	105	162	171	215	243	220	121	86

Figure 28: Pugh Matrix with the improvement proposals.

6.1 Material

In this subchapter, research questions one and two will be answered regarding material. It will include incoming material and problems regarding that.

Can and lid stoppages

Looking at the production outcome data, it is evident that there is a problem with supplying the production line with material in time. The researchers have found several causes behind the lack of supply of lids and cans. Firstly, *lids tend to get stuck on the conveyor belt on the mezzanine.* When lids get stuck on the mezzanine, it could result in stops on the production line for up to 60 minutes, since they require a lot of labor to remove the lids that are stuck. The lids that are stuck often lead to a pile-up of lids on the conveyor belt behind them, risking that defective lids fall back into the container beneath the conveyor belts. The first improvement proposal is to *install a net on the mezzanine* above the container to catch the defective lids that fall down, to ensure that they do not fall back into the container. This, of course, does not solve the root cause of the problem – the fact that lids get stuck on the conveyor belts in the first place.

Secondly, the most common stoppage locations for the lids are connected to the pallet turner. Thus, *defective lids getting stuck in the pallet turner door or the turning mechanism*, is another

cause of problems for the production line. Furthermore, the video recordings made by the researchers have shown that stoppages on the mezzanine conveyor belts usually occur due to two overlapping lids which might be a consequence of the lids overlapping right after the turning mechanism. All these outcomes could be traced back to a single possible cause; *defective lids present inside the process*. After interviewing the purchasing department, it became evident that defective lids are considered a natural variation in the process. Since the defective lids are considered to have a natural variation that might always occur regardless of specification limits, it is crucial for the company to have a robust process to handle this variation in a long-term perspective. The second improvement proposal is therefore to *start a robust design project of the pallet turner and the turning mechanism* to sort out the defective lids.

Additionally, it has been found that the signal system for stoppages in the pallet turner has a delay of approximately one minute, from when the stop occurs to when a warehouse worker gets the notification of the stop. Since the lead time for material from the warehouse to the production line is three minutes, only two minutes are left for the warehouse workers to react to and resolve a stop in the pallet turner. The reaction time is crucial to ensure an even flow of material and will consequently prevent unnecessary starting and stopping in the packing machines (argument about these risks will be further developed in chapter 6.3). Another cause of problems on the production line is thus that *the signals for stoppages in the pallet turner are delayed*, making the process sensitive to longer reaction times of the warehouse workers. To resolve this problem, the researchers' third improvement proposal is to *investigate if the signal system for the pallet turner can be updated* with a shorter, or no, delay.

Specifications

When the researchers investigated the quality of incoming material and compared pallets from different suppliers in the warehouse, several weaknesses were found. The most prominent one, excluding the quality of lids, was the way pallets were secured with tension bands. Supplier C, who does not manufacture cans and lids to production line, were using thicker, wider, and - most importantly - tighter tension bands for their pallets. These pallets were very rarely skewed or damaged upon delivery, as opposed to the pallets from supplier A and B. The skewed pallets were found to have a higher amount of damaged lids as a result of the uneven pressure and risked damaging other pallets when being stacked. The fourth improvement proposal therefore *requesting tighter tension bands on pallets from Supplier A and B.*

As presented in both chapter 4.3 and 5.1.3, the specifications for cans and lids are considered inadequate. The two different suppliers have two different specifications, and according to the purchasing department, the supplier knows more about what Swedish Match actually requires from the process than what the company can specify themselves. This shows weaknesses in their own insights of requirements, resulting in difficulties in owning their material procurement processes. Consequently, this leads to *a high variation in quality of the incoming materials since it is not standardized according to specifications*. The fifth improvement proposal is therefore to *initiate a project of standardizing and setting new specifications for the incoming material*.

Flow of materials

As described in subchapter 5.1.4, one area of the conveyor belts where cans tended to get stuck was found. When comparing this part of the conveyor belt to other production line's, it became evident that *a component holding down a metal bar over the conveyor belt was missing*. To resolve this issue, the researchers present a sixth improvement proposal of *installing an extra holder for the bar on the conveyor belt.* Furthermore, new transitions between the standard conveyor belts and the conveyor belts through that goes through walls have been identified on new production lines, which is a positive development. The transition consists of a tapered section, significantly reducing the risk for can and lid to get stuck. This represents a robust design improvement.

6.2 Method and Manpower

In this subchapter, research questions one and two will be answered regarding Method and Manpower. It will include a standardized way of working and reallocating of tasks.

Standardized way of working

A possible cause of problems on the production line regarding Method and Manpower is *the lack of a standardized way of working.* As mentioned in subchapter 5.2, the operators have the knowledge to, for example, change banner and labels, and change plastic to the oven, but they do it in different ways. Additionally, there is a variation in how attentive the operators are at stops and preventive work on the line. According to Liker and Meier (2006) standardized working methods are essential for continuous improvement. Furthermore, Sörqvist and

Bergendahl (2021) emphasize that best practices for successful operations are crucial to avoid unnecessary variation in execution. Therefore, it is important to implement and follow standardized work methods to ensure smooth and efficient operations.

