# Master Thesis

# Cost Optimization for Rejected Kegs at the Keg Line at Grolsch

Industrial Engineering and Management

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August 24

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# Preface

With great pleasure I present my Master Thesis. This Master Thesis represents the end of my Master Industrial Engineering and Management at the University of Twente. Completing this has been a challenging but rewarding experience and would not have been possible with the support from individuals. Therefore, I would like to take this opportunity to thank everyone involved in the realization of this research.

First and foremost, I want to express my gratitude to Grolsch and my supervisor Peter Koel, for providing me with the opportunity to conduct my research within the Packaging department. The resources, insights, and practical experience gained during my time at Grolsch have been invaluable in shaping the direction and depth of this thesis. In addition, I would like to thank everyone at Grolsch who contributed to this research for their cooperation, help and for sharing their knowledge and time. Their support was essential in making this research possible.

Secondly, I want to thank my two supervisors from the University of Twente. I would like to thank my first supervisor Dennis Prak for your valuable feedback and sparring sessions. Your feedback helped to get this research to a higher level. I also would like to thank my second supervisor Patricia Rogetzer, whose guidance and support have been integral to the completion of this thesis. Your feedback was really helpful and crucial in shaping my thesis. Thank you both for always getting me back on track whenever I got sidetracked.

Of course, I would like to thank my family and friends for the support and encouragement during my master's degree. It would not have been possible without their support. I would especially like to express my deepest gratitude to my parents, your unconditional love and support have always inspired me. Your faith in my abilities and constant encouragement throughout my studies have helped me through difficult times and motivated me to persevere. Thank you for everything you have done for me. Your support has made all this possible.

And finally, I would like to thank Hans, for your patience, understanding, and encouragement that have helped me through the most stressful times. Your ability to calm and cheer me up have been indispensable throughout this journey. Your motto "step by step" helped me but was also really annoying. Thank you for your unconditional support.

With sincere appreciation, I hope you enjoy reading this thesis.

Naomi Galama

*Hengelo, August 2024*

# Management Summary

This research is conducted at the Dutch beer brewing company Grolsch, located in Enschede, the Netherlands. In order to stay ahead of competition, Grolsch needs to continuously develop and improve the production and packaging operations. This also applies to the keg line, where kegs are processed and filled with beer. The focus of this research centers on improving the performance and reducing the costs of rejected kegs of the keg line. This is because the current rejection rate of the keg line is 5.3%, which directly relates to high rejection costs and is higher than desirable. Furthermore, it has been observed that Grolsch does not adhere to the quality standards of Asahi, the parent organization of Grolsch. To address this, Grolsch needs to implement a residual pressure check in the current keg line, which introduces more rejected kegs. Currently, the total associated costs with rejected kegs in the keg line is on a yearly basis €434,197, where the main portion of the costs (€187,527 per year) is due to the rejected kegs by the leak detection machine. Hence, the following research question is formulated:

***What improvements can be made to the keg line in order to decrease the cost of rejected kegs?***

The focus of this research is on two aspects. The first aspect is the introduction of the residual pressure check as this is a minimum quality requirement for Grolsch and must be introduced as quickly as possible and before the end of 2024. The second aspect is the reduction of the costs and rejection rate of the leak detection machine due to the high rejection cost per keg.

Several different implementation scenarios are developed on how to implement the residual pressure check. Two scenarios, referred to as internal scenarios, involve adding the residual pressure check to the current washing and filling machine. The other two, referred to as external scenarios, introduce a separate machine specifically for the residual pressure check. These different scenarios are quantitatively analyzed based on the KPIs throughput, production costs, and quality. Furthermore, sensitivity analyses regarding the operator costs and the justified versus unjustified rejection ratio are performed. For a justified rejection ratio below 60% the external scenario is recommended based on the cost and the payback period. Between a justified rejection ratio of 70% and 80% there is a crossover point between the internal and external scenarios. Above a justified rejection ratio of 80%, the internal scenario is recommended due to the payback period of the external scenario. Based on the current situation with a justified rejection ratio of 10%, the external scenario is recommended. For the current situation, the internal scenario where the residual pressure check is implemented in the washing and filling machine would result in a yearly cost of €183,000. Whereas the external scenario, where a new residual pressure check machine is introduced would result in a yearly cost of €46,000 with an investment cost of €90,000. When introducing the separate residual pressure check, several aspects need to be considered, for example the place of the machine, the impact on the current process, operator handling, and the maintenance cycle. To implement the separate residual pressure check as efficiently as possible, extra tests need to be performed to determine the optimal setpoint of the residual pressure check.

A study is conducted to determine if rejected kegs at the leak detection machine are rejected correctly and how much of the rejection rate is unjustified. Based on this study, the optimal rejection rate range is between 0.2% to 0.33%, since a 0% rejection rate cannot be reached as there are always justified rejections. A root cause analysis is performed with the use of an Ishikawa diagram regarding the potential root causes of the too high rejection rate of the machine. From the root cause analysis, it was determined that one root cause is that the setpoint setting of the leak detection is set tighter than prescribed by the manufacturer. This setpoint is used in the leak detection machine during the measurement of the $CO_2$ level of the keg to distinguish between a correct keg and a leaking keg due to micro or macro tear. The leak detection machine rejects a keg when the $CO_2$ level is above the setpoint. Furthermore, another root cause determined is the jumping of the $CO_2$ measurement levels. The measurements of the leak detection machine shows occasional jumps in $CO_2$ levels above the setpoint and back. This jumping happened not only during measurements of kegs, but also in stationary

conditions. When a jump occurs during a measurement of a keg, the keg is rejected unjustified. Finally, a lag in measurements of the leak detection machine was observed. The measurement of the leak detection machine should be finalized within a measurement time of five seconds. It was observed that the measurements values were updated after the measurement time of five seconds. This implies that leaking kegs are not rejected anymore.

Based on this root cause analysis, an impact and effort estimation for the potential root causes is conducted to prioritize the root causes on potential. The root causes with the highest potential were resolved first. By updating the setpoint of the leak detection machine to the recommended settings by the manufacturer, the rejection rate of 1.39% dropped to 0.81%. By resolving the incorrect measurements due to jumping in $CO_2$ levels and too late measurements, the rejection rate dropped further from 0.81% to 0.32%. Both incorrect measurements could be resolved by performing a cleaning and maintenance cycle on the leak detection machine. The reduced rejection rate for the leak detection machine of 1.07% saves a total yearly cost of €144,523. To prevent deterioration of the leak detection machine, a preventive and predictive maintenance strategy is advised. The preventive maintenance strategy is advised for critical machine components which are easily accessible. For the crucial machine components which are not easily accessible a predictive maintenance strategy is advised. This predictive maintenance strategy is based on extra data storage of the leak detection machine. Based on the constant monitoring of the $CO_2$ levels, it can be determined if unwanted $CO_2$ level jumps occur. When multiple $CO_2$ level jumps occur within a set period, a maintenance cycle is advised. Furthermore, when the data storage is split for both heads of the leak detection machine, the amount of rejected kegs and $CO_2$ levels for rejected kegs can be monitored to determine if both heads are working properly. Based on the data stored for each head, the maintenance cycle is made more efficient by performing maintenance only on a faulty head.

For future research, it is recommended to study the correlation between the residual pressure check and the leak detection machine. The introduction of the residual pressure check is expected to lower the rejection rate of the leak detection machine. Due to this lower rejection rate, the costs associated with the leak detection machine are reduced. Furthermore, the implementation of the separate residual pressure check will have an impact on the current procedures. To determine the impact and the optimal implementation, a simulation model can be introduced. This simulation model should include factors like throughput, production losses, quality and buffer spaces. Lastly, this research focused on the reduction of the cost due to rejected kegs by the residual pressure check and the leak detection machine. These two inspection points are not the only contributors to the costs due to rejected kegs, which leaves the opportunity to reduce the rejection ratio of the total keg line further.

The goal of this research was to reduce the cost due to the rejection of kegs for the two focus areas. For the residual pressure check, a cost-optimal scenario was obtained which meets the requirements from the quality standards set by Asahi. The rejection rate of the leak detection machine decreased by over one percentage point resulting in a cost reduction of €144,523 on a yearly basis.

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# Glossary

| | |
|---|---|
| AGPRM | Asahi Group Production Risk Management |
| BR | Best Requirements |
| CM | Corrective Maintenance |
| CoQ | Cost of Quality |
| DMAIC | Define, Measure, Analyze, Improve, Control |
| EQL | Economic Quality Level |
| F&B | Food and Beverage |
| FE | Factory Efficiency |
| GR | General Requirements |
| KPI | Key Performance Indicators |
| LSS | Lean Six Sigma |
| ME | Machine Efficiency |
| MR | Minimum Requirements |
| OEE | Overall Equipment Effectiveness |
| PDCA | Plan, Do, Check, Act |
| PdM | Predictive Maintenance |
| PM | Preventive Maintenance |
| RM | Reactive Maintenance |
| SGA | Small Group Activity |
| SKU | Stock Keeping Unit |
| TPM | Total Productive Maintenance |
| TQM | Total Quality Management |

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# 1. Introduction

This research focuses on the performance and the costs due to rejected kegs at the Dutch beer brewing company Grolsch. After conducting an analysis of the keg line, potential improvement options are explored, aiming to optimize the keg cleaning and refilling process. The first chapter introduces the research and outlines the project approach. In Section 1.1 the company Grolsch is introduced and in Section 1.2 the packaging lines are shortly discussed. Section 1.3 describes the motivation behind this research, Section 1.4 the problems Grolsch encounters, Section 1.5 states the research objective and in Section 1.6 the research questions are discussed. Finally, Section 1.7 describes the research methodology and outline of this research.

## 1.1. Company Description

Koninklijke Grolsch Brouwerij N.V., hereinafter referred to as Grolsch, is a Dutch beer brewing company located in Enschede, the Netherlands. Willem Neerfeldt established Grolsch in 1615 in Grol, which is nowadays known as Groenlo. Since 2016, Grolsch has been part of the Asahi Group Holdings (Asahi), which is a Japanese beverage company. Together with Peroni and Meantime, Grolsch constitutes the European branch of the Asahi Group. Apart from producing its own beer, Grolsch is involved in the production of various other beers, including De Klok and Peroni. Besides producing for the domestic market, Grolsch also produces for the international market, including those in Canada, France, and Australia. The brewery consists of several departments, such as Sales, Marketing, Finance & Commercial Services, and Supply Chain and Logistics. The actual beer production and bottling occurs at the subdepartments of Packaging and Brewing, which are part of the Supply Chain and Logistics department (*Grolsch*, n.d.).

In order to stay ahead of competition, Grolsch needs to continuously develop and improve the production and packaging operations. The department Packaging aims to continuously improve the current packaging lines with the focus on improving productivity, reducing waste and improving efficiency. In the production halls of Grolsch there are six different packaging lines, where bottles, cans, and kegs are filled and packed.

## 1.2. Packaging Lines

Within Grolsch there are several packaging lines and Table 1.1 provides an overview of the various packaging lines, with the specific bottle types, cans, or kegs for which each line is intended. Packaging line 5 and 6 are terminated and no longer in use.

*Table 1.1: Overview of packaging lines*

| Packaging line | Type |
|---|---|
| **Line 1** | Kegs |
| **Line 2** | Special returnable bottles |
| **Line 3** | Regular returnable bottles |
| **Line 4** | Swing-top bottles |
| **Line 7** | Non-returnable bottles |
| **Line 8** | Cans |

This research focusses on line 1, the keg line. The keg line is the production line where empty kegs from the market arrive, are cleaned, filled, checked for leaks, and are prepared for shipment, see Figure 1.1. The packaging process is a closed-loop process, which means that the empty kegs arrive from the market, are cleaned and straight away reintroduced into the packaging process again. The keg line processes three diverse types of kegs, which are 19.5-, 30-, and 50-liter kegs and various kinds of beers are filled in these kegs, such as Grolsch Pils, Grolsch Weizen and Peroni. In Section 2.1 the keg line is further explained in detail.

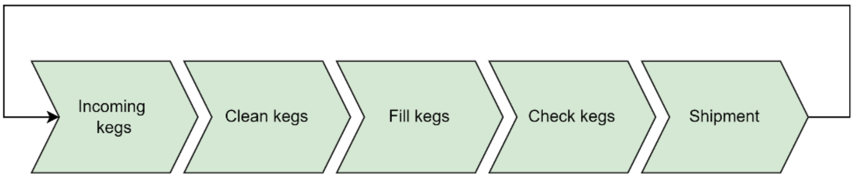


*Figure 1.1: Simplified process of the keg line*

### 1.3. Research Motivation

The primary objective of Grolsch is to meet customer needs and ensure their satisfaction with the final product. This objective can be maintained through continuously improving the overall performance of the processes and strictly complying with quality standards. Various Key Performance Indicators (KPIs) are used within Grolsch to systematically monitor and assess the performance of the packaging lines. Regarding operations, these are the Factory Efficiency (FE) and the Machine Efficiency (ME). The FE and ME are derived from the widely used Overall Equipment Effectiveness (OEE) framework, which is originated from the Total Productive Maintenance (TPM) concept introduced by Nakajima (Iannone & Elena, 2013).

Figure 1.2 demonstrates the various components of which the FE and ME are composed of. The total time are the hours that the packaging line is physically available for use, whether it is in operation or not. The total time consists of the total operations time and time that is not scheduled, which are the capacity losses and the hours that there is no paid work on the line. The total operations time consists of the loading time, which are the adjusted factory hours, and the unscheduled time, which is the idle time that is not planned and is outside the brewery's control. The loading time consists of the production time, which are the production hours, and the maintenance and cleaning, which is the scheduled cleaning at the beginning and the end of the week and the preventive period maintenance. The production time consists of the processing time and the authorized stops. Examples of authorized stops are the start-up and shutdown time of the line and converting the line when different kegs are going to be processed. The processing time consists of the machine time and service stops, the service stops is downtime due to factors outside the control of packaging, for instance, no beer supply, warehouse disruptions or automation problems. The last one is the machine time, which consists of the full production time and the losses. The full production time is the time that the production is at full speed, and the losses comprise machine malfunctions (such as unplanned maintenance breaks), speed losses, and production stops due to technical reasons (Grolsch, 2022).

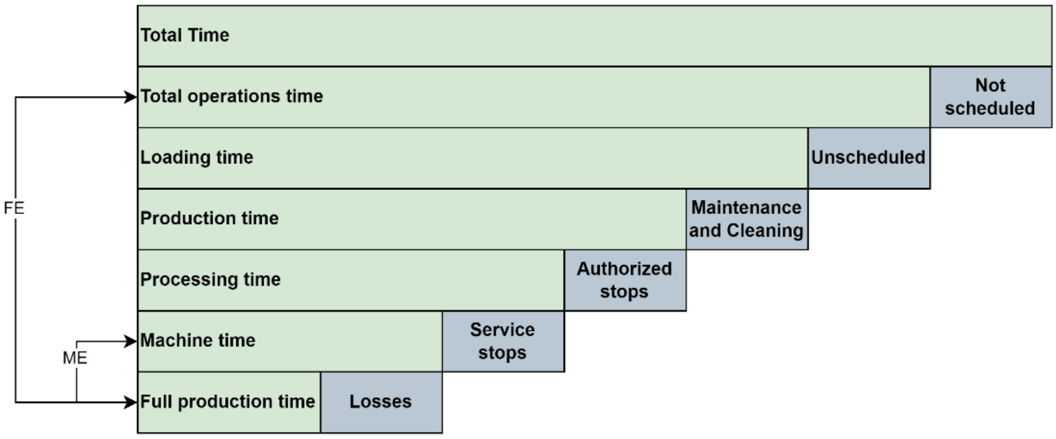


*Figure 1.2: Grolsch calculation for Factory Efficiency and Machine Efficiency* (Grolsch, 2022)

The FE refers to the overall efficiency of the line and is calculated by the full production time divided by the total operations time, whereas the ME refers to the efficiency of the line during running hours and is calculated by the full production time divided by the machine time.

Within Grolsch, FE and ME are important KPIs for assessing the efficiency of the packaging lines. These KPIs consist of many different parameters. This research focusses on the costs due to the rejected kegs of the keg line, therefore the KPIs for this research include the throughput, production costs and the quality of the production process and end products. The losses due to the rejection of kegs have a direct impact on the FE, when the rejection rate reduces, the FE increases.

The throughput of the production line refers to the number of kegs that the production line can successfully produce and deliver within a given unit of time. Some of the factors that influence the throughput are the speed of the production line, equipment reliability, quality control, and maintenance planning. Optimizing these factors within a production line is crucial to maximize the throughput and ensure the production line operates efficiently and profitably (Raza, 2024). The production costs include all costs associated with producing and packaging the kegs. The costs of the production line can be significantly affected by the number of rejected kegs. An increase in the number of rejected kegs can increase the costs due to the additional effort required to rework or the beer loss associated with the rejected kegs. Lastly, there are the quality standards; the quality standards determine the standards and specifications that the products and the production process must meet to be acceptable to the market. These requirements are vital to ensure consistency and high-quality products are crucial aspects for the success of the business (Judi et al., 2011).

An overarching concept that relates to the KPIs and aspects mentioned is Total Quality Management (TQM) (Anupindi et al., 2014). TQM is a management approach that provides a framework within which an organization can manage and improve the overall quality of their products, processes, and performance. It touches on the important aspects that influence the mentioned KPIs and aspects in the production line.