Furthermore, it is crucial to *develop an understanding of the impact of the operator's work.* This includes recognizing the importance of responding to alarms promptly, reaction time, selecting the correct stop cause on the packing machine's panel, collaborate on the line, and more. Creating this understanding is essential for why these tasks are important. Engaging operators and colleagues with a sense of involvement and commitment is a prerequisite for continuous improvements (Sörqvist & Bergendahl, 2021; Liker & Meier, 2006).

Another possible cause of the problem related to this is *training and onboarding*. During observations, insufficient training and onboarding have been identified in how to perform task in the most optimal and effective way, as well as the team's collaboration, communication, and overall strategy. To establish a standard among all employees, it is essential to ensure that the instructors have the necessary knowledge to convey accurate information. Currently, there is a four-page checklist followed during training. Due to the uncertainty surrounding the instructor's expertise, the checklist effectiveness is significantly diminished.

According to Hasanbegovic and Merhawi (2019) standardized training and understanding in what, how, and why tasks are performed can create more understanding and foster engagement and responsibility. Additionally, communication and strategy need to be discussed during training. One might think that an operator's job is individual, but on this line, where there is a high flow and constant activity, collaboration and communication are necessary to solve and prevent problems in the best possible way. Communication and teamwork are central factors in building a strong team, which also fosters trust, understanding, and successful teamwork (Bui, et al., 2019).

Standardized work methods and training are fundamental to ensuring productivity and improving efficiency (Hasanbegovic & Merhawi, 2019). Therefore, the seventh improvement proposal is to establish *standardized work methods and training programs* where the quality of instructors is assured to ensure the correct quality is taught. Additionally, strategy, communication and collaboration will be emphasized during training as they are crucial components in the workplace.

Today, the company has an employee dedicated to improving the training process. The findings from this project will be communicated to the employee responsible for the improvement. Primarily, it is about working proactively rather than reactively. Here, strategy at the workplace is very important together with how tasks are prioritized, standardized methods for handling rework and discarded cans, cleaning routine during the day, the best and most efficient way to change materials, as well as collaboration and communication.

Reallocation of tasks

During the extensive observations, it becomes evident that the operator responsible for the end of line has a very stressful job. It is decided that each packing machine should have one operator each and help the lonely operator on the end of line when needed. However, due to the design and layout of the production line, it is difficult for the packing machine operators to see all the stops at the end of the line and to be able to help in time. One identified possible cause of problem is that *the operator at the end of the line has too large area of responsibility*.

Therefore, the eighth improvement proposal is to *reallocate the operators on the production line so that there are two operators responsible for the end of the line*. This does not mean that the last packing machine should be unstaffed all day. The idea is that one operator at the end of the line will focus only on the end of line, while the other will be responsible for one of the packing machines during start-up, cleaning at the end of the day, or during snus changes. The rest of the time, this operator will focus on the end of line together with the other operator. This reallocation will result in a more consistent flow at the end of the line. Even during breaks, there will still be an operator fully focused on the end of the line.

6.3 Machine

This subchapter will answer research questions one and two regarding the packing machines, label machines and the conveyor belts.

Packing machines

As mentioned in subchapter 5.3, one of the identified possible causes of problems on the production line is issues with the automatic stop and start functions of the packing machines. When the packing machines automatically stop and then restart, every packing machine spills

twenty pouches to ensure the quality. When the packing machines stop due to “queue from line” and all machines start up simultaneously, this often leads to the packing machines stopping at least once more because the packing machines together deliver so many cans. This affects both components in the packing machines, more specifically rotating parts where it is perceived that they wear faster but also increases unnecessary waste.

To minimize unnecessary waste and wear on rotating parts, the nineth improvement proposal is to *implement a delay in the start-up time for some of the packing machines*. If half of the packing machines have a delayed start-up time, the number of stops and starts will be reduced. The recommendation is that the packing machines with the shortest conveyor belts start up as usual, while the packing machines with the longest conveyor belts have a delayed start-up. This will allow the longest paths to empty slightly before they start up. This part of the project will be handed over to electricians and line mechanics who will be responsible for its implementation.

Label machines

The speed of the label machines has been discussed and is an identified possible cause on problem on the line. There were many unnecessary stops and banner breaks perceived to be related to the designed speed. During observations and discussions with the line mechanics, the speed of the label machines was further discussed. The line mechanics then collectively decided to reduce the speed of the label machines by ten cans per minute as a test for a period. The perceived and observed result were a more stable flow, better quality, and fewer stops.

With that said, the tenth improvement proposal is to *suggest that the new optimal speed and standard for label machines* should be ten cans less per minute. Even if one label machine is running, the production target can still be met, allowing time to change labels, perform necessary cleanings, or adjust settings on one of the label machines without feeling stressed. Additionally, the perceived quality is much better as the number of label breaks significantly decreased at this reduced speed.