## 1.4. Problem Description

In order to ensure consistency and high-quality products, a performance assessment is performed by Grolsch, which resulted in a higher rejection rate of kegs than desired. During this performance assessment it is found that the current rejection rate is 5.3%. The same holds for the costs of the rejected kegs, as these are directly related to the rejection rate. Furthermore, Grolsch recently had an internal audit, where the packaging lines were evaluated. This audit revealed that Grolsch currently does not adhere to all the quality standards set by their parent organization Asahi. For example, it was determined that there is no residual pressure check present in the keg line. The consequences of failing an audit can lead to a potential risk of non-compliance with the requirements of Asahi and the Dutch Food and Consumer Product Safety Authority. Currently Grolsch has been given an extension by Asahi, to investigate how the quality standards of Asahi could be met. The decision regarding the appropriate course of action needs to be made before the end of 2024.

Maintaining high-quality standards for food products is a critical focus for companies operating in the Food and Beverage (F&B) industry. Quality standards for food and beverages are established for various reasons. They primarily serve to protect consumers by ensuring the safety and hygiene of food and beverage products. These standards also promote consistency in production, allowing consumers to trust in the uniform quality of a product regardless of its origin or time of production (Muscad, 2022).

## 1.5. Research Objective

Based on the problem description, the goal of this research is to improve the performance and reduce the costs of rejected kegs of the keg line based on the KPIs throughput, production costs, and the quality standards prescribed by Asahi. In this research the keg line is analyzed based on an analytical model of these KPIs, and following this analysis, advice is provided on how to optimize the keg line processes within Grolsch.

The focus is on the keg line, therefore the other five packaging lines that process different types of bottles and cans are excluded from this research. In the keg line, the steps taken before the pallets arrive and after they depart from the keg line are not considered. Furthermore, the quality of the returned kegs from the market is left out of scope.

## 1.6. Research Questions

Considering the problem description and the research objective, the main research question is: *What improvements can be made to the keg line in order to decrease the cost of rejected kegs?*
Since the main research question has been stated broadly, the following three sub-questions will support the main research question:

1) How is the current performance of the keg line regarding the KPIs?
2) What are the best improvements for the current situation?
3) How to implement the best and most suitable options?

In order to answer the research question, several sub-questions have been formulated. These sub-questions are explored and answered in the subsequent chapters.

Chapter 2: Context analysis: Production and process description

- 2.1. How does the keg line currently operate and how are the kegs being processed?
- 2.2. What are the relations between the KPIs and the performance of the keg line?
- 2.3. What are the main focus areas for improvement for the keg line regarding its performance?

In this chapter, the current situation is outlined of how the keg line operates and how the kegs are processed. The performance of the keg line is assessed based on the KPIs. From this assessment, the main focus areas to improve are determined. This chapter provides insights into the current situation of the keg line and serves as the starting point for the analysis in subsequent chapters.

Chapter 3: Literature Review

- 3.1. What method is available in literature for quality improvement?
- 3.2. What method is available in literature to provide insight into costs incurred with quality?
- 3.3. How do quality inspections relate to maintenance activities?

In the literature review, research is conducted on the factors that influence product quality within the production process and on quality improvement methodologies. A strategy that can be used to provide insight into costs incurred with (poor) quality is researched. Furthermore, the impact that maintenance has on quality inspection strategies is explored.

Chapter 4: Methodology

- 4.1. What requirements must the implementation scenarios meet for introducing the residual pressure check?
- 4.2. What possible implementation scenarios are available for the current situation to introduce the residual pressure check?
- 4.3. What methodology can be used to identify the root causes of the unjustified rejection rate of the leak detection machine?

This chapter describes the approach for introducing the residual pressure check in the current keg line and reducing the unjustified rejection rate of the leak detection machine. First, this chapter describes suitable implementation scenarios for introducing the residual pressure check in the current keg line which comply with the requirements needed for the residual pressure check. Hereafter, the approach on how to reduce the unjustified rejection rate of the leak detection machine is described. Furthermore, the method for a root cause analysis is given and how to solve these root causes.

Chapter 5: Results

5.1. Which implementation scenario for the residual pressure check is the best and most suitable for the current situation?
5.2. What are the root causes of the issues found in the performance analysis for the leak detection machine?
5.3. What is the performance of the keg line after the implementation of the residual pressure check and the leak detection machine improvements?

In the results chapter, the proposed implementation scenarios for the residual pressure check of Chapter 4 are analyzed. The various options for implementation are compared based on sensitivity analysis on the KPIs and literature. By using the KPIs, we can assess which scenarios are more likely to lead to the desired outcomes and align with the objectives of Grolsch. Furthermore, this chapter identifies the root causes of the issues found with the leak detection machine and outlines the steps to address and resolve these problems.

Chapter 6: Implementation Plan & Recommendations

6.1. Which steps should be taken to introduce the residual pressure check in the keg line?
6.2. Which steps should be taken to improve the performance of the leak detection machine?

In this chapter, an implementation plan and recommendations are described that ensures a smooth implementation of the suggested improvements.

## 1.7. Research Methodology

The goal of this research is to improve the performance and the costs due to rejected kegs for the keg line at Grolsch. Several methodologies are described by researchers and practitioners to use for quality improvement of production processes. Lean six sigma techniques such as DMAIC and the PDCA-cycle of TQM are methods which are widely used for improving production processes and reducing defect rates. Although there are some differences between these methodologies in terms of tools, terms and approaches, there are also a lot of resemblances between these methodologies. Appendix C provides an extensive overview comparing these three methodologies. For this research, the DMAIC method was selected as the framework. However, the scope is limited to the Define, Measure and Analyze phases, and does not extend to the Improve and Control phase.

This research is organized as follows: Chapter 2 describes the current situation of the keg line, how the keg line operates, provides a cost analysis of the current situation, and describes the main focus for this research. In Chapter 3, the found literature on the topics of quality control, quality costing and quality inspections is discussed. This is followed by Chapter 4 which describes the methodology for the implementation of the residual pressure check and the approach for the unjustified rejections at the leak detection machine. Chapter 5 describes the obtained results, and in Chapter 6 an implementation plan and recommendations are described for Grolsch on how the costs of the rejected kegs can be reduced for the keg line. Finally, Chapter 7 concludes this research.

# 2. Context Analysis: Production and Process Description

This chapter provides a detailed description of the keg line and explains the process that kegs undergo. Furthermore, the keg line is analyzed on the previously described KPIs. In Section 2.1, the keg line is globally described and Section 2.2 describes the detailed processing steps of a keg. Section 2.3 elaborates on the different produced SKUs on the keg line, and in Section 2.4 an analysis is made of the current situation. Lastly, Section 2.5 concludes the chapter.

## 2.1. Process of the Keg Line

The keg line has a U-shaped form and consists of several processes. Figure 2.1 gives a schematic overview of the keg line and the different machines that are used. The keg line is divided into a wet and dry area, as visible in Figure 2.1 with the grey and green area, respectively. The dry area is where the pallets and kegs are destacked and stacked. The wet area is the area where the kegs are washed and filled. Between each processing step, the kegs are transported via conveyer belts. These conveyer belts also serve as buffers between the machines. At the starting point indicated in Figure 2.1, empty kegs arrive on pallets from the warehouse to the dry area of the keg line by means of an automated system. First the pallets are destacked and afterwards the kegs are destacked from the pallets onto the conveyer belt. The kegs are checked at step 4 and possibly rejected. Afterwards, the kegs are turned at the empty keg turner at step 5, with the fitting facing down, by a robotic arm. Then the kegs are transported through the exterior cleaner, which will clean the outside of the kegs from old labels and stickers. The kegs will then go to the washing and filling machine at step 7, where the kegs are directed one by one to one of the lanes. The supply of the kegs is at the beginning of lane 1, therefore lane 5 has priority due to the longest route a keg must take to get there. In the washing and filling machine there are five parallel lanes where the keg undergoes several stages, each pair of heads simultaneously processes the kegs. In heads 1&2, 3&4, and 5&6 the keg is cleaned internally with lye, acid and sterilized with steam, respectively, and in head 7&8, the keg is filled with beer. When kegs are at the end of the lanes, the kegs are placed simultaneously on the conveyer belt. When the conveyor belt before the full keg turner is empty, the washing and filling machine receives a signal, allowing the lanes to place full kegs on the conveyer belt before the full keg turner. The kegs are turned at the full keg turner by a robotic arm, with the fitting facing up. Thereafter, the keg is checked by the leak detection machine and the scale at step 9 and 10 to detect leaks and ensure it has the correct weight. Afterwards, the keg is fitted with a cap and labeled. Finally, the kegs are stacked on pallets and the pallets are stacked at a height of two or three pallets. Hereafter, the pallets receive a strap and label at steps 15 and 16 and are transported to the warehouse.

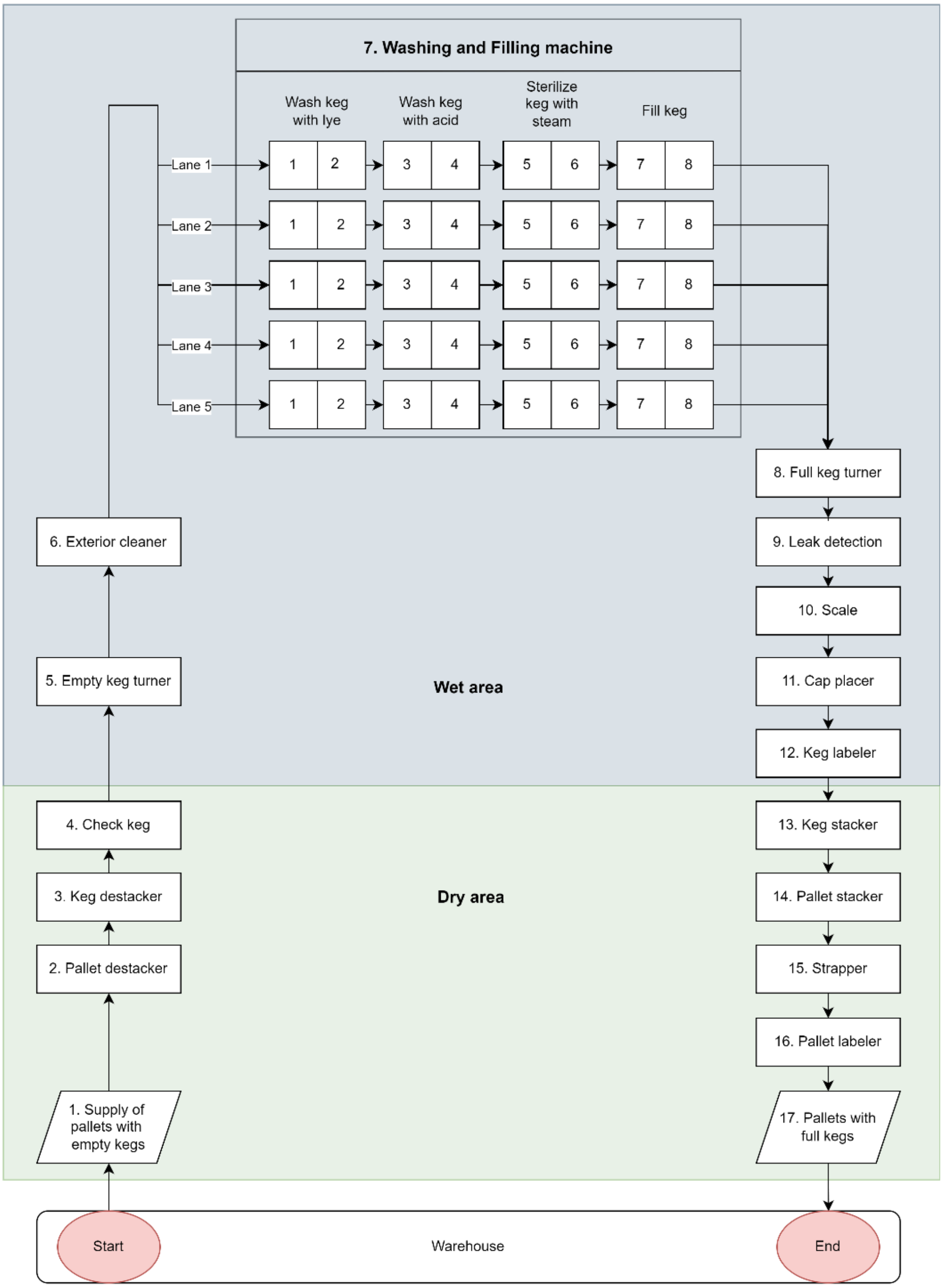


*Figure 2.1: Schematic overview of the process of the keg line*

To provide more insights into the keg line also a visual representation of the keg line is shown. Figure 2.2 shows the dry area of the keg line. On the right side of Figure 2.2 empty kegs arrive from the warehouse, and after destacking the pallets, the empty kegs are destacked onto the conveyor belt. On the left side of Figure 2.2 the full kegs are stacked onto a pallet by a yellow robotic arm and afterwards the pallets are stacked, strapped, and labeled, before they are transported to the warehouse.

Figure 2.2: Dry area

Figure 2.3 shows the wet area of the keg line. On the left side of the picture displayed in Figure 2.3 the empty kegs arrive from the dry area and continue to the exterior cleaner. After the exterior cleaner, the kegs arrive at the washing and filling machine, which is seen at the top center of the picture. On the right side of Figure 2.3 the full keg turner, leak detection machine, weighing scale and the capper are shown. More detailed pictures of the machines are found in Appendix A.

Figure 2.3: Wet area

## 2.2. Product Inspection Process

To clarify the keg inspection process, Figure 2.4 displays a detailed flowchart of the keg line. This represents the flow and the numerous steps a keg undergoes in the keg line. The oval symbol represents a start or end point, the rectangle symbol represents a process step, and the diamond shape symbols indicate a decision that needs to be made. The orange-colored symbols indicate that an operator needs to perform some action and that the process flow depends on the action of the operator, and the blue-colored symbols indicate when a keg is being rejected from the keg line. The keg undergoes several processes in the keg line in which its quality is assessed. Throughout the keg line, there are several quality inspection points. If a keg does not meet the established standards at any of these quality inspection points, the keg is rejected. These quality inspection points are further explained in the following paragraphs.

Step 4.1 of Figure 2.4 represents the first quality inspection point, where an initial check is done on any damage on the exterior of the keg and the weight of the keg. The diamond shape symbol represents the decision if a keg is accepted or rejected. When a keg is not within the set boundaries or when there is damage on the outside of the keg, the keg is automatically rejected from the keg line. When kegs are rejected due to their weight, the keg is drained. The drained keg is examined on external damage and when no damage is found, the keg is returned to the conveyer belt before the exterior cleaner at step 4.5. When the rejected kegs have any external damage, the kegs are rejected and needs to be repaired. This initial check is currently experiencing operational issues and is undergoing improvements to enhance its functionality. Therefore, data is not available and is excluded from this research.

Within the washing and filling machine process, several checks are performed, which can result in different errors. When an error occurs, the keg remains within the lane and will not be rejected straight away from the line. The keg will no longer be processed in the subsequent heads, and the keg will be checked at the end of one of the five lanes. When an error occurs in processing steps 1&2 or 3&4, then an F10 procedure is started. An F10 procedure entails that an operator must check the keg at the end of a lane. If this keg is empty, the operator puts the keg back on the conveyer belt, so it can continue to the full keg turner. When the keg is not empty, the operator will drain the keg at step 7.4, and afterwards places the keg on the conveyer belt. When an error occurs in head 5&6, or 7&8, then there is no F10 procedure as the kegs are already empty and the kegs will continue to the full keg turner. The F10 procedure is a temporary implementation to replace step 4, since the keg check in step 4 is disabled.

After the washing and filling machine, the leak detection machine will check if a keg is leaking at step 9.1. When a leakage is detected, the keg is rejected. An operator drains the keg, and the keg is shipped for repair. At the scale in step 10.1 the keg is checked on weight. When the weight of the keg is not within set boundaries, the keg is rejected. An operator drains the keg if there is any beer left inside the keg. Afterwards, the empty kegs are returned to the conveyer belt just before the exterior cleaner.

At steps 11.1 and 12.1 it is checked if the keg has received a cap and label. If a cap or label is not detected on the keg, the keg is rejected and undergoes automatically the process again of receiving a cap and/or label.