Conveyor belts

Furthermore, *collisions and stops at mergers of conveyor belts* are a frequent and unnecessary cause of stoppage and an identified possible cause of problem on the line. These collisions and stops resulting in several hidden stops per day that also lead to stops at the packing machines.

Through observations and video recording, the cause of the stops has been captured, which has been sent to the electrician responsible. The issue stems from the sensors that close the passage for cans hitting directly on a can, which signals that the passage is not closed. The sensor then starts to pulse to be closed, causing an extra can to pass through and risk colliding with the parallel sensor's batch. The eleventh improvement proposal is to *review the signals for when the sensors are open or blocked* to prevent an extra can from being released, thereby reducing the risk for collisions and stoppages.

6.4 Measurements

This subchapter will answer research questions one and two regarding the measurements. It will include both manual measurements on the packing machine panel, and the overall measurements to understand the line's performance.

Measurements packing machine panel

During the observations it became evident that the data in Power BI was not entirely reliable. This was mainly due to manual stop causes and some of the automatically stops like "queue from line". One of the observed identified possible causes of problems is that the *packing machines do not have the correct stop causes available on the panels.* This includes order change, change of type, rework, etc. If all stop causes are not accessible, it becomes impossible for operators to select the correct stop cause, which is crucial for later use of the data from the lines to analyze its performance. For instance, an order change is currently recorded as "queue stop from line", which is completely wrong and results in misleading data in Power BI.

The twelfth improvement proposal is to *ensure that the correct stop causes are available on the packing machines panel* to obtain accurate data. When discussing this improvement proposal with one of the improvements leaders at the company, they mentioned that they have started developing this as it aligns which what PMI aims to implement. Consequently, this initiative is already in progress on some lines, but far from all. This provides a much better overview of the necessary stop causes, and the findings from the project's observations have been communicated.

As mentioned in subchapter 6.2, operators need to understand the importance of using the stop causes correctly. During the observations, it was clear that the manual stop causes are used

incorrectly, even though the correct stop cause is available. This issue is related to improvement proposal seven and mentioned under Method and Manpower. It is vital to create an understanding of doing things right from the start to enable follow-up and continuous improvement.

Measurements on the whole production line

Most of the stop causes in Power BI are based on the packing machines which makes it difficult to understand where issues are occurring on the line. During the define and measure phase, new measurements on the end of the line were needed to understand the data in Power BI and understand what the real problems were. An identified possible cause of problems is *lacking measurements on the production line.*

The thirteenth improvement proposal is to *improve the measurements to be able to monitor the whole production line.* To achieve this, the measurements on the line need to be synchronized so that the stop causes communication with each other. It is important to monitor both the uptime and downtime of the machines, as well as the reasons why the label machine stops, whether it is due to an automatic alarm, banner or label change, or banner breakage. The goal is to be able to see how each machine on the line is performing and receive alerts about any variations. Monitoring uptime and downtime of these different components will allow for better oversight of a machine's performance, enabling the identification of variations and the ability to react to them (Wheeler, 2000). This is something that has been implemented on some production lines and is planned to be implemented on all production lines.

6.5 Summary of the two Research Questions

In this subchapter, a summary of all the improvement proposals and their corresponding M of the 5M:s and affected department in the factory is presented.

Table 4: Summary of the 13 improvement proposals with the corresponding M and department in the factory

5 M	Affected department	Proposal
Material	Warehouse department	1. Net installed on the mezzanine
		2. Robust design of the pallet turner
		3. Updated signal system of the pallet turner
	Supplier/purchasing	4. Tighter tension bands
		5. New specifications for incoming material
	Electrician	6. Extra holder for rail on conveyor belt
Manpower & Method	Employee training responsible	7. Standardized work method
	Area manager	8. Reallocation of tasks
Machine	Electrician/line mechanics	9. Delay in the start-up times for some of the packing machines
	Line mechanics	10. New optimal speed for the label machines
	Electricians	11. Review the signals for when the sensors are opened or blocked on the conveyor belts
Measurements	Automation	12. Ensure that the correct stop causes are available on the packing machine's panel
		13. Improve the measurements on the production line to be able to monitor the whole production line

6.6 List of Priority

In this subchapter, a prioritization of all the improvement proposals is presented. The prioritization in Table 5 is based on the final weighted score from the Pugh Matrix in Figure 29.

Table 5: A prioritization of the improvement proposals. Proposals marked in bold are already implemented.

Priority	Improvement proposal
Critical	11. Updated signal times on conveyor belts **10. Lower speed of banner machine** **9. Delayed start of packing machines**
High	8. Extra operator for end of line **7. Standardized training and onboarding** 3. Update signal system pallet turner 2. Robust design pallet turner
Medium	12. Update packing machine options 4. Tighter tension bands on pallet **6. Extra holder for rail on conveyor belt**
Low	13. New measurement values 5. New specifications for incoming material 1. Net installed on the mezzanine

The weighted score from the Pugh Matrix is based on the four weighted criteria which mainly includes how the improvements affect the daily operations. Thereby, there are some improvement proposals further down in the priority list that are quicker to implement and will also have a good impact on the production line. Improvement proposals six, seven, nine and ten have already, or almost already, been implemented and are currently being followed up. Furthermore, improvement proposal eight and eleven are scheduled to be initiated shortly.