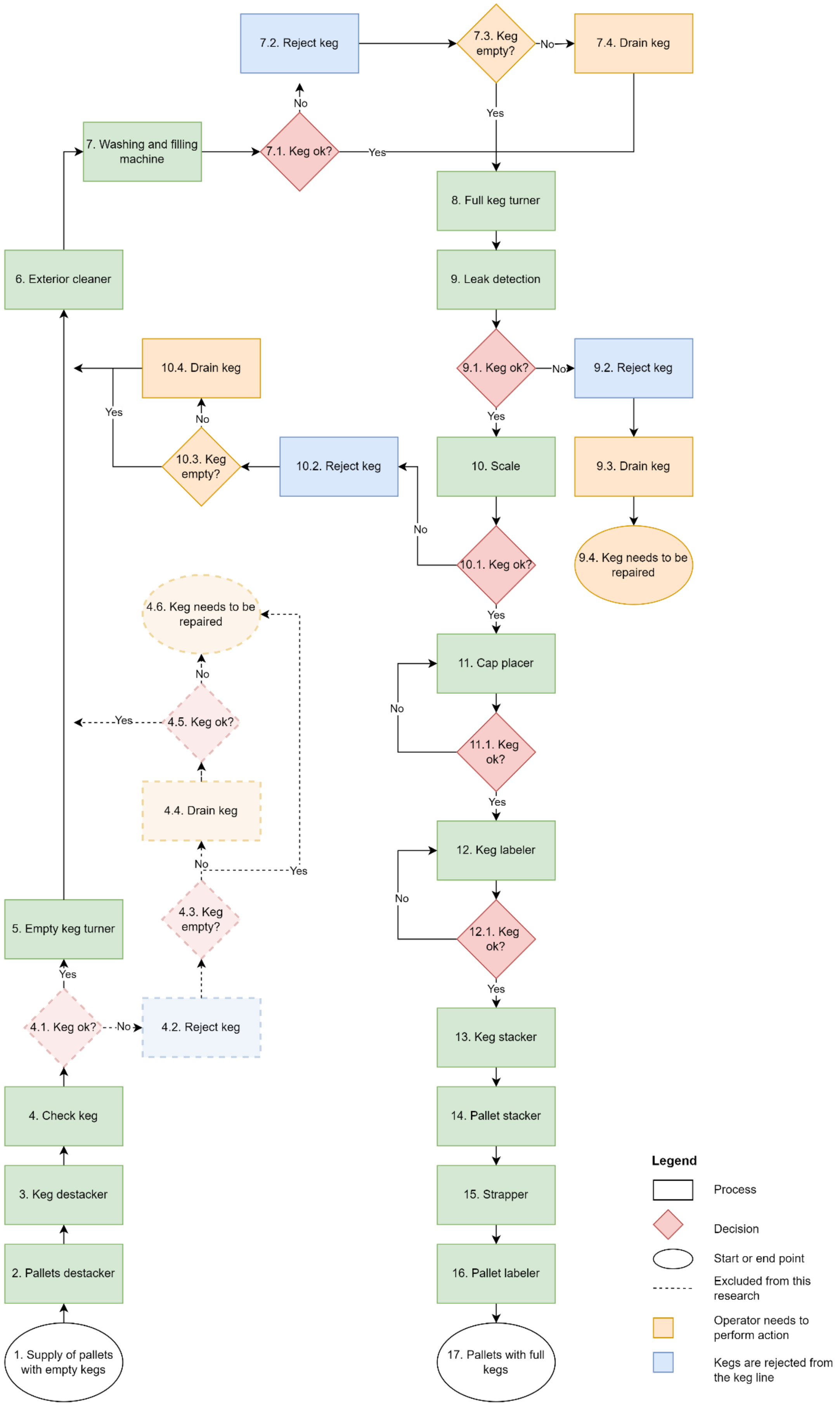


*Figure 2.4: Flowchart of the process steps of the keg line*

## 2.3. Various SKUs

The keg line processes three diverse types of kegs: the 19.5-, 30- and the 50-liter kegs, as shown in Figure 2.5. In Figure 2.5, it is observed that the 19.5-liter kegs are smaller in diameter compared to the 30- and 50- liter kegs, which have the same diameter but differ in height. Due to their smaller size, the 19.5-liter kegs are processed in the keg line using a dummy (Figure 2.6). The 19.5-liter keg is placed in this dummy at the empty keg turner, this allows the 19.5-liter keg to go through the process and have the same diameter as the 30- and 50-liter kegs. When the 19.5-liter full kegs are stacked onto pallets, a robotic arm lifts the 19.5-liter keg out of the dummy, and the dummy continues via a conveyer belt to the empty kegs which arrive from the warehouse.

*Figure 2.5: 19.5-liter keg (left); 30-liter keg (middle); 50-liter keg (right)*

*Figure 2.6: 19.5-liter keg with dummy (left); dummy (right)*

The three diverse types of kegs are filled with several different beers, such as De Klok Bier, Grolsch Pils, Grolsch Triple, Weizen, Herfst- and Zomerbok, Radlers and Peroni. This leads to more than fifteen different SKUs being processed by the keg line. Besides the diverse types of kegs, there are also different kinds of fittings on the kegs. There are three types of fittings, which are the A-fitting, S-fitting, and the G-fitting, see Figure 2.7. The S-fitting is used for 50-liter Peroni kegs, the G-fitting is used for the 30-liter Export kegs, and the A-fitting is used for all other SKUs.

*Figure 2.7: S-fitting; G-fitting; A-fitting*

## 2.4. Analysis Current Situation

In this section the current costs due to rejected kegs of the keg line are analyzed, and the associated rejection rate and the quality are discussed. To base the analysis on representative data, the dataset from week 34 until 52 of 2023 is used.

### 2.4.1. Rejection Rate

In the keg line, there are four steps where kegs are rejected by the machines, which are indicated by the blue rectangles in Figure 2.4. However, the kegs rejected by the washing and filling machine are not directly rejected from the keg line. The kegs that are rejected by the washing and filling machine are drained by the operator and then placed back on the conveyor belt, causing the kegs to be rejected from the keg line at the scale.

**Washing and filling machine**

The washing and filling machine cleans the kegs internally and fills the kegs with beer. In all the heads several errors can occur, such as purge failed, spear in rejects and seal failures. In Table 2.1 an overview is found from the available data of the total losses due to the rejected kegs of the 19.5-, 30-, and 50-liter kegs from the washing and filling machine. Table 2.1 indicates per keg type, the number of accepted kegs, number of rejected kegs, and the total kegs being processed by the washing and filling machine. The percentage of rejected kegs is shown in the last column. The results show that the 50-liter kegs cause relatively the highest rejection rate, with a total of 3.73% and that the average rejection rate over all types of kegs is 3.53%. Appendix B provides a complete overview of the specific errors of the rejects that occurred in the washing and filling machine.

*Table 2.1: Rejection rates of the washing and filling machine*

| Content Keg [L] | Accepted kegs [#] | Rejected kegs [#] | Total kegs [#] | Percentage rejected kegs [%] |
|---:|---:|---:|---:|---:|
| 19.5 | 98,789 | 3,517 | 102,306 | 3.44 |
| 30 | 37,083 | 912 | 37,995 | 2.40 |
| 50 | 259,056 | 10,043 | 269,099 | 3.73 |
| **Total** | **394,928** | **14,472** | **409,400** | **3.53** |

**Leak detection machine**

The leak detection machine checks for $CO_2$ leaks on the keg. If there is a difference of more than 10% in $CO_2$ levels between the keg headspace and atmospheric $CO_2$, the keg is labeled as leaking, and it is automatically rejected. Kegs may leak because they were brought back from the market already leaking or because of something which happened in the process of the washing and filling machine. Table 2.2 indicates per keg type, the number of accepted kegs, number of rejected kegs, and the total kegs being processed by the leak detection machine. The percentage of rejected kegs is shown in the last column. The results show that the 30- and 50-liter kegs cause relatively the highest rejection rate of the leak detection machine, with 1.50% and 1.49%, respectively. The average rejection rate of the leak detection machine over all types of kegs is 1.39%.

*Table 2.2: Rejection rates of the leak detection machine*

| Content Keg [L] | Accepted kegs [#] | Rejected kegs [#] | Total kegs [#] | Percentage rejected kegs [%] |
|---:|---:|---:|---:|---:|
| 19.5 | 109,718 | 1,204 | 110,922 | 1.09 |
| 30 | 49,940 | 760 | 50,700 | 1.50 |
| 50 | 251,587 | 3,815 | 255,402 | 1.49 |
| **Total** | **411,245** | **5,779** | **417,024** | **1.39** |

**Scale**

The scale after the leak detection machine checks if the weight of the keg is within set boundaries. When the keg is empty, underfilled or overfilled, the keg is rejected. Empty kegs are caused by the fact that these kegs have been rejected by the washing and filling machine and were drained by the operator. The empty kegs are then rejected by the scale. Underfilled kegs can be caused, for example, by the fact that the filling step was interrupted, which results in underfilled kegs. Overfilled kegs could be caused by the washing and filling machine, but also due to an error that causes two kegs to end up on the scale at the same time, causing the scale to think that the keg is overfilled. Table 2.3 indicates per keg type, the total empty, underfilled and overfilled kegs, which results in the total rejected kegs by the scale. Furthermore, the number of accepted kegs and the total number of kegs being processed are shown. The percentage of rejected kegs by the scale is shown in the last column. The results show that the 50-liter kegs cause relatively the highest rejection rate, with 4.30%. The average rejection rate of the scale over all types of kegs is 4.08%.

*Table 2.3: Rejection rates of the scale*

| Content keg [L] | Total empty kegs [#] | Total underfilled kegs [#] | Total overfilled kegs [#] | Total rejected kegs [#] | Total accepted kegs [#] | Total kegs [#] | Percentage rejected kegs [%] |
|---:|---:|---:|---:|---:|---:|---:|---:|
| 19.5 | 3,726 | 118 | 7 | 3,851 | 96,327 | 100,178 | 3.84 |
| 30 | 829 | 127 | 0 | 956 | 30,900 | 31,856 | 3.00 |
| 50 | 10,179 | 1,171 | 3 | 11,353 | 252,466 | 263,819 | 4.30 |
| **Total** | **14,734** | **1,416** | **10** | **16,160** | **379,693** | **395,853** | **4.08** |

### 2.4.2. Cost of Rejected Kegs

Internal failure costs are associated with poor quality products in the production line before they are delivered to the customer and are costs that could have been avoided. These costs cover a variety of costs such as waste, unnecessary repetition of tasks, idle or wasted time, and reinspection and fixing defect products (Al-Assaf & Schmele, 1993). These costs associated with poor-quality, are related to the costs associated with rejected kegs. Within the keg line, these are translated into the repair cost, operator cost, costs of beer loss and cost of production loss. In this subsection, these costs are discussed in further detail and at the end an overview is shown of the total costs due to the rejected kegs of the keg line.

**Repair cost**

Kegs that do not meet the quality inspection points and are not permitted to be returned to the keg line need to be repaired. The repair of kegs is conducted by an external company. The only rejected kegs, which are sent for repairs, are the rejected kegs from the leak detection machine. The rejects from the leak detection machine are not permitted to be returned to the keg line. The cost of repairing a keg depends on the level of damage to a keg. For simplicity for this research, the cost to repair a keg is based on the average repair cost in 2023, which results in a cost of €5.75 per keg. Table 2.4 shows the total number of rejected kegs per keg type and the associated total repair costs.

*Table 2.4: The repair cost of the different keg types*

| Content keg [L] | Repair cost | |
|---:|---:|---:|
| | Rejected kegs [#] | Repair cost [€] |
| 19.5 | 1,204 | 6,923 |
| 30 | 760 | 4,370 |
| 50 | 3,815 | 21,936 |
| **Total** | **5,779** | **33,229** |

**Operator cost**

The rejected kegs at the washing and filling machine, leak detection machine and the scale need to be handled and processed by the operators. The operator costs are based on the average time an operator needs for handling the rejected kegs. The handling time of the operators is estimated based on observations and interviews with the operators. To calculate the operator costs for the different handling steps, the labor cost must be known. Within Grolsch a rate of on average 37.5 €/hour is calculated as labor costs. At the washing and filling machine, when a keg is being rejected with the F10 procedure, the operator needs to check this keg manually, drain the keg and put it back onto the conveyer belt. This procedure takes on average 90 seconds per keg, resulting in a cost of €0.94 per rejected keg. Rejected kegs by the leak detection machine need to be manually drained by the operator and collected on pallets. These pallets are transported to the warehouse, where the pallets with damaged kegs are sent for repairs. This procedure of draining and transporting takes on average 150 seconds per keg, resulting in a cost of €1.56 per rejected keg. The kegs that are rejected at the scale are empty, underfilled or overfilled. The kegs with beer inside need to be drained by the operators and collected on pallets. The pallets with empty kegs are then returned to the conveyer belt just before the exterior cleaner. This procedure takes on average 100 seconds per keg, resulting in a cost of €1.04 per rejected keg. Table 2.5 shows the total number of rejected kegs per keg type and the associated total operator costs.

*Table 2.5: The operator costs of the different keg types*

| Content keg [L] | Operator cost | | | | | |
|---|---|---|---|---|---|---|
| | Washing and filling machine | | Leak detection machine | | Scale | |
| | Rejected kegs [#] | Operator cost [€] | Rejected kegs [#] | Operator cost [€] | Rejected kegs [#] | Operator cost [€] |
| 19.5 | 1,682 | 1,577 | 1,204 | 1,881 | 3,851 | 4,011 |
| 30 | 393 | 368 | 760 | 1,188 | 956 | 996 |
| 50 | 3,660 | 3,431 | 3,815 | 5,961 | 11,353 | 11,826 |
| **Total** | **5,735** | **5,377** | **5,779** | **9,030** | **16,160** | **16,833** |

**Cost of beer loss**

The rejected kegs at the leak detection machine and scale cause beer loss. Beer loss occurs from kegs that have already been filled and are subsequently being rejected. The beer is drained from the kegs by the operators, thereafter the damaged kegs need repairing and the other kegs are returned on the conveyer belt before the exterior cleaner. To calculate the cost of beer loss, the cost per liter beer loss must be known. Within Grolsch a rate of 4.98 €/hectoliter is calculated for the keg line, which results in 0.0498 €/liter. Consequently, the cost of beer loss incurred from emptying a full 19.5-liter keg is €0.97, while a 30-liter keg results in €1.49 and a 50-liter keg in €2.49.

To determine the costs of beer loss from the leak detection machine, the assumption is made that each keg rejected by the leak detection machine is on average the standard content of the keg. For the rejected kegs of the scale this is different because there are kegs that are empty, underfilled and overfilled. Since the actual weights of the processed kegs at the scale are known, an analysis is performed to determine the average weight of an accepted, underfilled and overfilled keg. The result of this analysis are shown in Table 2.6. The deviation for 19.5-, 30- and 50-liter underfilled kegs compared to the accepted kegs are respectively 33.1%, 36.63% and 40.37%. There is no data available for overfilled kegs. Therefore, the assumption is made that overfilled kegs have the same deviation as the underfilled kegs compared to the accepted kegs for their content.

*Table 2.6: Average weight of accepted, underfilled and overfilled kegs for different contents*

| Content keg [L] | Average weight [kg] | | |
|---|---|---|---|
| | Underfilled [Kg] | Accepted [Kg] | Overfilled [Kg] |
| 19.5 | 21.22 | 31.72 | 42.22 |
| 30 | 25.67 | 40.51 | 55.35 |
| 50 | 37.3 | 62.55 | 87.8 |

With these deviations, the total amount of beer loss for the leak detection machine and the scale are determined. These results are shown in Table 2.7. The data indicate that the scale leads to significantly less beer loss compared to the leak detection machine.

*Table 2.7: The cost of beer loss of the different keg types*

| Content keg [L] | Cost of beer loss | | | | | |
|---|---|---|---|---|---|---|
| | Washing and filling machine | | Leak detection machine | | Scale | |
| | Beer loss [L] | Beer loss [€] | Beer loss [L] | Beer loss [€] | Beer loss [L] | Beer loss [€] |
| 19.5 | 0 | 0 | 23,478 | 1,168 | 1,721 | 86 |
| 30 | 0 | 0 | 22,800 | 1,134 | 2,414 | 120 |
| 50 | 0 | 0 | 190,750 | 9,490 | 35,125 | 1,747 |
| **Total** | **0** | **0** | **237,028** | **11,792** | **39,261** | **1,953** |

**Cost of production loss**

Finally, the costs of production losses for Grolsch are translated into the FE of the keg line. The definition of FE is described in Section 1.3 in detail. Kegs that do not pass the quality inspection points are rejected from the keg line. These rejected kegs have a financial impact since they influence the production capacity negatively. Due to this negative influence on the production capacity, the output of kegs is reduced, which reduces the revenue.

The FE is calculated based on the time lost due to rejected kegs per machine and are at the expense of production capacity. The FE is not divided into the content of the keg, but calculated for the total amount of rejected kegs when these are added to the throughput of the line. Based on these production capacity losses, the production loss costs are shown in Table 2.8.

*Table 2.8: The cost of production loss of the different keg types*

| Content keg [L] | Cost of production loss | | | | | |
|---|---|---|---|---|---|---|
| | Washing and filling machine | | Leak detection machine | | Scale | |
| | Rejected kegs [#] | Cost of production loss [€] | Rejected kegs [#] | Cost of production loss [€] | Rejected kegs [#] | Cost of production loss [€] |
| 19.5 | 3,517 | 6,884 | 1,204 | 2,263 | 3,851 | 7,840 |
| 30 | 912 | 1,785 | 760 | 1,428 | 956 | 1,946 |
| 50 | 10,043 | 19,656 | 3,815 | 7,171 | 11,353 | 23,112 |
| **Total** | **14,472** | **28,325** | **5,779** | **10,862** | **16,160** | **32,898** |

**Total cost**

The total cost due to rejected kegs in the keg line for the various machines are shown in Table 2.9, Table 2.10, and Table 2.11. The washing and filling machine and the scale do not have rejected kegs that need to be repaired and are therefore set to zero. From these results it is observed that the rejection rate of the leak detection machine is much lower compared to the rejection rate of the scale. However, the costs due to the rejected kegs at the leak detection machine are higher than the costs due to the rejected kegs at the washing and filling machine and the scale. Whereas the cost of the operators is higher on the scale, the cost of the leak detection machine is particularly higher for beer loss and repairs. As is shown in Table 2.12, this results in a total cost of €150,299 for the rejected kegs in the period of weeks 34 until 52 of 2023.

*Table 2.9: Total cost of rejected kegs at the washing and filling machine*

| **Washing and filling machine** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Content keg [L]** | **Percentage rejected kegs [%]** | **Total rejected kegs [#]** | **Cost beer loss [€]** | **Repair cost [€]** | **Operator cost [€]** | **Cost of production loss [€]** | **Total cost [€]** |
| 19.5 | 3.44 | 3,517 | - | - | 1,577 | 6,884 | 8,460 |
| 30 | 2.40 | 912 | - | - | 368 | 1,785 | 2,153 |
| 50 | 3.73 | 10,043 | - | - | 3,431 | 19,656 | 23,088 |
| **Total** | **3.53** | **14,472** | **-** | **-** | **5,377** | **28,325** | **33,701** |

*Table 2.10: Total cost of rejected kegs at the leak detection machine*

| **Leak detection machine** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Content keg [L]** | **Percentage rejected kegs [%]** | **Total rejected kegs [#]** | **Cost beer loss [€]** | **Repair cost [€]** | **Operator cost [€]** | **Cost of production loss [€]** | **Total cost [€]** |
| 19.5 | 1.09 | 1,204 | 1,168 | 6,923 | 1,881 | 2,263 | 12,235 |
| 30 | 1.50 | 760 | 1,134 | 4,370 | 1,188 | 1,428 | 8,120 |
| 50 | 1.49 | 3,815 | 9,490 | 21,936 | 5,961 | 7,171 | 44,558 |
| **Total** | **1.39** | **5,779** | **11,792** | **33,229** | **9,030** | **10,862** | **64,913** |

*Table 2.11: Total cost of rejected kegs at the scale*

| **Scale** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Content keg [L]** | **Percentage rejected kegs [%]** | **Total rejected kegs [#]** | **Cost beer loss [€]** | **Repair cost [€]** | **Operator cost [€]** | **Cost of production loss [€]** | **Total cost [€]** |
| 19.5 | 3.84 | 3,851 | 86 | - | 4,011 | 7,840 | 11,937 |
| 30 | 3.00 | 956 | 120 | - | 996 | 1,946 | 3,062 |
| 50 | 4.30 | 11,353 | 1,747 | - | 11,826 | 23,112 | 36,685 |
| **Total** | **4.08** | **16,160** | **1,953** | **-** | **16,833** | **32,898** | **51,684** |

*Table 2.12: Total cost per machine*

| **Machine** | **Total Cost for week 34 until 52 of 2023 [€]** | **Yearly total cost [€]** |
|---|---|---|
| Washing and filling | 33,701 | 97,360 |
| Leak detection | 64,913 | 187,527 |
| Scale | 51,684 | 149,310 |
| **Total** | **150,299** | **434,197** |

The total cost is based on a representative dataset of weeks 34 until 52 of 2023. This dataset is extrapolated to estimate the cost of a full year. The highest cost driver is the leak detection machine with a yearly cost of €187,527, followed by the scale with €149,310. The lowest cost driver is the washing and filling machine with a yearly cost of €97,360. This results in a total estimated yearly cost of €434,197. Two factors contribute to the main part of the costs of the leak detection machine, namely the repair cost and the cost of beer loss. For the washing and filling machine and the scale the main cost driver is the operator cost and cost of production losses.

When these costs are translated into the costs per rejected keg for the various machines, the leak detection machine is the largest cost driver with €11 per rejected keg. Next is the scale, with €3 per rejected keg and lastly the washing and filling machine with €2.50 per rejected keg. From this, it follows that the rejected kegs at the leak detection machine incur the highest costs per keg.

### 2.4.3. Findings on the Costs due to Rejected Kegs of the Keg Line

In Section 2.4.1 and Section 2.4.2, a quantitative analysis of the various costs due to rejected kegs is discussed. This section further explores other findings and key issues on the keg line, based on the previously presented data, Gemba walks, and interviews with the operators. At the end of Section 2.4.4, these findings are summarized in an Ishikawa diagram. The following findings about the keg line and the costs due to rejected kegs are found:

**Leak detection machine**

- The leak detection machine checks for micro and macro-$CO_2$ leakages on the kegs. The leak detection machine will automatically reject the keg from the line when its measurement is out of bounds. Based on visual inspection of the keg line and the leak detection machine, it has been determined that the leak detection machine rejects kegs unjustified. The leak detection machine should only reject kegs that have a micro or macro leakage. However, it has been observed by the operators and the researcher that a considerable number of kegs that are rejected do not have a leakage which is visible. The exact reason for this malfunctioning is not known. This might imply that a large portion of the 1.39% rejected kegs by the leak detection machine are unjustified. Furthermore, the manufacturer of the leak detection machine considers a rejection rate of 0.5% to be normal for the machine. When the unjustified rejection is prevented, the rejection rate can be reduced significantly. Moreover, it has been found that there is minimal awareness of the maintenance needs of the leak detection machine. Over the past years preventive maintenance measures have been neglected, while corrective maintenance is only carried out in response to failures. The effects of these neglected maintenance measures on the leak detection machine are currently unknown.

- To perform a quantitative analysis on the performance of the leak detection machine, several types of data need to be available. However, the current implementation of the leak detection machine stores little to no data. The only parameters available are the number of kegs processed and how many of these kegs have been rejected. Furthermore, it has been observed that the counter for the number of processed kegs is sometimes negative, ultimately resulting in no data in the system. It would be helpful to know the $CO_2$ values of the rejected kegs to determine the correct boundaries for the measurement. The reason why kegs are rejected is not clear since the exact error code of the leak detection machine is not stored. Therefore, it is unknown how many kegs are rejected due to machine failures and which due to leakage of the kegs.

**Entire keg line**

- For analysis on the performance of the keg line the importance of solid data processing cannot be stressed enough. There seems to be gaps in the data analysis within the keg line of Grolsch. Based on the flowchart of the process seen in Figure 2.4, new kegs should not be entering on the line between the washing and filling machine, leak detection machine and scale. However, as shown in Table 2.1 and Table 2.2, there is a difference of 7,600 kegs between the washing and filling machine and the leak detection machine. The leak detection machine processed 7,600 kegs more than the washing and filling machine. The same applies to the number of accepted kegs of the leak detection machine, which proceed to the scale. The number of accepted kegs of the leak detection machine and the total kegs being processed by the scale differ by more than 15,000 kegs from each other. The number of accepted kegs of the leak detection machine is 15,392 higher than the processed kegs by the scale. Both differences cannot be explained based on Figure 2.4.

After analyzing the data further, it was found that the data about the total throughput of the machines cannot be directly compared to each other for the entire line. Since there is a mismatch when selecting weeks in the database, a discrepancy in the dataset is created. The discrepancy in the data set is due to a mismatch in total throughput. This difference in throughput is caused by not having the same starting and end point when selecting weeks. As the data per machine is accurate, this discrepancy in the dataset can be resolved by performing calculations based on percentages or by scaling to a reference throughput. By using one of these methods, it is ensured that the comparisons are consistent and accurate across the different machines. For further research, it is necessary to keep this in mind, as for making a good model, this dataset cannot be directly used without compensation. One of the consequences is that no direct conclusions on the available dataset can be drawn about the entire line, as these differences in the number of processed kegs indicate that the data storage of the different machines is not 100% reliable. The differences can influence the data where the ME and FE of the line are based on, as it may indicate possible inconsistencies in the data collection. This can have as a consequence that reliability analysis is biased and can make effective decision making on the production data hard.

- The rejects handling at the washing and filling machine is an important factor for the overall efficiency of the line. The kegs that are rejected by the washing and filling machine are not directly rejected from the keg line. The rejected kegs are processed by the full keg turner and the leak detection machine before they are rejected at the scale. The leak detection machine cannot detect a leak on these rejected kegs because these kegs are empty. The reason being that the leak detection machine only looks at the difference in $CO_2$ measurement, which is only detectable when there is beer inside the keg. Therefore, this is at the expense of higher production cost and lower efficiency since the full keg turner and the leak detection machine needs to handle approximately 14,500 extra kegs, according to the dataset of weeks 34 until 52 of 2023. These extra kegs use additional resources and time from the machines before the kegs are rejected and introduce an extra risk of wear and damage within the machinery.

- The kegs that are rejected in the keg line at the various machines can have different causes. Some causes can be resolved while other rejected kegs cannot be reduced and will always be present. Therefore, the rejected kegs from the various machines can be divided into justified and unjustified rejections. The keg line will always have rejected kegs because the kegs return from the market and are re-used.

  The leak detection machine detects whether a keg is leaking or not. If a keg is rejected by the leak detection machine, and the keg is actually leaking, this means that the keg is a justified rejection. However, if a keg is rejected and not leaking, this means that this keg has been rejected incorrectly and unjustified. The rejected kegs from the leak detection machine can be detected as leak due to several reasons. This can be due to kegs that return damaged from the market, a problem that has occurred in the washing and filling machine causing the keg to leak, or incorrect measurement of the leak detection machine. The first two reasons are the main reasons why the leak detection machine is in place. The last reason is resolved by ensuring that the machine works properly.

Where kegs are rejected in the keg line is not always due to the machine itself where the kegs are rejected. The rejected kegs from the washing and filling machine and the scale are interconnected. The kegs that are rejected from head 1&2, and 3&4 at the washing and filling machine with the F10 procedure are checked and then proceed to the scale. The rest of the heads do not have an F10 procedure, and these kegs automatically proceed to the scale. The scale will reject empty, underfilled, and overfilled kegs, where some of these empty kegs were already rejected at the washing and filling machine. The scale therefore itself is not the problem, because it does not cause a root cause of the error that causes the kegs to be rejected from the keg line. To address the rejection rate from the scale, the washing and filling machine should be examined. In Appendix B an overview is shown of the common errors detected by the washing and filling machine. The three most common errors are seal failures with 49% of the rejected kegs at the washing and filling machine, steam to temperature failure with 14%, and the pressure switch failed ON with 6.4%. The rest of the errors are below 5%. The cause of seal failures is mainly because a keg is not correctly positioned in the washing and filling machine or there is a problem with closing off the head of the keg, which means that the system is not closed properly to check the head of the keg. This is an error caused by the position of the kegs or the machinery itself, which results in these kegs are rejected unjustified. Steam to temperature failure occurs because before sterilization, the keg is blown through with steam, when the steam temperature is not reached within a set time, the washing and filling machine rejects these kegs. The cause for this problem lies within the boiler that generates the steam for sterilizing the kegs. The rejection of these kegs is unjustified since the root cause lies in the machinery. Finally, the pressure switch failed ON, this error is machine related, which means that the pressure switch is not turned on at the right time. This can have several causes and depends on the machinery. These rejections are unjustified since the root cause lies in the machinery. In conclusion, for the washing and filling machine, the steam to temperature failure and pressure switch failed ON errors can be errors where kegs are rejected unjustified and can be prevented. For the leak detection machine, the kegs that are rejected due to incorrect measurement of the leak detection machine are rejected unjustified and can be prevented.

There are unjustified rejections at the washing and filling machine and the leak detection machine. These unjustified rejections influences the rejection rate and therefore the four different types of costs associated with rejected kegs. When the rejection rate is reduced, these costs will also decrease. Because the kegs return from the market and the keg deteriorate by keg handling and transport, there are always justified rejections. Therefore, the four different types of costs will always be present. However, when there are only justified rejections, these costs are kept to a minimum.

- In terms of costs, Table 2.9, Table 2.10, and Table 2.11 show that the rejection rate of the leak detection machine is much lower compared to the rejection rate of the scale. However, the introduced costs by the rejected kegs at the leak detection machine are higher than the costs associated with the rejected kegs at the washing and filling machine and the scale. Although the operator's cost and cost of production loss is much higher for the washing and filling machine and the scale, beer loss and repair costs result in higher costs by the leak detection machine and ultimately results in the highest cost.

### 2.4.4. Quality

Asahi works with a list of Asahi quality standards, also called Asahi Group Production Risk Management (AGPRM). The goal of the implementation of the standards is to prevent quality and food safety incidents and whenever there is not complied with the quality standards, a production stop can be enforced. Within the quality standards list, different priorities of the standards are used. The subdivision is as follows: MR (minimal requirements), GR (general requirements), and BP (best practice), where the MR are the highest priority quality standards. After an internal audit in 2023, Grolsch received a notice that there is insufficient quality control of the kegs before they are filled. This notification has been converted into an AGPRM project, to ensure that this quality control is pursued. This AGPRM project is labeled as MR, which means that this project is of minimal requirement for Grolsch, and the internal deadline is set to the end of 2024.

The reason for the insufficient quality control before the kegs are filled, is that there is no residual pressure check in the keg line. The quality standards of Asahi prescribe that every keg returning from the market should undergo a residual pressure check before being refilled. The purpose of this residual pressure check is to check whether returning kegs still have residual pressure. This check is intended to prevent the risk of deliberately manipulated kegs or leaking kegs being refilled with beer.

On the washing and filling machine there is a residual pressure check available, in head 1&2, however Grolsch has this function disabled. The reason why the check is disabled, is because Grolsch does find this check inefficient, and is at the expense of the filling process of the kegs as it causes extra production losses. As a result, leaking kegs are currently being filled with beer. By not checking the quality of the kegs before the filling process, it has an impact on beer loss, production losses and operator cost.

The consequences for switching the residual pressure check on are not clear and therefore the extent of the consequences are not clear. There are two options for Grolsch for implementing the residual pressure check. The first option is to switch on the current residual pressure check in the washing and filling machine. The second option is to purchase an external residual pressure measuring machine and install it in the keg line. Since there is limited data available for either option, it is unknown what the preferred option is.

In Figure 2.8 an Ishikawa diagram is shown based on the findings in Section 2.4 on the current situation. The Ishikawa diagram organizes and visualizes possible causes of the suboptimal performance of the keg line, showing the relationships between these causes and the effect.

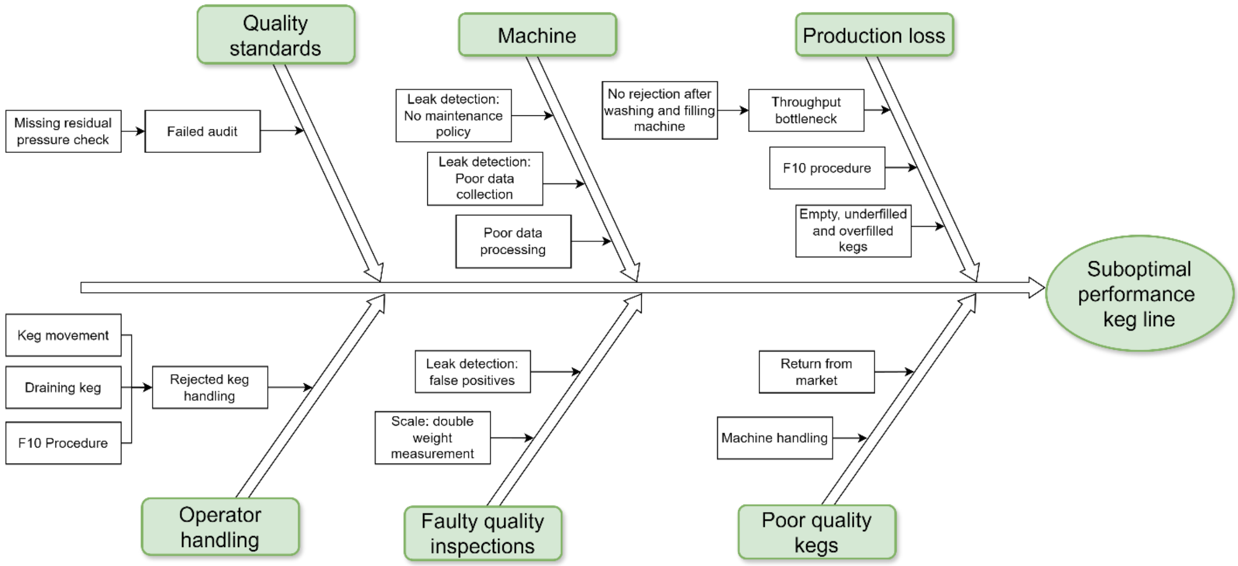


*Figure 2.8: Ishikawa diagram of findings*

## 2.5. Conclusion

In this chapter, the current process and costs due to the rejected kegs in the keg line are evaluated. The focus of this research is on reducing the costs due to rejected kegs, which improves the performance of the keg line. From the analysis, it is concluded that the rejection rate within the keg line are caused by the washing and filling machine, leak detection machine and scale. The main portion of the costs due to the rejected kegs in the keg line within the weeks 34 until 52 of 2023 are caused by the leak detection machine. During these weeks, the washing and filling machine resulted in a percentage of rejected kegs of 3.53%, the leak detection machine in 1.39%, and the scale in 4.08%. The total associated costs are €150,299 for all machines. This is divided into €33,701 for the washing and filling machine, €64,913 for the leak detection machine, and €51,684 for the scale. These costs due to rejected kegs are due to repair cost, operator cost, cost of beer loss, and cost of production losses. All the rejected kegs at the leak detection machine also causes loss of beer since the rejected kegs are all full. This is in contrast to the washing and filling machine and scale, where most of the rejected kegs are empty. However, the cost of production losses is higher for the washing and filling machine and scale, compared to the cost of production losses for the leak detection machine. Nevertheless, this has led to the cost of rejected kegs for the leak detection machine being higher than the cost from the washing and filling machine and the scale.