7. Discussion & Conclusion

In this chapter, the improvement proposals will be further discussed to strengthen the arguments as to *why* they are relevant for the company to consider. Secondly, a conclusion of the study will be drawn. Here, the researchers will also present how this study can contribute and supplement existing research in the field. Lastly, three possible future studies - that is outside the scope of this research project, but still highly relevant - will be presented.

7.1 Improvements proposals

This DMAIC improvement project has resulted in thirteen improvement proposals. They have been placed on a priority list based on the weighted score in the Pugh Matrix. The improvements have a decreasing weighted score the further down the list, see Table 5.

Critical priority

There are three improvement proposals ranked as critical priority and expected to have a high impact on the production line by reducing unnecessary stops and waste. By implementing these improvement proposals, lean wastes like waiting, error and rework can be minimized by eliminating unnecessary stops (Sörqvist & Bergendahl, 2021). This will be achieved by eliminating stops caused by collisions on the conveyor belts, banner breakages and unnecessary stop and starts in the packing machines at automatic stops. These are clear examples of how improvement proposals can increase efficiency and optimize the flow on the production line, which is central to lean (Liker & Meier, 2006). Regarding the stops on the conveyor belts, the frequency measurements indicate a lot of stops with several minutes of downtime in the label machines per day. The data was collected by the operators and the stop minutes were estimated. However, not all stops have been recorded due to the human factor, it is likely that the actual number of stops is higher. The lower speed of the banner machine has resulted in fewer breakages and higher uptime on the label machines and needs to be established as a new standard. Lastly, having a delay in some of the packing machines start-ups after automatic stops will reduce the number of wasted pouches. This has been practically implemented on the production line and the results will be assessed during the upcoming weeks.

High priority

There are four improvement proposals that are categorized as high priority. Firstly, an extra operator at the end of the line will be evaluated during the next month with the goal of reducing the downtime on the end of the line. More specifically, the aim is to reduce lean wastes such as waiting, error, and rework (Sörqvist & Bergendahl, 2021). The end of line is sensitive to disturbance and by being two operators they will be able to see the stops more quickly and reduce the waiting time. Secondly, the ongoing improvement of standardized training and onboarding is to work after a standard and in the most effective way. To minimize unnecessary variation in how tasks are carried out and work after the best practice will improve the overall stability and enable continuous improvements (Berger, 1997; Liker & Meier, 2006). Competence and standardized training are central to lean, both for creating a common perspective and for working effectively on improvements (Sörqvist & Bergendahl, 2021; Liker & Meier, 2006). How people collaborate and think about their work is also incredibly important. People are a resource that is essential for improvement and problem solving (Berger, 1997; Sörqvist & Bergendahl, 2021). These improvements are placed in the top of the priority list as they contribute to the performance of the production line. The researcher's refelctions on training and onborading are that it is one of the most important aspects. By working on the most efficient way and having a common vision and strategy on how to work toghether will make everyones work easier, reduce unnecesassy downtime and and increace well-being. Reducing downtime and maintain continuous flow, the line's full capacity can be used.

Thirdly, updated signals on the pallet turner are required as the signals have a delay of approximately one minute. This is considered critical because the lead time from the pallet turner to the production line is three minutes, leaving only two minutes for the warehouse operators to react to and solve the problem after the delayed signal. By reducing the delay of the signal, it can minimize the downtime in the production which is related to the waste waiting (Sörqvist & Bergendahl, 2021). This is considered as high priority due to its effect on the production line output.

Fourthly, a more robust design of the pallet turner is required in the future to be able to have the incoming variation. As mentioned in subchapter 6.1, the defective lids are considered to have a natural variation, thus falling under what Arvidsson and Gremyr (2007) call *noise factors*. To further develop the argument regarding the importance of initiating a robust design of the pallet turner rather than solely relying on tighter supplier tolerances, the researchers

would like to highlight some key points. Firstly, it is evident that even though the suppliers deliver material within the set specifications, a variation within those limits still exists. Since the suppliers are external it could be difficult to control their processes as well as be quite expensive to require tighter tolerances. Secondly, robust design focuses on making the internal process more insensitive to variation, regardless of which supplier delivers the material. In other words, instead of pushing for tighter tolerances for the suppliers – which will ultimately increase costs – robust design principles should be applied. By designing the pallet turner to be insensitive to variation, a high quality and reduced supplier costs could be ensured. This proposal is therefore recommended as a future improvement for the pallet turner.

Medium priority

There are three improvement proposals with medium priority. Firstly, updating the packing machines panels so that the correct stop cause can be selected at manual stops and the correct data can be compiled. It is important to be able to analyze the production lines performance, all needed stop causes need to be accessible to be able to choose the right stop cause. The aim is to have a standard and work according to the best standard to be able to make improvements (Sörqvist & Bergendahl, 2021). However, if not all the stop causes exist, it is impossible for the operators to do it correctly. Furthermore, if the right stop cause is missing, the data of the production lines performance will never be correct. For this to be successful, the operators need to understand the importance of choosing the right stop cause, otherwise, this implementation will be pointless.