From the process and performance analysis it is determined that for the leak detection machine, the kegs that are rejected due to incorrect measurement can be influenced and reduced. The leak detection machine also does little to no data storage, which makes it difficult to perform a quantitative analysis on the performance of the leak detection machine. For the entire keg line, it has become clear that there seems to be a gap in the data. It was determined that there is a mismatch when selecting weeks in the database, creating a discrepancy in the throughput in the dataset. This difference in throughput is caused by not having the same starting and end point when selecting weeks. Therefore, the data for the different machines cannot be compared to each other for the entire line. Furthermore, the keg line does not handle rejected kegs optimally, which results in the use of additional resources and time from the machines. Lastly, there is a difference between the justified and unjustified rejected kegs of the keg line. For the washing and filling machine, the steam to temperature failure and pressure switch failed ON could be influenced to be reduced.

Within this research the focus is on two different aspects. The first aspect is the introduction of the residual pressure check as this is a minimum quality requirement for Grolsch and must be introduced as quickly as possible and before the end of 2024. The problem and consequences for introducing the residual pressure check are further analyzed. The second aspect is the reduction of the rejection rate of the leak detection machine. The main contributing factor is the high rejection cost per keg for the leak detection machine. This is because the leak detection machine causes high costs in beer loss and repair costs and most improvement can be obtained by fine tuning this machine as it rejects kegs unjustified. The rejected kegs at the washing and filling machine result in higher operator costs. However, since it is the operator’s responsibility to manage the rejected kegs, improving the rejection rate of the washing and filling machine will have less impact.

A literature review is conducted to find methods to provide a deeper insight into the different costs related to quality. With the found method we analyzed the costs within Grolsch on a deeper level. The different scenarios for the residual pressure check have an impact on the costs within Grolsch. A framework to perform a comparison based on the impact is searched for within literature. For the leak detection machine, it is found that there is no maintenance strategy available within Grolsch. A literature study is performed to determine the impact of maintenance on the quality of the product. To advise on a suitable maintenance strategy for Grolsch, several different strategies are analyzed.

# 3. Literature Review

This chapter gives an overview of relevant literature for this thesis. Section 3.1 gives a description of quality control. Section 3.2 elaborates on the Cost of Quality methodology within quality control, which provides insights into the costs incurred with quality. Section 3.3 discusses the relationships between quality and maintenance, and finally Section 3.4 concludes this chapter.

## 3.1. Quality Control

Judi et al. (2011) define quality as meeting the required standards or requirements of customers with no defects. Products are deemed high-quality when they function correctly and reliably (Judi et al., 2011). Quality Control are the activities and frameworks used by organizations to ensure the products consistently meet the standards and expectations of internal and external customers. Within the quality control system, focus is placed on the knowledge and skills of the employees and the transformation capacity of the machines (Van Der Bij & Van Ekert, 1999). Quality control within the F&B industry ensures, for example, that the food and beverages are safe and of high quality, and that none of the ingredients are contaminated. This involves controlling the processes, including checking for leaks and inspecting packaging (Aadil et al., 2019). Therefore, an important part of quality control is setting up clear control points or inspection points within the production process (Varghese et al., 2022). TQM is a comprehensive approach that involves all employees of an organization in improving processes, products, and culture to achieve long-term success through continuous improvement and customer satisfaction (Riley & Juran, 1999).

## 3.2. Cost of Quality

Cost of Quality (CoQ) is a methodology within quality control that provides insights into the costs incurred with quality, but also costs associated with products that do not achieve the desired quality. Manufacturing companies often lack a realistic idea of the actual amount of profit lost due to poor quality products (Schiffauerova & Thomson, 2006). Tracking the cost of poor quality has three main reasons. The first reason is to measure the size of the problem to support the need for improvement. Secondly, it is to guide the improvement of that effort. Lastly, it is to monitor the results of the improvement initiatives (Riley & Juran, 1999). The importance of CoQ in assisting manufacturing companies to improve continuously has been well studied and highlighted in the literature (Al-Dujaili, 2013; Omachonu et al., 2004). However, in the F&B industry, CoQ has not received much attention (Chatzipetrou & Moschidis, 2017). CoQ can help organizations to guide the trade-offs that need to be made between improving quality and lowering the costs (Farooq et al., 2017). The CoQ costs are divided into four different quality costs, which are Prevention, Appraisal, Internal and External Failure costs. Each cost type has different kinds of costs that belong to the four different categories. The first two categories are costs related to control costs (costs of conformance), while the internal and external failure costs come from failures (costs of non-conformance). Prevention costs are proactive costs, aimed at preventing defects from occurring in the first place, while appraisal costs are reactive costs, focused on identifying defects through inspection and testing. Both these costs are investments in maintaining high quality and reducing the likelihood of defects. The internal failure costs are associated with poor-quality products in the production line before they are delivered to the customer, whereas external failure costs are associated with products that are found to be unsatisfactory after they have been delivered to the customer (Gupta, 1995). An important effect of quality improvement is reducing the internal and external failure costs (Mitra, 2016).

Figure 3.1 shows the relationship between the CoQ and quality improvement efforts. It stresses the importance of using CoQ information to support and drive quality improvement activities. The identification process of CoQ, shown in the dotted line in Figure 3.1 outlines the process for identifying, analyzing, and using this data to improve quality. First it is determined what CoQ means within the manufacturing organization, whereafter the data related to the costs is gathered. Lastly, this data is used to motivate and prioritize quality improvement projects and activities. This includes identifying high-impact areas where improvements can lead to significant cost savings (Riley & Juran, 1999). Figure

3.1 emphasizes a structured approach to quality improvement: by establishing the need for improvement, the process for improvement that will yield the highest cost savings and quality gains can be selected, and lastly will identify and prioritize improvement opportunities. It demonstrates how manufacturing organizations can systematically reduce costs associated with poor quality but also improve customer satisfaction and operational efficiency (Riley & Juran, 1999).

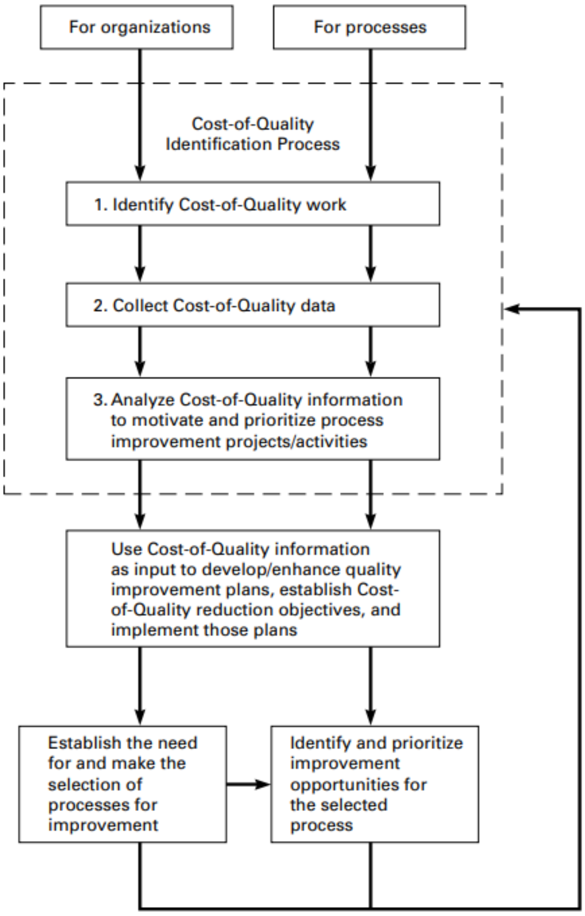


*Figure 3.1: CoQ and quality improvement framework (Riley & Juran, 1999)*

The CoQ approach provides a method to balance two competing objectives, which are achieving high-quality while minimizing expenses. By assigning costs to quality, this approach integrates these goals into a single objective of reducing overall quality-related costs. It simplifies decision-making when comparing different production processes and inspection strategies. The CoQ definition varies by organization and should be customized for each organization. Furthermore, being consistent is more important than debating which cost elements should be included and how they should be categorized (Schiffauerova & Thomson, 2006).

Figure 3.2 shows the quality of conformance, where the relationship between the conformance costs and non-conformance costs is shown, as well as how these relate to the total CoQ. Low conformance costs mean that if little investment is made in quality control, the costs of defective products will be high. Whereas, with a lot of investment in quality control, the defects and therefore non-conformance costs are low. The Economic Quality Level (EQL) is the point where the total costs of quality (conformance and non-conformance) are minimal. Here is the optimal balance between investment in quality control and the cost of defects. In the quality of conformance, the trade-offs are visualized by comparing the costs and benefits of different options for rejected products. The goal is to find the EQL where the total CoQ is minimal, thus choosing the most cost-effective approach to quality assurance and defect handling (Farooq et al., 2017).

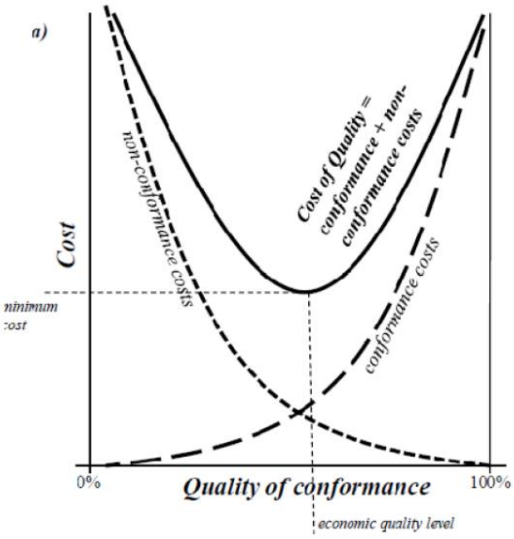


*Figure 3.2: Trade-off conformance and non-conformance costs (Farooq et al., 2017)*

## 3.3. Quality and Maintenance

In manufacturing, it is essential that the production processes run smoothly, and high-quality products are produced. Maintenance has a direct impact on the quality of a product and therefore also directly on the rejection rate and profitability of the production line. When there is no predictive or condition-based maintenance carried out, the quality of the product and equipment will decrease due to the deterioration process, which results in an increase in defective or near defective products (Ben-Daya & Duffuaa, 1995). This deterioration process is due to the wear and tear of the production machinery. Maintenance is therefore seen as a manner to prevent abnormal conditions or prevent restoration from producing quality failures (Kurniati et al., 2015). Kurniati et al. (2015) claim that the incorporation of both quality and equipment maintenance is therefore crucial.

The TQM philosophy suggests including also quality inspections along the production line rather than the final inspection only (Kurniati et al., 2015). This change maintains quality inspection as a crucial part of quality assurance and will eliminate defects at their source (Ben-Daya & Duffuaa, 1995). By conducting quality inspections, quality control can achieve its objectives. Quality inspections play an important role in a production line to obtain information about the demonstrated product quality (Kurniati et al., 2015). The main goal of quality inspections is to find products that do not meet the preset boundaries. Products that do not comply will be discarded or reworked. By investing in quality inspection, companies can avoid shipping defective products to the market and ensure their products meet customer expectations (Lopes, 2018).

When there is no maintenance done on the whole production line, including the quality inspection, faulty products can enter the market. Aging and deterioration of the quality inspection machine has a negative impact on the quality of the product. The rejection rate of a quality inspection machine provides adequate feedback on the state of the production line when monitored and can serve as an indicator of the deterioration process (Kurniati et al., 2015). The consequence of no maintenance on quality inspection machines is that good products are falsely rejected, and faulty products are not detected. There is a tradeoff between maintenance costs and production losses (Lopes, 2018).

By applying an appropriate maintenance policy, equipment that has deteriorated can be brought back to operational condition, which can lead to improvements in process capability and ensures that product quality will meet customer requirements (Kurniati et al., 2015). In the F&B industry, four main types of maintenance strategies are often used, which are divided into Reactive Maintenance (RM) and proactive maintenance (Uzoigwe, 2024). RM or also called Corrective Maintenance (CM) is a maintenance strategy where maintenance is performed when the equipment has broken down

(Gackowiec, 2019). Although this strategy seems straightforward, there are possible disadvantages to consider. When CM is carried out, this results in unplanned downtime, higher repair costs, safety risks and reduced lifespan. Therefore, it is important to opt for CM when the situation requires this. CM is suitable in situations where costs are low and when machines are not critical, backup machines are available, and there is an unpredictable failure pattern. Furthermore, CM presents additional challenges for the F&B industry. Strict regulations require reliable equipment to safeguard the hygiene of the products, fast-paced production increases the breakdown risks, and downtime with perishable products leads to spoilage and financial losses (Uzoigwe, 2024).

In comparison with RM, proactive maintenance is intended to prevent failures and repairs (Gackowiec, 2019). Proactive maintenance can be divided into Preventive Maintenance (PM), Predictive Maintenance (PdM), and prescriptive maintenance. PM is a maintenance strategy where maintenance is scheduled based on a time-interval and performed to prevent failures from occurring. The maintenance tasks are performed during machine stoppages or shutdowns. PM is typically used for critical equipment, improving reliability and reducing downtime, but it is costly due to the time and resource investment required. Within the F&B industry, the advantages of PM include less downtime and production loss, improved product quality, increased food safety, reduced maintenance costs, and longer equipment life. By implementing a solid PM strategy, the F&B manufacturers boost their efficiency, maintain food safety, and achieve long-term success (Uzoigwe, 2024).

PdM is an advancement of PM and is a type of maintenance that uses data analytics to anticipate when equipment will fail (Basri et al., 2017). PdM improves reliability and reduces downtime by performing maintenance when necessary and potentially lowering costs compared to PM. However, PdM demands substantial investment in technology for the data collection and analysis. The F&B industry can benefit from PdM by less downtime, improved product quality and safety, reduced maintenance costs, and increased profitability (Uzoigwe, 2024). Although the objectives of PM and PdM are similar, PM is normally carried out when a machine is stopped, while with PdM maintenance is carried out when a machine is still operating (Basri et al., 2017).

Prescriptive maintenance is an advanced type of maintenance strategy, which carries out maintenance by using data analytics and artificial intelligence (AI) to anticipate equipment failures and suggest precise preventive measures. While PdM already demand substantial investment in technology for data collection, this is even bigger for prescriptive maintenance. Advantages of prescriptive maintenance in F&B industry include less downtime and production loss, better equipment reliability and longer lifespan, improved product quality and safety, and lower maintenance costs (Uzoigwe, 2024).

While the benefits of PM, PdM, and prescriptive maintenance are very similar. Introducing these types of maintenance strategies brings several diverse challenges for manufacturers. Therefore, based on the circumstances and demands of the specific manufacturer, the best strategy can be selected.

## 3.4. Conclusion

Quality can be defined as meeting the standards and requirements of customers without any defects. One framework which can be used to assure this is Quality Control. A methodology based on Quality Control is CoQ. This methodology focuses on the cost associated with products quality. The costs associated with quality are divided into two categories, namely conformance and non-conformance cost. The point where the optimal balance between the two categories of costs is reached is called the EQL. In Section 2.4.2 the costs of the rejected kegs at the keg line of Grolsch are discussed. These are linked to the internal failure costs of the CoQ methodology, as these costs are associated with the rejected products. This research focuses therefore mainly on the internal failure costs. In Chapter 5, the CoQ is used to compare different residual pressure check implementation scenarios based on the quality of conformance. To prevent non-conforming products from entering the market, quality inspection is of major importance. During the quality inspection the product is compared to preset boundaries, which ensures that the products meet the expectations of the customers. However, quality inspection and production machines are deteriorating over time. To prevent the negative consequences of this deteriorating process, an appropriate maintenance policy should be selected. The maintenance policies can be divided into reactive and proactive policies. Within Grolsch, there is currently only reactive maintenance done for the leak detection machine and no proactive maintenance. In Chapter 6, a maintenance strategy for Grolsch is advised for the leak detection machine.

# 4. Methodology

In this chapter, the approach for introducing the residual pressure check and the reduction of the unjustified rejection rate of the leak detection machine is described. Section 4.1 describes the different scenarios developed for the implementation of the quality inspection point of the residual pressure check in the current process of the keg line, and how these different scenarios are analyzed. Section 4.2 describes the approach on how to reduce the unjustified rejections of the leak detection machine.

## 4.1. Residual Pressure Check

### 4.1.1. Scenario description

To comply with the standards from Asahi, a residual pressure check needs to be implemented. Within this research, four different implementation scenarios are considered. Two of those scenarios are referred to as the internal scenario and are based on an introduction of the residual pressure check in the current washing and filling machine. For the other two scenarios, referred to as the external scenarios, a dedicated residual pressure check machine is introduced. The scenarios are as follows:

1. **Internal scenario**
   1.1. **Internal scenario**, where the rejected kegs are handled at the washing and filling machine.
   1.2. **Internal scenario**, where the rejected kegs are handled at the scale.
2. **External scenario**
   2.1. **External scenario**, kegs are rechecked by an operator.
   2.2. **External scenario**, kegs are rechecked by the residual pressure check machine.

To provide more insights into why these four scenarios are considered, the implementation of the residual pressure check for the internal and external machine is first discussed. The general handling process of the rejected kegs and the four different scenarios are discussed hereafter. The method for determining the impact of these scenarios compared to the current situation is discussed afterwards through an impact and sensitivity analysis.