Secondly, tighter tension bands on pallets are required to avoid deformations during transportation and stacking in the warehouse. To assess this, a study visit will be carried out at one of the suppliers to compare how the pallets look when they leave their factory compared to how they look when they arrive to Swedish Match's warehouse. The purpose of this evaluation is to determine whether tighter tension bands can maintain the pallet quality. The researcher's idea is that it will contribute to better incoming quality and ensuring that the outgoing quality from the supplier is the same when it arrives to the warehouse.

Thirdly, installing an extra holder for one of the rails on the conveyor belts to avoid collisions due to the cans getting stuck. By eliminating these types of hidden stops, the production will be able to run much better and minimize lean waste in type of waiting. The investigation of the height of the rails raised another question for the researchers: *what is the correct height of the*

rail? This is connected to one of the main principles of lean, standardization. The researchers therefore recommend that while the rail is being adjusted, the height of the rail should also be standardized to minimize the risk of lids getting stuck at another location. These three improvements are ranked as medium priority as they do not contribute as much to the production as the previous improvements do. The human factor affects the first two of these improvements, while the third has a positive impact on the production but does not occur so often. Therefore, they end up as medium priority.

Low priority

Lastly, there are three improvement proposals with low priority starting with new measurements on the whole production line. To analyze the line and understand the performance, more measurements on all synchronized parts of the production are needed. To improve the production line, standard is needed and without complete data on the production line's performance, it can be difficult to follow up some types of improvements (Sörqvist & Bergendahl, 2021). Furthermore, new and developed specifications on incoming material are needed to ensure that the incoming material have the right quality. Having knowledge about the specifications is incredibly important to be able to improve them but also to "own" the product and not be completely dependent on the suppliers. Lastly, a net at the mezzanine will remove the risk that defected lids will fall back into the pallet turner when stoppages on the mezzanine occur. This is not a solution to the root cause but a solution to minimizing further errors. These three improvement proposals are slightly more long-term improvements and the reason they end up at the bottom of the list. They will have a positive impact on the production, performance, and knowledge in the long-term, but will not affect daily production in the near future.

The improvement project initiative on this production line has been relevant and on the agenda for over a year. Small greenbelt projects have been implemented along the production line but have generally had to narrow scope and failed to consider all contributing factors. For example, there has been one greenbelt project only looking at the sensors on the conveyor belts, something that have been investigated more deeply in this project. The success of this project is the broad scope together with an extensive define phase and a deep root cause analysis. This structure has led to thirteen data-based improvements for the company to consider. Some areas of improvements have been known by the company before but have remained stagnant as definitive data has never been found.

7.2 Contribution to existing research

Although this improvement project was limited to only analyzing one specific manufacturing line in Sweden, it aligns with established research conducted in the field. The use of the DMAIC cycle together with tools such as fishbone diagrams, control charts, FMEA and Pugh Matrix reflects a systematic approach to data-driven improvement projects that are widely supported in both international and Swedish literature (Sörqvist, 2004; Carleton, 2016; Gitlow & Gitlow, 1987). The researcher's final results – thriteen different improvement proposals within different areas of the organization – proves how Six Sigma tools can be applicable to adress diverse challenges in a manufacutring environment.

Some findings and improvement proposals that are specific for the production and not generalizable are aspects regarding the machines, the speed on the machines, conveyor belts, and signals. However, aspects that are generalizable on other lines in the factory are incoming material, the supply of material, measurements, and the human factor. Better insights on the incoming material and better communication with the suppliers can lead to better control of the incoming material and better quality. More customized measurements values and making all stop causes available on the panel of the packing machine is something that is absolutely generalizable on other lines and are an ongoing development. Additionally, the human factor plays an important role, and everything start with proper training and onboarding. As mentioned earlier, good collaboration and communication are key to have a good flow on the production line and be able to cope with everything that happens when colleagues are on breaks. This is also applicable in other industries since an optimal flow will reduce waste and optimized resource utilization. This, together with the human factor of execute the tasks in the most optimal and efficient way will reduce variation and increase quality.

This thesis project contributes to the existing body of research by providing a practical application of the DMAIC methodology in a large-scale Swedish manufacturing organization. While much of the exisiting literature on Six Sigma and Lean focuses on theoretical frameworks, this project offers a detailed and context-specific example of how the afformentioned tools can be used. This study shows that identification and implementation of several improvement initiatives can be done effectivley through an application of the Six Sigma and DMAIC methodology. Furthermore, this research complements the existing data by highlighting the importance of cross-functional collaboration and group dynamics in

improvement initiatives. This is an area often acknowledged in theory, but less frequently illustrated in applied studies (Liker & Convis, 2012; Bui et al., 2019). With this, the researcher's findings hope to bridge the gap between theory and practice within the Swedish snus manufacturing industry.