**Implementation of the internal scenario**

The current washing and filling machine has the option to switch on the residual pressure check on heads 1 and 2 of each lane. Activating the residual pressure check in the washing and filling machine is straightforward and can be achieved by enabling the feature in the machine. The process of checking the residual pressure of the kegs is as follows: kegs arrive at head 1 or 2 in the washing and filling machine, here kegs are connected to the system and a spear will go into the keg to measure the residual pressure inside the keg. Based on a fixed setpoint, the pressure gauge will check if the pressure of the keg is above or below this setpoint. If the pressure of the keg is below the setpoint, the keg is rejected; if above, it is accepted and it proceeds to the next steps.

These rejected kegs need to be handled separately from the other rejected kegs at the washing and filling machine. Therefore, a new procedure should be set up. The rejected kegs by the residual pressure check cannot return to the keg line directly, while this is the normal procedure for the other rejected kegs. Since the rejected kegs need to be handled manually after the washing and filling machine, the waiting time until an operator is available introduces extra downtime of the machine. The main difference between the two internal scenarios is where the kegs are handled. For scenario 1.1, the kegs are handled directly after the washing and filling machine. For scenario 1.2, the kegs will follow the normal procedure and are rejected by the scale.

**Implementation of the external scenario**

A new residual pressure check machine is a dedicated machine that only checks the residual pressures of the kegs. How the residual pressures are checked by the machine will be similar to the process at heads 1 and 2 of the washing and filling machine. However, because this is a new machine, it is likely that the setpoint will be adjustable. This new machine needs to be introduced into the keg line before the washing and filling machine, as the residual pressure needs to be checked before the filling process. Possible locations for this new machine is before or after the exterior cleaner. However, since a spear must enter the keg during the residual pressure check, it is better to clean the keg first to prevent contamination that could interfere with the process. Therefore, the best choice is to introduce the residual pressure check after the exterior cleaner. The main difference for the external scenarios is who will check the kegs after being repressurized. For scenario 2.1, the kegs are manually checked by an operator. For scenario 2.2, the kegs are automatically checked by the residual pressure check machine.

**Detailed scenarios**

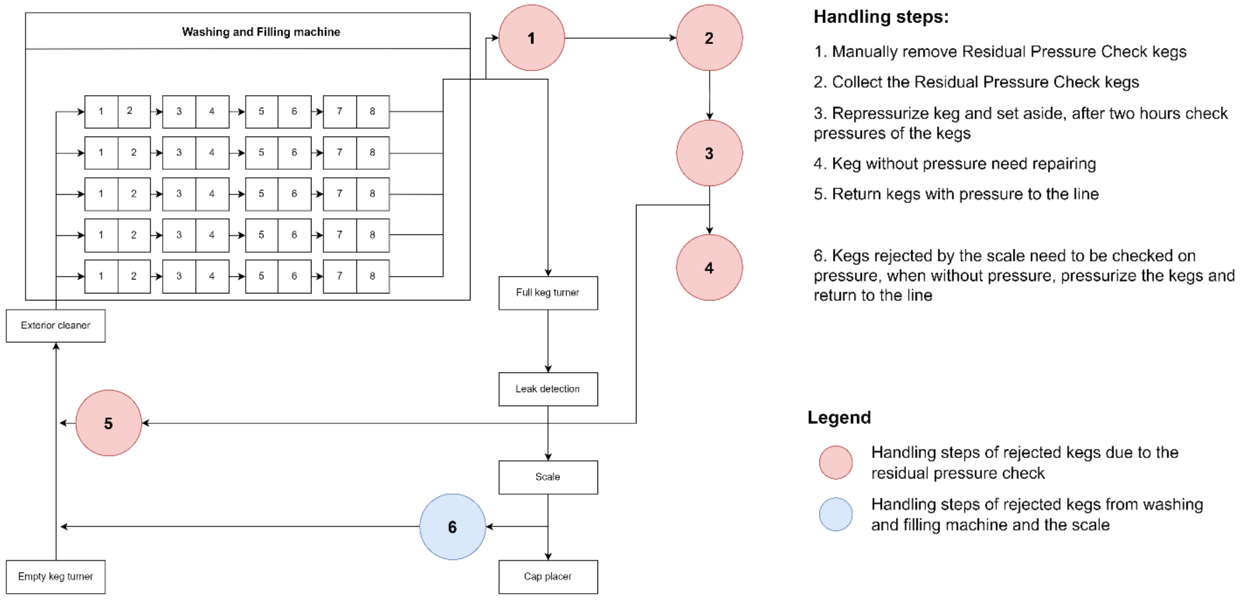
At other breweries within the Asahi group, where the residual pressure check is implemented, the experience is that a large portion of kegs rejected by the residual pressure check are not manipulated or leaking. As a result, additional tests are implemented in both the internal and external scenario to see which rejected kegs are manipulated or leaking. These additional tests are based on the implementation of other breweries and consist of a step where the operator repressurizes the rejected kegs. After a two-hour period, the kegs are checked again by the residual pressure check or by an operator with a manual pressure gauge. Kegs with pressure above the setpoint can return to the keg line and kegs with no residual pressure must be repaired. This results in that if no additional steps are taken, a lot of rejected kegs are rejected unjustified, which causes high repair costs.

These additional steps necessary to implement the residual pressure check into the keg line result in extra needed resources. First, operators need to handle these extra rejected kegs, resulting in additional time and effort required. Furthermore, the available space is important since the rejected kegs need to be stored and handled at the storage location. A manual pressure gauge should be available for the operators at the storage location. The rejected kegs that should return to the keg line need to be transported back to the line, which ensures that routes should be available for the operators to pass through.

Lastly, the kegs that are rejected at the scale should be handled differently than usual for the internal scenario. Some kegs that are rejected at the scale are without pressure and therefore, these kegs cannot return directly to the keg line. Otherwise, these kegs are straight away rejected at the residual pressure check. Therefore, the pressure of these rejected kegs should be checked, and when the pressure is below the setpoint, the kegs should be pressurized and afterwards returned to the keg line.

### Sub-scenario 1.1: Internal scenario, where the rejected kegs are handled at the washing and filling machine

The process and the steps necessary to implement the first internal scenario, where the residual pressure check is implemented in the washing and filling machine, are shown in Figure 4.1. In Figure 4.1 the red colors indicate the handling steps of the rejected kegs due to the residual pressure check. The blue color indicates the handling step for the other rejected kegs from the washing and filling machine and scale. The rejected kegs by the residual pressure check are manually removed from the keg line directly after the washing and filling machine and lifted from the conveyor belt by an operator at step 1. These kegs are collected on a pallet, pressurized and checked. The normal procedure is to reject the kegs from the washing and filling machine at the scale. However, for this scenario the choice has been made to remove the rejected kegs from the residual pressure check straight away at the washing and filling machine. This is due to the space available at the washing and filling machine and because it minimizes the wear and tear of the machines after the washing and filling machine. When the kegs are rejected again after the second check, they are transported to the warehouse at step 4. When it is found that the keg is not manipulated or leaking, the keg will be transported to the input of the exterior cleaner machine at step 5. This handling action implies that the operators need to cross the keg line and need dedicated routes. The transport of these kegs will take a significant amount of time. In step 6, the other rejected kegs by the washing and filling machine and the scale are checked, repressurized and return to the keg line.



**Handling steps:**

1. Manually remove Residual Pressure Check kegs
2. Collect the Residual Pressure Check kegs
3. Repressurize keg and set aside, after two hours check pressures of the kegs
4. Keg without pressure need repairing
5. Return kegs with pressure to the line
6. Kegs rejected by the scale need to be checked on pressure, when without pressure, pressurize the kegs and return to the line

**Legend**

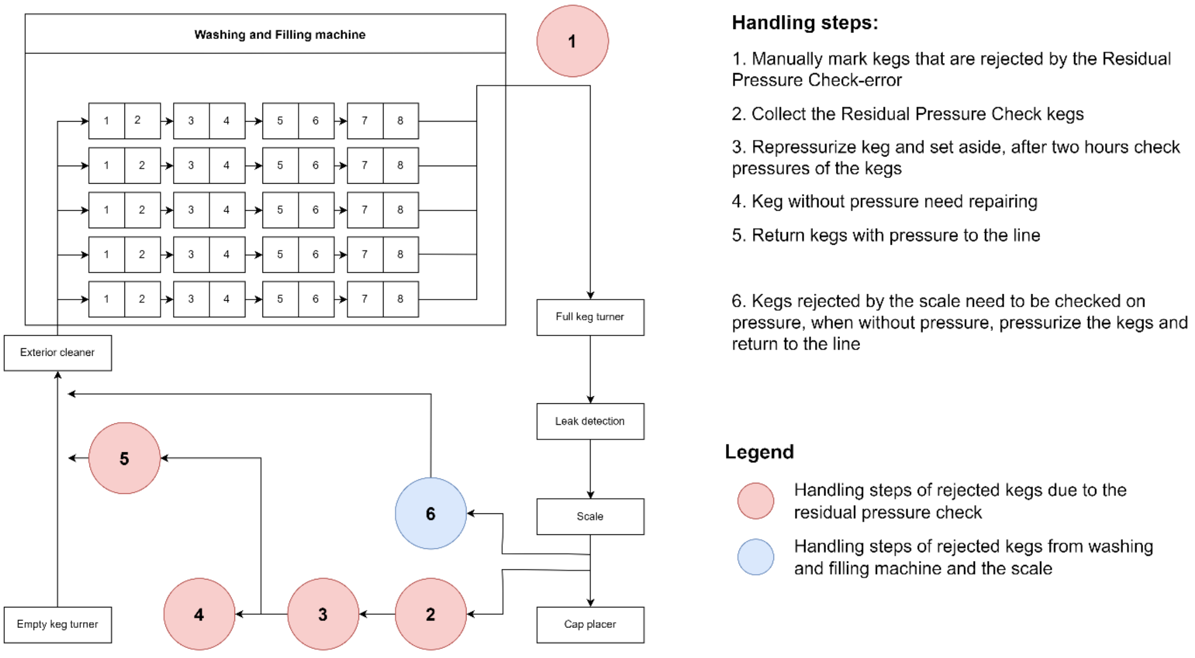
🔴 Handling steps of rejected kegs due to the residual pressure check

🔵 Handling steps of rejected kegs from washing and filling machine and the scale

*Figure 4.1: Internal scenario, rejection at the washing and filling machine*

### Sub-scenario 1.2: Internal scenario, where the rejected kegs are handled at the scale

Figure 4.2 shows the process and the steps necessary to implement the second internal scenario. The rejected kegs by the residual pressure check are manually marked directly after the washing and filling machine at step 1. Hereafter the rejected kegs continue to the scale, where these rejected kegs are automatically rejected. Apart from marking the kegs, this procedure is comparable to the normal procedure for the rejected kegs from the washing and filling machine. It was decided to reject the kegs at the scale from the residual pressure check here as well, since there is space for the rejected kegs and the handling of the other rejected kegs also takes place here. The handling steps 2 until 6 are the same as for the other internal scenario, where the kegs are collected, pressurized and checked. The main difference is the transport distance for step 5. The transporting distance for the kegs that re-enter the keg line is shorter since the scale is nearby the exterior cleaner. Furthermore, the rejected kegs at step 4 in Figure 4.2 must now be transported across the keg line, as these kegs needs to be repaired and be removed from inside the keg line.



**Handling steps:**

1. Manually mark kegs that are rejected by the Residual Pressure Check-error
2. Collect the Residual Pressure Check kegs
3. Repressurize keg and set aside, after two hours check pressures of the kegs
4. Keg without pressure need repairing
5. Return kegs with pressure to the line
6. Kegs rejected by the scale need to be checked on pressure, when without pressure, pressurize the kegs and return to the line

**Legend**

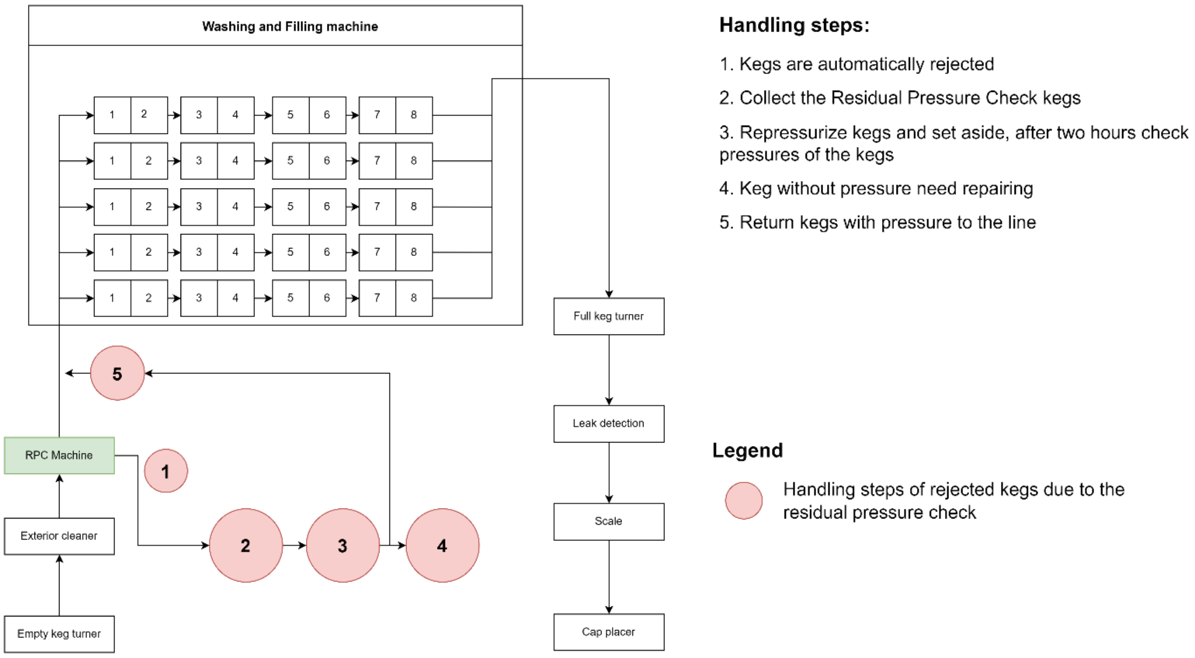
🔴 Handling steps of rejected kegs due to the residual pressure check

🔵 Handling steps of rejected kegs from washing and filling machine and the scale

*Figure 4.2: Internal scenario, rejection at the scale*

### Sub-scenario 2.1: External scenario, kegs are rechecked by an operator

The process and the steps necessary to implement the first external scenario, where a new residual pressure check machine is implemented, are shown in Figure 4.3. The rejected kegs by the residual pressure check are automatically rejected at step 1 and thereafter handled manually by the operators. The handling steps 2 until 5 are the same as for the internal scenarios, where the kegs are collected, pressurized and checked. The non-leaking kegs are placed back manually after the residual pressure check machine in the keg line at step 5. The transporting distance for the kegs to re-enter the keg line is short, since handling the kegs is nearby the conveyer belt. Only the kegs that need to be repaired must be transported across the keg line and removed from inside the keg line.



**Handling steps:**

1. Kegs are automatically rejected
2. Collect the Residual Pressure Check kegs
3. Repressurize kegs and set aside, after two hours check pressures of the kegs
4. Keg without pressure need repairing
5. Return kegs with pressure to the line

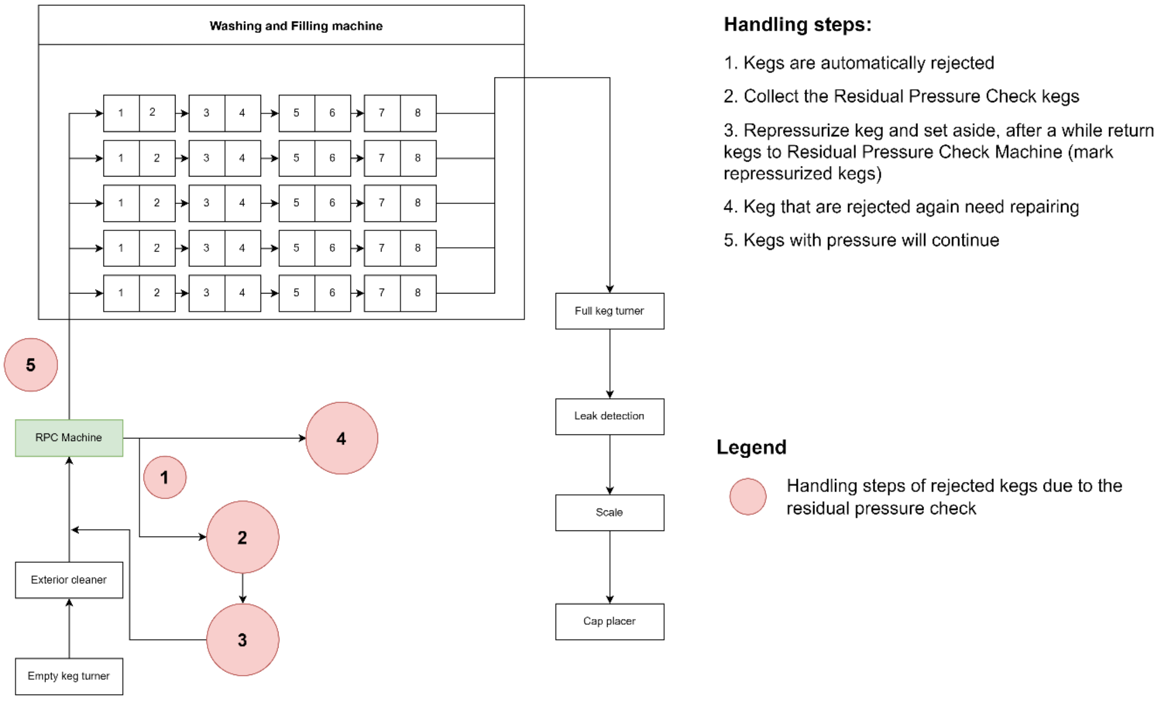
**Legend**

● Handling steps of rejected kegs due to the residual pressure check

*Figure 4.3: External scenario, kegs are rechecked by an operator*

### Sub-scenario 2.2: External scenario, kegs are rechecked by the residual pressure check machine

Figure 4.4 shows the process and the steps necessary to implement the second external scenario. The rejected kegs by the residual pressure check are automatically rejected at step 1. Hereafter, the kegs are collected at step 2 and pressurized, marked and returned to the residual pressure check machine at step 3. The kegs are then rechecked by the residual pressure check machine. Kegs that are without pressure are rejected again by the residual pressure check machine, and when the keg is marked, it means that this keg is rejected a second time and must be sent for repair in step 4. Only the kegs that need to be repaired must be transported across the keg line and removed from inside the keg line.



**Handling steps:**

1. Kegs are automatically rejected
2. Collect the Residual Pressure Check kegs
3. Repressurize keg and set aside, after a while return kegs to Residual Pressure Check Machine (mark repressurized kegs)
4. Keg that are rejected again need repairing
5. Kegs with pressure will continue

**Legend**

Handling steps of rejected kegs due to the residual pressure check

*Figure 4.4: External scenario, kegs are rechecked by the residual pressure check machine*

### 4.1.2. Impact and Sensitivity Analyses

**Impact analysis**

The four different scenarios have an impact on conformance and non-conformance costs, and thereby impact on the KPIs throughput, production costs, and quality. During this impact analysis, we investigate whether costs are introduced or prevented in different scenarios compared to the current situation, where no residual pressure check is implemented. The impact of the different scenarios are analyzed in Chapter 5. More background information regarding the rejection rate is needed to be able to determine the impact of the scenarios. To provide insights into the rejection rate of the residual pressure check, tests are conducted with the residual pressure check enabled in the current washing and filling machine. During these tests the total throughput and the number of rejected kegs by the residual pressure check are monitored. Based on these tests the expected rejection rates are obtained. The rejection rate will vary over time, therefore a range in rejection rate is considered. This range is based on variations in rejection rates for other errors in the washing and filling machine based on the dataset from weeks 34 until 52 of 2023. This change in errors is assumed to be representative of the expected change in average rejection rate of the residual pressure check. With this range in rejection rate, a change in costs is estimated for each scenario. The same setpoint and rejection rate for the internal and external scenarios is used to make a comparison based on the same conditions. Several non-conformance costs like the costs of beer loss and repair costs are the same for all the scenarios. The other conformance and non-conformance costs based on the range of rejection rates are described per scenario.

**Sensitivity analysis on operator costs**

After the impact of the scenarios compared to the current situation is known, a sensitivity analysis on operator costs is performed for each scenario. The baseline of this sensitivity analysis is the current situation within Grolsch based on the typical rejection rate. Due to the lack of exact data, the sensitivity analysis is performed based on assumptions. For the scenarios, the parameter which can be varied by external influences is the qualification level of the operators and therefore the hourly operator costs. The other parameters like beer loss and repair costs are a direct result of the number of rejected kegs. Therefore, the hourly operator cost is used in the sensitivity analysis to determine its impact on the annual cost of the proposed scenarios and to identify potential risks and opportunities. Based on the qualification of the operators, several handling actions are improved or decreased. The speed and efficiency with which operators work will have a direct impact on the production losses by an increase or decrease in downtime of the washing and filling machine for the internal scenarios. At a higher qualification level of the operator, the assumption is made that an error or fault situation is earlier detected, and it will take less time to resolve this situation resulting in less downtime. The total time it takes to repressurize kegs and check their pressure cannot be made more efficient since they are depending on machines or tooling used. The total repair costs and costs due to beer loss will not vary due to a change in operator costs, since they are solely based on the amount of rejected kegs. By varying the operator cost, it is determined if the current hourly operator cost is indeed the most beneficial situation for the total cost due to rejected kegs.

**Sensitivity analysis on the justified versus unjustified rejection ratio**
Based on the insights gained in the impact analysis, a typical rejection rate is established for the residual pressure check. Based on experience of other breweries within the Asahi group, a large portion of the kegs rejected by the residual pressure check are not manipulated or leaking. As a result, the residual pressure check rejects kegs justified and unjustified. Due to the lack of exact data about the ratio of justified and unjustified rejected kegs, a sensitivity analysis is performed. The aim of this sensitivity analysis is to evaluate the scenarios related to additional costs in relation to the justified versus unjustified ratio. By adjusting the setpoint of the residual pressure check, it is assumed that the ratio between the justified and unjustified rejection can be influenced. The parameter under variation is this ratio of justified and unjustified rejections. In this analysis, the number of justified rejections is kept constant. The ratio between the justified and unjustified rejection is varied from 10% to 100% justified rejections of the total number of rejected kegs. This analysis provides insights into the costs for the four different scenarios after a possible finetune step of the setpoint of the residual pressure check. Due to the new insights provided by the sensitivity analyses, the four scenarios are better compared.

## 4.2. Leak Detection Machine

To gain more insight into the ratio of unjustified rejected kegs at the leak detection machine, two measurement methods are described. Furthermore, a method is described for the root cause analysis to gain a complete understanding of the leak detection machine.

**Ratio of unjustified rejected kegs**
In order to gain more insight into the number of unjustified rejected kegs of the leak detection machine, tests are performed on the rejected kegs. First, the rejected kegs by the leak detection machine are manually placed back before the leak detection machine so they are checked another time. By doing this, it can be monitored if a previously rejected keg is rejected a second time. This provides insight into the consistency of the measurements performed by the leak detection machine. In addition, the pressure of the rejected kegs are checked manually with a pressure gauge over time. By measuring the pressures of the kegs over several days, it is determined whether there is a leakage in the keg. This is concluded when the pressure in the keg is gradually decreasing. Accepted kegs from the leak detection machine are pressure tested simultaneously as a reference point, allowing one to ascertain from these kegs the typical pressure of accepted kegs. All kegs used during this measurement are filled with beer by the washing and filling machine. After the filling process, all kegs have the same internal pressure.

**Root cause analysis**
In Section 2.4.3, several potential root causes for the performance of the leak detection machine have been identified. Based on the high rejection rate of the leak detection machine and these identified issues, the expectation is that the rejection rate can be reduced. To get a full understanding of the leak detection machine and other potential root causes, a deeper analysis is needed. Using another Ishikawa diagram focusing on the unjustified rejection rate of the leak detection machine, it is determined in a structured way where the problems for the suboptimal performance of the leak detection machine lie. By means of an impact and effort estimation for the potential root causes, it is determined which root cause are resolved first. These possible causes are then further analyzed, and the expected outcome is quantified when the issue is resolved. Optimizing the performance of the leak

detection machine is done through iterative steps. Since the actions to be taken differ drastically between each issue, it is not possible to describe a common method. The analysis of the impact of each step has a common method. After each step when an issue is resolved, it is verified if the expected performance improvement matches with the obtained performance improvement. Based on this comparison, further steps are determined to reach the goal of no unjustified rejected kegs.

## 4.3. Conclusion

In this chapter, the approach is described for the introduction of the residual pressure check and the reduction of unjustified rejected kegs at the leak detection machine. Section 4.1 describes four different implementation scenarios for the introduction of the residual pressure check into the current keg line. In Section 5.1 these implementation scenarios are quantitatively analyzed and compared based on the impact of the keg line. In Section 5.2 the root causes are analyzed and the different solutions for the leak detection machine are described based on the approach described in Section 4.2.

# 5. Results

This chapter provides an impact analysis of the implementation scenarios discussed in Chapter 4. To assess the impact of the uncertainties, two different sensitivity analyses for each scenario are performed. Based on the findings from these analyses, an implementation scenario is recommended. Furthermore, this section provides a root cause analysis and solutions to reduce the number of unjustified rejections of the leak detection machine.

## 5.1. Residual Pressure Check

To gain insight into the consequences of enabling the residual pressure check with a setpoint of 0.5 bar, tests are conducted with the residual pressure check in the current washing and filling machine. This setpoint is chosen since this is the standard setpoint of the residual pressure check in the washing and filling machine. Based on these tests, the rejection rate of the residual pressure check is determined for this setpoint. The residual pressure check is done on multiple occasions and with different types of kegs. Table 5.1 shows the results and rejection rates obtained from these tests.

*Table 5.1: Rejection rates of the residual pressure check*

| Content Keg [L] | Rejected kegs [#] | Total kegs [#] | Percentage rejected kegs [%] |
|---|---|---|---|
| 19.5 | 88 | 6,639 | 1.33 |
| 30 | 4 | 627 | 0.64 |
| 50 | 51 | 3,323 | 1.53 |
| **Total** | **143** | **10,589** | **1.35** |

Based on these tests, an average rejection rate of 1.35% is obtained. At other breweries within the Asahi group, only approximately 10% of the rejected kegs is estimated to be manipulated or leaking for a setpoint of 0.5 bar, and 90% is still usable for production. This results in an estimated additional repair rate of 0.135% of the total number of kegs processed due to the residual pressure check. Based on the experience with the other machines within Grolsch, the reject rate will vary over time. To include the effect of a change in the average rejection rate, a range around 1.35% of ±0.25% is taken. The ±0.25% is based on the change in errors observed in the washing and filling machine over the weeks 34 until 52 of 2023. This change in errors is assumed to be representative of the expected change in average rejection rate of the residual pressure check. With a change in average rejection rate of ±0.25%, also the repair rate will vary with ±0.025%.

In the dataset from week 34 until 52 of 2023, a total of 409,400 kegs were processed by the keg line. When extrapolated to a period of a year, this would result in a total throughput of 1,182,712 kegs per year. With a rejection rate of 1.35 ±0.25%, this would result in a total number of 15,967 ±2,957 kegs being rejected by the residual pressure check in the washing and filling machine. This results in a total number of kegs that need to be sent for repair of 1,596 ±296.

**Repair costs**

The kegs rejected at step 4 in Figure 4.1 to Figure 4.4 are shipped for repair. This introduces extra repair costs for the total keg line compared to the current situation, because the rejection rate increases. Combining the total rejected kegs of the residual pressure check with a repair cost of €5.75 per keg would result in an additional repair cost of €9,181 ±€1,700 per year. The assumption is made that all kegs rejected by the residual pressure check would otherwise not be found by the leak detection machine. If the leak detection machine detects an amount of rejected residual pressure kegs, the repair cost would be lower since the rejection rate at the leak detection machine will decrease.

**Cost of beer loss**

The costs of beer loss compared to the current situation will decrease, because leaking kegs will be rejected before the filling process takes place. The costs saved by removing the leaking kegs earlier in the process are based on the 1,597 ±296 kegs rejected on a yearly basis. With the cost per liter beer loss at Grolsch of 0.0498 €/liter, an average of 30.7 liter per rejected keg, and the assumption that all these kegs are filled with beer, this results in a total cost saving of €2,436 ±€451 per year.

### 5.1.1. Internal Scenarios

#### Sub-scenario 1.1: Internal scenario, where the rejected kegs are handled at the washing and filling machine

**Non-conformance costs**

Operator costs

The operator time and costs will increase compared to the current situation, because operators need to handle extra rejected kegs by the residual pressure check. The extra time it takes for the separate handling steps of the operators for this scenario, shown in Figure 4.1, is estimated next. The complete handling after the washing and filling machine is estimated to take on average 405 seconds per keg. The two main steps of influence are the reaction time of answering to the rejection procedure of the washing and filling machine in step 1 and the return of the keg to the keg line at step 5. The estimated time for the steps are 180 seconds for step 1 and 120 seconds for step 5. The extra check after the scale is estimated to take on average 60 seconds. Combining these two, it takes on average an extra 465 seconds of operator handling per rejected keg by the residual pressure check. The total cost due to operator handling per keg is calculated by the total handling time of a keg and the average labor cost at Grolsch. Within Grolsch an average labor rate of 37.5 €/hour is applicable, this results in a total operator cost of €4.84 per keg. The operators need to handle all rejected kegs from the residual pressure check. Therefore, the extra operator costs incurred by handling the rejected kegs at the washing and filling machine are based on 15,967 ± 2,957 rejected kegs from the residual pressure check on a yearly basis, which results in a total cost of €77,338 ± €14,322 per year.

Costs of production loss

The rejected kegs cause an increase in production loss and costs due to the downtime of a lane at the washing and filling machine since the rejected keg needs to wait until an operator is available to remove the rejected keg. Therefore, the production capacity is affected negatively, and the throughput of the keg line is reduced. It is assumed by Grolsch that this stoppage of a lane will have a negative impact of twice the percentage of rejected kegs, which results in a production loss of 2.7% ±0.5%. Furthermore, approximately 90% of the kegs return into the keg line before the exterior cleaner. These 14,370 ±2,661 kegs re-entering the keg line increases the production loss with 1.215% ±0.225%. Lastly, the introduction of the residual pressure check introduces extra downtime to the washing and filling machine, which is estimated by Grolsch to be 0.1%.

This results in a 4.02% ±0.72% increase in production loss on a yearly basis. Within Grolsch there is an internal assumption that if a line has 1% more throughput, the FE will increase with 0.5%. An increase of 1% FE is estimated to save on a yearly basis nearly €55,000. Based on this assumption, the increase of production loss is estimated to be €110,413 ±€19,938 per year.

**Conformance costs**

Within the scope of this research, the conformance costs discussed within Grolsch are the introduction costs, maintenance cost and the costs incurred with fine tuning of the system. The introduction of the residual pressure check in the washing and filling machine incurs no costs because this check is already available in the washing and filling machine. The additional maintenance costs will be low, as the washing and filling machine is already part of a maintenance cycle. This maintenance cycle only needs to be extended for the residual pressure check. The maintenance costs are estimated based on the total maintenance cost of the washing and filling machine in 2023 of €25,000. The additional maintenance cost is estimated to be €1,250. Only for fine tuning the residual pressure check, there are higher costs involved. The residual pressure check procedure is quite tight and not easily adjustable. Therefore, if other boundaries are needed than the standard setpoint of 0.5 bar, this would introduce large costs. Since there are no exact numbers available for the finetuning costs, an estimation is done. The total implementation and finetuning is estimated at €2,500.

**Total additional costs**

An overview of the total non-conformance and conformance costs of introducing sub-scenario 1.1 are shown in Table 5.2. The non-conformance and conformance costs result in a total additional annual cost of €200,618 ±€36,411 per year and investment costs of €2,500. In Table 5.2 the positive costs indicate an increase of total costs and negative costs indicate a saving of costs.

*Table 5.2: Total additional costs internal scenario 1.1*

| Non-Conformance Costs | Min amount [€] | Typical amount [€] | Max amount [€] |
|---|---:|---:|---:|
| Repair | + 7,481 | + 9,181 | + 10,881 |
| Beer loss | - 1,985 | - 2,436 | - 2,888 |
| Operator | + 63,016 | + 77,338 | + 91,660 |
| Production loss | + 90,475 | + 110,413 | + 130,350 |
| | | | |
| **Conformance Costs** | | | |
| Introduction (once) | - | - | - |
| Maintenance | + 1,250 | + 1,250 | + 1,250 |
| Finetuning (once) | + 2,500 | + 2,500 | + 2,500 |
| | | | |
| **Total cost per year** | **+ 164,207** | **+ 200,618** | **+ 237,029** |
| **Investment cost** | **+ 2,500** | **+ 2,500** | **+ 2,500** |

**Quality of conformance**

The conformance and non-conformance cost have been calculated for a quality of conformance level of 98.65%, which is a result of the total rejection rate of the residual pressure check of 1.35%. The EQL point is where the total cost due to the combination of conformance and non-conformance costs are the lowest. Based on Figure 3.2 the expectation would be that for a quality of conformance level of 98.5%, the conformance costs would be significantly higher than the non-conformance costs. However, in this scenario the non-conformance costs of €162,957 are significantly higher than the conformance costs of €1,250. The finetune costs are a one-time investment and are therefore excluded from the quality of conformance calculation. Based on this, the EQL point would be at a quality of conformance level of 100%. Since there are justified rejected kegs at the residual pressure check, the 100% conformance level cannot be reached in the current situation. This implies that unjustified rejections by the residual pressure check should be minimized as much as possible.

**Sensitivity analysis on operator costs**

By adjusting the operator costs, the handling time of an operator also changes. In this scenario, the operator time is adjusted for step 1 in Figure 4.1. This is the time it takes for an operator to react to the procedure for removing the rejected keg at the washing and filling machine. By increasing the operator costs, it is assumed that the total time of an operator at step 1 will decrease. The assumption is that this step will be 20 seconds faster or slower, when the hourly operator cost is increased or decreased by 5 €/hour. The other operator's handling steps are excluded, since these steps will not change significantly when operator costs are changed. By the changing operator costs, the costs of production loss will also be adjusted. The operator's handling time at step 1 is directly related to the production loss of the downtime of a lane at the washing and filling machine. When a keg is rejected by the washing and filling machine, the lane will not continue until the rejected keg is removed by an operator. The longer the operator takes, the longer the lane will not continue, and the production loss will become higher. The assumption is that this production loss is directly related to the change in operator time at step 1. When the operator handling time at step 1 increases with 11%, this production loss will also increase with 11%. The sensitivity analysis and therefore the impact of operator cost on the total annual non-conformance cost is shown in Table 5.3.