Sustainability

The aspects of sustainability – environmental, economic and social – have not been assessed previously in this report. However, the researchers would like to highlight some points that have been considered during the project. Firstly, the improved environmental aspects of this project could be, for example, material waste reduction. This is achieved by improvement proposal 4 (tighter tension bands on pallet), 5 (new specification for incoming matierial), 6 (extra holder for rail on conveyor belt), and 9 (delay in the start-up times for some of the packing machines). When implemented, all of these proposals have the aim to reduce the matieral waste in terms of less damaged lids and cans in transportation and handling. Improvement proposal 9 will reduce the numbers of automatic starts and stops, and since the packing machine wastes 20 pouches with every start-up this will lead to reduced waste of pouches.

Secondly, the improved economic aspects of this project could be connected to every imrpovement proposal, but more specifically for improvement proposals 5 (new specification for incoming matierial) and 8 (reallocation of tasks). New specifications could lead to less money spent on matieral that arrive deformed from the supplier. A reallocation of tasks on the production line could result in the company not having to hire another operator for the productioin line, thus utilizing the resources they already have by reallocating them better.

Thirdly, the improved social aspects of this project are connected to improvement proposal 3 (updated signal system for the pallet turner), 7 (standardized work method), 8 (reallocation of tasks), and 11 (signals for when the sensors are opened or blocked on the conveyor belts). Proposal 3 and 11 will reduce the amount of times operators and warehouse workers have to intervene to resolve cans that are stuck on the conveyor belts, as well as gives them more time to react to the alarm. This will undoubtably reduce the stress level they experience during the day. Proposal 7 relates to creating a standard for how the work is carried out during the day and how the operators should communicate in the shift changes. Proposal 8 aims to create a

more even workload between the operators, especially on the end of line. The overall aim of these proposals is to enhance job satisfaction and reduce stress levels.

7.3 Conclusion

This research project aimed to analyze the production efficiency for a single production line at Swedish Match's Kungälv factory. The research should develop clearly described improvement proposals that could increase productivity, minimize waste, and optimize material flow when implemented. To guide the researchers through the study two research questions were formulated:

RQ1: What are the identified possible causes of problems on the production line?

RQ2: What changes can be made to increase uptime and improve efficiency on the production line?

The research was based on the DMAIC cycle, which included tools like capacity analysis, fishbone diagram, FMEA and Pugh Matrix to effectively answer both research questions. The improvement proposals primarily focus on one production line but can be used on other lines and in that way affect the whole factory. The research's findings ended in thirteen improvement proposals in different areas of the production. Four of the improvement proposals are already under evaluation after being implemented. Two more improvements are planned to be implemented next month.

The early implementation of the improvement proposals indicates the practical relevance of the findings. As mentioned in the discussion, some of the findings can be used on other productions lines in the factory, thus improve the material flow and how the human factor contributes to the output. Already, the management team of the factory has expressed their satisfaction with the results of this research project, and as mentioned, has already implemented some of the improvement proposals. As an example of how valuable this project has been for the factory, the production manager has initiated projects on other production lines based on the method and findings from this work.

Most of the improvement proposals are connected to eliminating unnecessary stops and waste. The speed on the production line is high which means that every stop needs to be resolved as

fast as possible to not result in the packing machines stopping. One of the key aspects is training, onboarding and cross-functional collaboration. Everything starts with the employees and their knowledge. Helping each other and perform the tasks in the most efficient way. This paves the way to implementing the other improvement proposals more efficiently.

7.4 Future Studies

This subchapter will outline suggestions for future studies that were beyond the scope for this report.

Raw snus

Observations and interviews revealed that the moisture and stickiness of the snus significantly affect production quality. The moistness and stickiness of snus are affected by the time the snus have been resting in the containers before being used in the production. This primarily impacts the amount of waste produced by the machine, including for example weight, empty pouches, and pouch size. However, there is no concrete evident that support this or know the optimal time before production. Therefore, this is seen as a potential area for future research where different types of snus should be examined to determine the optimal resting period for production. This varies across different production lines, as they produce different products and have different filling methods.

Robust design – Lid application

A potential future study that has been identified is a robust design of the lid applications. Today, the production line handle cans with five different colors. The different colors result in some small variations in the material resulting in that the line mechanics need to make some small adjustments on the lid application when the color of the cans and lids are changed. Instead of constantly adjusting the lid applicators, the recommendation is to create a robust design that can manage incoming variation and minimize errors further down the line, such as missing lids or lids that are not properly attached.

M: Maintenance troubleshooting

The stop cause “M: Maintenance troubleshooting” is used when a packing machine is running poorly, and the line mechanics need to stop the packing machine and do some maintenance work. This stop cause is the fifth most common when it comes to total stop minutes (see figure

13). Is this something that can be maintained? Is there anything that can be done in preventive maintenance, and how should it be organized? Currently, the line mechanics have some maintenance work they do in specific intervals. Given that this stop cause is relatively high, a future study could be to investigate if the maintenance work is doing in right time sequences or should be done more frequently.

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Appendix 1

Interview questions for operators

- What are the responsibilities and tasks of an operator?
- What knowledge does an operator need?
  - How much should the operator do with their packing machine before calling for a line mechanic?
- Does the packing machine have any standard settings? Or how does it work during startup after cleaning?
- What changes do you experience on a typical workday?
- How many hours should a packing machine run per day?
- Where do the stoppages usually occur?
- Can stoppages be prevented?
- Today you have one operator per packing machine and one at the end of the line. How does this distribution and workload function for you?
- What are the differences between day and evening shifts?
  - Your group dynamic? New vs experienced operators?
- How does the carton rework process function?

Interview questions for electricians

- Can you tell us a bit about the initial situation before you made changes to the conveyor belts?
- What changes have you made and why?
- Have you seen any result from those changes?
- What challenges are there now?
- Are there any limitations to the changes that could be made?

Interview questions for line mechanics

- What responsibilities do you have during a typical workday?
- Are you responsible for other lines as well?
- How often are you called in for help?
- Are there any “unnecessary” tasks that you get from the operators? Like tasks they can do themselves.
- Can anything in their job description/training be changed to reduce the number of times you have to intervene?
- How does the lid application work? How does it work when switching between different cans and lids?
- We have both seen that filled cans go forward without lids even though there is quality control.
  - Is there any way to prevent this?
- Are you involved in any work on the conveyor belts?

Interview questions for warehouse workers

- Tell us about your daily work and tasks you do here in the warehouse.
- How is the division of tasks among you?
- For which pallet turner stations of cans and lids are you responsible for?
- Is there any prioritizing of lines/signals or how is the work order?
- How often is the shortage of cans/lids due to not being refilled vs. getting stuck somewhere along the way?
- How often do you notice that the lids are turned incorrectly?
- How does it work at the pallet turner stations? Describe a typical workday.
- How long does it take before a container on the production line is empty and needs to be replaced?
- How do you see if there is a stop/something needs to be fixed?
- How long time do you have to fix a stop before production notices it?
- How does it work when changing color of cans and lids?
- When you change color or at the end of each day, what do you need to do?

Interview questions for raw snus manufacturing workers

- What are your tasks here at the warehouse?
- Distribution of tasks among you?
- How long does a preparation of snus take? And how does it work?
- How long before production is the snus prepared?
- Where can you see the alarms for the containers at emptying stations?
- Does the snus rest for 3 days? Or how fast is the raw snus used in the production?
- What do you do if there is snus left at the end of the day?

Interview questions for purchasing department

- What specifications are there for cans and lids?
- How do the specifications vary between the two suppliers?
- How do the specifications vary between the different colors? Softness? Sizes?
- How is deviation reporting managed when the quality does not meet the standard?

Appendix 2

Date	Stop in the switch? If yes, draw a line	Was the label machine stopped? If yes, draw a line	If yes, for how long approximately?

Appendix 3

Date	Time	Color on can & lid	Explain where and how the stop occurred	For how long the stop occurred?

Appendix 4

Date	Time	Draw a line if: Stop on conveyor belts on operators' side	Draw a line if: Stop on conveyor belt on the warehouse side	Where did the stop occur?

Appendix 5

Process Step	Input	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class	Potential Cause(s)/Mechanisms of Failure	Occurrence	Current Process Controls Detection	Detection	RPN	Recommended Actions(s)
Include step from Process Map in all rows for sorting	Include input from Process Map in all rows for sorting	Failure of input or symptom	Impact on the customer requirements	How Severe is the effect to the cusotmer?		Causes to input failure. Add row for each cause within step/Input	How often does cause or FM occur?	Existing controls that prevent the cause or the Failure Mode	How well can you detect cause or FM?	S x O x D	Actions for reducing the occurrence of the cause or improving detection?
Processing of snus	Snus	Shortage of delivery	Packing machines are stopped	5		Snus not prepared in time	2	Andon and notis signal	1	10	
		Sticky/bad quality snus	Problems with producing pouches	3		Snus produced too close upon production time	2	NO signal. More difficult to produce	3	18	Future study, research the optimal storage time for each type of snus
Pallet turner	Can & lid	Defective from supplier	Attachment problems	2		Transportation	2	NO controls. Just warehouse workers who throw away broken lids if they see them	3	12	Number of stacked pallets
											Ensure strapping around pallet is tight enough
						Bad/old tools used for producing cans and lids					Update/repair broken tools
			Lid getting stuck in pallet turner	2		Damaged lid or by accident	2	No signal or Signal after 1 minute?	3	12	
			Collisions on conveyor belts	3		Disposer lid or defect lid or get stuck	2	Sometimes signal, otherwise lid rain or producton stopped	3	18	Install a net to catch lid rain, research what causes lids to get stuck
		Shortage of delivery	Packing machines are stopped	5		Logistics departments have not supplied the pallet turner with	2	Andon signal	1	10	
						Stop in the turning mechanism or door		Signal after one minute	2	20	Update signals system and robust design pallet turner
						Stop on the conveyor belts		Notis signal. Sometimes NO signal	2	20	Install a net to catch lid rain, research what causes lids to get stuck
Conveyor belts	Can & lid	Collisions	Packing machines are stopped	5		Defective cans and lids	2	NO signal	3	30	Install a new rail, research what causes lids to get stuck
Packing machine	Snus, can & lid	Welding seam	Waste	4		Incorrect settings	2	Signal sometimes. Sometimes NO signal. Operator quality control every 20 min	3	30	Ensure quality controls are done correctly
		Star-shaped filler	Rework	2		Incorrect star-shape	2	No signal. Vision 3	1	8	
			Waste	4		Incorrect star-shape	2	No signal. Vision 3	1	4	
			Packing machines are stopped	5		Pouch stuck in filler	2	Andon signal	1	8	
		Wrong weight	Waste	4		Incorrect settings	1	Scale to weigh cans	1	5	
		Pouch paper	Packing machines are stopped	5		Change of paper roll	3	Andon signal	1	15	
						Paper roll not changed	2		1	10	

Appendix 5

Process Step	Input	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class	Potential Cause(s)/Mechanisms of Failure	Occurrence	Current Process Controls Detection	Detection	RPN	Recommended Actions(s)
Include step from Process Map in all rows for sorting	Include input from Process Map in all rows for sorting	Failure of input or symptom	Impact on the customer requirements	How Severe is the effect to the cusotmer?		Causes to input failure. Add row for each cause within step/Input	How often does cause or FM occur?	Existing controls that prevent the cause or the Failure Mode	How well can you detect cause or FM?	S x O x D	Actions for reducing the occurrence of the cause or improving detection?
Lid Application	Can & lid	Lid placed up side down	Can with poorly attached lid	3		Lids going through the brush without flipping	2	Height control on the can. If 3 incorrect in a row --> the packing machines stops	3	18	Ensure fewer stops in the brush to prevent upside down lids being pushed forwards
			Can without lid	3			2		2	12	
		Failed lid application	Can with poorly attached lid	3		Defective lids	2	Height control on the can. If 3 incorrect in a row --> the packing machines stops	2	12	
						Incorrect settings	2		3	18	Robust design, future studies.
			Can without lid	3		Defective lids	2	Height control on the can. If 3 incorrect in a row --> the packing machines stops	2	12	
						Misplaced can	2		2	12	
						Incorrect settings	2		2	12	
Buffer	Cans	Switches	Collisions in switch	3		A switch closes and hits the middle of a can --> lets it pass on	2	Human control, sometimes a signal	3	18	Electricians research the optimal time for opening and closing the switches
						Switches overloaded					
		Can without lid	Cans getting stuck	2		Failure to attach lid correctly	2	Human control, sometimes a signal	3	12	
Label machine	Cans	Can without lid	Collisions/explosion inside machine	3		Failure to attach lid correctly	2	Human control, sometimes a signal	2	12	
		Incorrect placed label on can	Rework	2		Wrong settings	3	Vision camera to scan the labels when they are applied	1	6	
			Waste	4		Wrong settings	2	Vision camera to scan the labels when they are applied	1	8	
			Label on the conveyor belt = stop	2		Happens by accident when the machine misplaces a label	2	Vision camera to scan the labels when they are applied	1	4	
		Labels	Banner breaks, machine stopps	3		Speed too high	3	Speed given on the machine screen, line mechanic manually changes	1	9	
						Bad quality of back paper	2	No control	3	18	Optimal speed on label machines
											Future study, research the optimal specification limits
		Finished roll of labels	Machine stops to change labels	2		Reaction time to change rolls high	2	Andon signal and	1	4	

Appendix 5

Process Step	Input	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Class	Potential Cause(s)/Mechanisms of Failure	Occurrence	Current Process Controls Detection	Detection	RPN	Recommended Actions(s)
Include step from Process Map in all rows for sorting	Include input from Process Map in all rows for sorting	Failure of input or symptom	Impact on the customer requirements	How Severe is the effect to the cusotmer?		Causes to input failure. Add row for each cause within step/Input	How often does cause or FM occur?	Existing controls that prevent the cause or the Failure Mode	How well can you detect cause or FM?	S x O x D	Actions for reducing the occurrence of the cause or improving detection?
Conveyor belts 2	Cans	Merge of two conveyor belts	Collision	3		Switches overloaded	2	Vision camera	3	18	Review the signals for when the sensors are opened or blocked on the conveyor belts
		Cans getting stuck in turn	No cans continue trasporting	2		Cans with sharp edges	1	No signal?	3	6	
Oven	10 cans	Cans getting stuck in the fallout	The oven is stopped	2		The 10 cans end up in the wrong place / getting stuck in the fallout	2	Andon signal	2	8	
		Finished roll of plastic	The oven is stopped	2		Reaction time to change rolls high	2	Andon signal	2	8	
Carton filler	Bundle	Problems with the cartons, etc	The robot is stopped	2		Technical issue	2	Andon signal	2	8	
		Bundels are not pushed forward correctly, etc	The robot is stopped	3		Technical issue	2	Andon signal	2	12	

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