*Table 5.3: Sensitivity analysis on operator costs scenario 1.1*

| Hourly operator costs [€] | Step 1 operator time [Sec] | Total operator time [Sec] | Total operator costs [€] | Downtime lane production loss [%] | Total production loss [%] | Total costs of production loss [€] | Total annual non-conformance costs [€] |
|---|---|---|---|---|---|---|---|
| 27.5 | 220 | 505 | 61,593 | 3.29 | 4.61 | 126,748 | 199,958 |
| 32.5 | 200 | 485 | 69,909 | 3.00 | 4.32 | 118,580 | 200,106 |
| 37.5 | 180 | 465 | 77,338 | 2.70 | 4.02 | 110,413 | 199,368 |
| 42.5 | 160 | 445 | 83,880 | 2.40 | 3.72 | 102,245 | 197,742 |
| 47.5 | 140 | 425 | 89,535 | 2.11 | 3.43 | 94,078 | 195,230 |

From Table 5.3 it is observed that lowering the operator cost negatively influences the total annual non-conformance costs and an interesting finding is that for operator costs of 27.5 €/hour the total annual costs is lower than 32.5 €/hour. Above the 32.5 €/hour the change in total annual costs is predominantly determined by the change in costs of production loss. However, in between 27.5 and 32.5 €/hour this shifts towards the change in operator costs. There is a cross-over point where the cost of production loss stops being dominant, and the operator costs takes over.

When the operator costs are increased, the total annual costs are reduced. The higher the operator costs becomes, the faster the total annual costs are reducing. The optimal point for the annual costs would be that the operator's handling time at step 1 becomes almost 0 and thus the downtime of the washing and filling machine to be as minimum as possible. However, this would imply that an operator is continuously monitoring the washing and filling machine. Due to the low rejection rate, this would imply that one operator has no action for the main part of the time. Therefore, this scenario is deemed realistic and not included in the sensitivity analysis.

Based on the total annual non-conformance costs in Table 5.3, it is preferred to have an hourly operator cost of 47.5 €/hour for scenario 1.1. When the qualification level of the operator and thus the operator costs is changed, a difference of less than €5,000 is obtained. This change of annual costs of €5,000 is only of minor influence on the total annual costs of around €200,000.

**Sensitivity analysis on justified versus unjustified rejection ratio**

The ratio between justified and unjustified rejections is varied to get more insights in the total additional yearly costs. In Table 5.4 the total additional yearly costs is shown for scenario 1.1. The total repair costs and costs due to beer loss will not vary due to a change in unjustified rejections, since they are solely based on the number of repaired kegs. As the percentage of justified rejections increases, the total additional costs decrease due to a lower number of rejected kegs. This results in lower operator costs and reduced costs of production loss. For ratios above 60%, the increase in cost is almost linear, while for ratios below 30% the growth becomes more exponential.

*Table 5.4: Sensitivity analysis on justified versus unjustified rejection ratio scenario 1.1*

| Justified rejection percentage [%] | Total additional yearly costs [€] |
|---:|---:|
| 10 | 200,618 |
| 20 | 106,284 |
| 30 | 74,825 |
| 40 | 59,095 |
| 50 | 49,658 |
| 60 | 43,366 |
| 70 | 38,872 |
| 80 | 35,501 |
| 90 | 32,880 |
| 100 | 30,782 |

### Sub-scenario 1.2: Internal scenario, where the rejected kegs are handled at the scale

**Non-conformance costs**

Operator costs

In this scenario, the operator time and costs will increase compared to the current situation because operators need to handle extra rejected kegs by the residual pressure check. The extra time it takes for the separate handling steps of the operators for this scenario, shown in Figure 4.2, is estimated next. The complete handling after the washing and filling machine and scale is estimated to take on average 290 seconds per keg. The main difference compared to internal scenario 1.1 is the time it takes to return the keg to the keg line. For this scenario the time is decreased due to the shorter transport distance and the time is assumed to be 10 seconds. The extra check after the scale is the same as for the other internal scenario, which is on average 60 seconds. Combining these two, it takes on average an extra 350 seconds of operator handling per rejected keg by the residual pressure check. The total handling time results in a total cost of €3.65 per keg. Therefore, the extra operator costs incurred by handling the rejected kegs at the washing and filling machine and the scale are €58,212 ±€10,780 per year.

Costs of production loss

The costs of production loss for this scenario is very comparable with the other internal scenario 1.1. The only difference is an extra loss due to opening the line for removing the residual pressure check kegs that need to be repaired. This difference is of minor influence, since the extra loss is around 0.01%. This results in a 4.03% ±0.73% increase in production loss on a yearly basis, which is estimated to be €110,688 ±€19,938 per year.

**Conformance costs**

The introduction cost for this scenario is the same as for the internal sub-scenario 1.1. However, the maintenance costs is expected to be higher due to the higher wear and tear of the full keg turner and the leak detection machine. The extra maintenance needed for the full keg turner and leak detection machine is estimated to be €1,250 resulting in a total maintenance cost of €2,500 per year.

**Total additional cost**

An overview of the total non-conformance and conformance costs of introducing sub-scenario 1.2 are shown in Table 5.5. The non-conformance and conformance costs result in a total additional annual cost of €183,016 ±€32,869 per year and investment costs of €2,500.

*Table 5.5: Total additional costs internal scenario 1.2*

| Non-Conformance Costs | Min amount [€] | Typical amount [€] | Max amount [€] |
|---|---:|---:|---:|
| Repair | + 7,481 | + 9,181 | + 10,881 |
| Beer loss | - 1,985 | - 2,436 | - 2,888 |
| Operator | + 47,432 | + 58,212 | + 68,991 |
| Production loss | + 90,750 | + 110,688 | + 130,625 |
| | | | |
| **Conformance Costs** | | | |
| Introduction (once) | - | - | - |
| Maintenance | + 2,500 | + 2,500 | + 2,500 |
| Finetuning (once) | + 2,500 | + 2,500 | + 2,500 |
| | | | |
| **Total cost per year** | **+ 150,147** | **+ 183,016** | **+ 215,885** |
| **Investment cost** | **+ 2,500** | **+ 2,500** | **+ 2,500** |

**Quality of conformance**

The quality of conformance of this scenario is similar to internal sub-scenario 1.1 except for minor details. The conformance costs of €2,500 of this scenario is slightly higher compared to the other internal sub-scenario. When the non-conformance costs of this scenario is compared to the other internal sub-scenario, the same conclusion is drawn. Based on the similarities the EQL will also be at a 100% conformance level. Therefore, also for this scenario the optimal situation is reached when there is no unjustified rejection of kegs at the residual pressure check.

**Sensitivity analysis on operator costs**

The same reasoning for the change in hourly operator costs and the directly related production loss applies to this scenario as it does to sub-scenario 1.1. The sensitivity analysis and therefore the impact of operator cost on the total annual non-conformance cost is shown in Table 5.6.

*Table 5.6: Sensitivity analysis on operator costs scenario 1.2*

| Hourly operator costs [€] | Step 1 operator time [Sec] | Total operator time [Sec] | Total operator costs [€] | Downtime lane production loss [%] | Total production loss [%] | Total costs of production loss [€] | Total annual non-conformance costs [€] |
|---|---|---|---|---|---|---|---|
| 27.5 | 225 | 390 | 47,567 | 3.29 | 4.62 | 127,023 | 174,590 |
| 32.5 | 205 | 370 | 53,333 | 3.00 | 4.32 | 118,855 | 172,188 |
| 37.5 | 185 | 350 | 58,212 | 2.70 | 4.03 | 110,688 | 168,899 |
| 42.5 | 165 | 330 | 62,203 | 2.40 | 3.73 | 102,520 | 164,723 |
| 47.5 | 145 | 310 | 65,308 | 2.11 | 3.43 | 94,353 | 159,660 |

Table 5.6 shows that lowering the operator cost negatively influences the total annual non-conformance costs and when the operator costs are increased, the total annual costs will reduce. The higher the operator costs, the faster the total annual costs are reducing. As in scenario 1.1, the optimal point is that step 1 becomes almost 0 and thus the downtime of the washing and filling machine is to be as minimal as possible. However, this is deemed realistic and therefore not included in the sensitivity analysis. In this scenario, the total operator costs change less quickly compared to the cost of production loss. Therefore, the costs of production loss are more dominant in this sensitivity analysis.

Based on the total annual non-conformance costs in Table 5.6, it is preferred to have an hourly operator cost of 47.5 €/hour for scenario 1.2. When the qualification level of the operator and thus the operator costs is changed, a difference of less than €10.000 is obtained. This change of operator cost of €10.000 is only of minor influence on the total annual costs of around €169.000.

**Sensitivity analysis on justified versus unjustified rejection ratio**

When the ratio between the justified and unjustified rejection is varied for scenario 1.2, the result is comparable with scenario 1.1. The total additional yearly costs are shown in Table 5.7. The total yearly costs of scenario 1.2 are slightly lower compared to scenario 1.1, and the cost versus rejection ratio shows a similar trend for scenario 1.1.

*Table 5.7: Sensitivity analysis on justified versus unjustified rejection ratio scenario 1.2*

| Justified rejection percentage [%] | Total additional yearly costs [€] |
|---:|---:|
| 10 | 183,016 |
| 20 | 98,243 |
| 30 | 69,973 |
| 40 | 55,838 |
| 50 | 47,357 |
| 60 | 41,703 |
| 70 | 37,664 |
| 80 | 34,635 |
| 90 | 32,279 |
| 100 | 30,394 |

### 5.1.2. External Scenarios

Sub-scenario 2.1: External scenario, where kegs are rechecked by an operator

**Non-conformance costs**

Operator costs

The operator time and costs will increase compared to the current situation. However, the rejected kegs do not have to be removed manually but are rejected automatically. The extra time it takes for the separate handling steps, shown in Figure 4.3, is estimated next. The complete handling of the kegs after they are rejected at the residual pressure check machine is estimated to take on average 105 seconds. The step contributing the most is the transport of the kegs with a total effort of around 60 seconds. The total handling time results in a total cost of €1.09 per keg. Therefore, the extra operator costs incurred by handling the rejected kegs at the new residual pressure check machine result in €17,463 ±€3,234 per year.

Costs of production loss

Since the leaking kegs are removed in the process before the throughput bottleneck, a higher throughput is achieved for the complete line. The increase in total throughput is related to the number of kegs rejected at step 4 in Figure 4.3. The increase of throughput is directly translated into a decrease in production loss. A total decrease of production loss of 0.135% ±0.025% is obtained. When the residual pressure check machine has a higher throughput than the bottleneck machine, this has no negative effect on the throughput of the line. The downside of this implementation is that, compared to the current situation, an extra machine results in extra downtime. It is assumed that this downtime will have 0.5% impact on the production loss. Furthermore, there is an extra negative effect, which is caused by opening the line for removing the residual pressure check kegs that need to be repaired. The impact of this is assumed to be 0.01%. This results in a 0.375% ±0.025% increase in production loss on a yearly basis, which is estimated to be €10,313 ±€688 per year.

**Conformance costs**

The introduction of a new residual pressure check machine will incur purchasing cost, which is estimated to be €90,000. This amount includes the new machine, installation, modification of the conveyor belts, and a new rejection belt. Additional maintenance costs will be high, as a new maintenance cycle and strategy need to be set in place. For finetuning the external residual pressure check machine, there are no costs involved, as it is assumed the new machine has this already in place.

**Total additional cost**

An overview of the total non-conformance and conformance costs of introducing sub-scenario 2.1 are shown in Table 5.8. The non-conformance and conformance costs result in a total additional annual cost of €46,893 ±€4,698 per year and investment costs of €90,000.

*Table 5.8: Total additional costs internal scenario 2.1*

| **Non-Conformance Costs** | **Min amount [€]** | **Typical amount [€]** | **Max amount [€]** |
|---|---:|---:|---:|
| Repair | + 7,481 | + 9,181 | + 10,881 |
| Beer loss | - 1,985 | - 2,436 | - 2,888 |
| Operator | +14,229 | + 17,463 | + 20,697 |
| Production loss | + 11,000 | + 10,313 | + 9,625 |
| | | | |
| **Conformance Costs** | | | |
| Introduction (once) | + 90,000 | + 90,000 | + 90,000 |
| Maintenance | + 7,500 | + 7,500 | + 7,500 |
| Finetuning (once) | - | - | - |
| | | | |
| **Total cost per year** | **+ 42,195** | **+ 46,893** | **+ 51,591** |
| **Investment cost** | **+ 90,000** | **+ 90,000** | **+ 90,000** |

**Quality of conformance**

The conformance and non-conformance have been calculated for a quality of conformance level of 98.65%. Based on Figure 3.2 the expectation would be that for a quality of conformance level of 98.5%, the conformance costs would be significantly higher than the non-conformance costs. The one-time investment costs of €90.000 are excluded from the EQL determination since they are a one-time investment and do not influence the yearly cost. In this scenario the non-conformance costs of €39,393 are significantly higher than the conformance costs of €7,500. Based on this, the EQL point in this external scenario is also at a quality of conformance level of 100%. This implies that the unjustified rejections of the residual pressure check should be minimized as much as possible.

**Sensitivity analysis on operator costs**

In this scenario the handling time of an operator does not change by adjusting the operator costs. The operator time is mainly depending on handling actions which cannot be speed up by a more qualified operator. For example, the movement of a keg from point a to point b will still take the same amount of time independent of the qualifications of the operator. However, the production loss due to the downtime of the machine could change when the downtime is noticed or treated sooner, however this is minimal. The assumption is that the influence of the hourly operator cost on production loss due to machine downtime is minimal. This could influence the downtime of the machine by 0.05% since the main part of the downtime is due to the repair actions to resolve the error. The sensitivity analysis and therefor the impact of operator costs on the total annual non-conformance cost is shown in Table 5.9.

*Table 5.9: Sensitivity analysis on operator costs scenario 2.1*

| Hourly operator costs [€] | Total operator time [Sec] | Total operator costs [€] | Extra downtime production loss [%] | Total production loss [%] | Total costs of production loss [€] | Total annual non-conformance costs [€] |
|---|---|---|---|---|---|---|
| 27.5 | 105 | 12,807 | 0,60 | 0,475 | 13,063 | 25,869 |
| 32.5 | 105 | 15,135 | 0,55 | 0,425 | 11,688 | 26,823 |
| 37.5 | 105 | 17,463 | 0,50 | 0,375 | 10,313 | 27,776 |
| 42.5 | 105 | 19,792 | 0,45 | 0,325 | 8,938 | 28,729 |
| 47.5 | 105 | 22,120 | 0,40 | 0,275 | 7,563 | 29,683 |

From Table 5.9 it is observed that lowering the operator costs positively influences the total annual non-conformance cost. When changing the operator cost per hour, the operator cost will change with the same percentage. The cost due to production loss will change with a lower amount. Therefore, the total annual cost is mainly determined by the change in operator cost. Based on the total annual non-conformance costs in Table 5.9, it is preferred to have an hourly operator cost of 27.5 €/hour for sub-scenario 2.1.

**Sensitivity analysis on justified versus unjustified rejection ratio**

The impact of varying the ratio of justified and unjustified rejection in scenario 2.1 is shown in Table 5.10. When the percentage of justified rejection is above 40%, the difference in cost is minor. Between a justified rejection percentage of 40% and 100% only a difference in total additional yearly cost of €2,620 is obtained. When the percentage becomes below 40%, the increase in cost grows exponentially.

*Table 5.10: Sensitivity analysis on justified versus unjustified rejection ratio scenario 2.1*

| Justified rejection percentage [%] | Total additional yearly costs [€] |
|---:|---:|
| 10 | 46,893 |
| 20 | 38,166 |
| 30 | 35,255 |
| 40 | 33,799 |
| 50 | 32,926 |
| 60 | 32,343 |
| 70 | 31,927 |
| 80 | 31,616 |
| 90 | 31,373 |
| 100 | 31,179 |

### Sub-scenario 2.2: External scenario, where kegs are rechecked by the residual pressure check machine

**Non-conformance costs**

Operator costs

The operator time and costs will increase compared to the current situation. The extra time it takes for the separate handling steps, shown in Figure 4.4, is estimated next. The complete handling of the kegs after they are rejected at the residual pressure check machine is estimated to take on average 100 seconds. The main difference compared to the other external scenario 2.1 is that the second time a keg is checked it will automatically continue to the washing and filling machine. This difference causes a minor decrease in total handling time. The total handling time results in a total cost of €1.04 per keg. Therefore, the extra operator costs incurred by handling the rejected kegs at the new residual pressure check machine are €16,632 ±€3,080 per year.

Costs of production loss
The costs of production loss are the same as for the other external sub-scenario 2.1.

**Conformance costs**
The conformance costs are the same as for the other external sub-scenario 2.1.

**Total additional cost**
An overview of the total non-conformance and conformance costs of introducing sub-scenario 2.1 are shown in Table 5.8. The non-conformance and conformance costs result in a total additional annual cost of €46,062 ±€4,544 per year and investment costs of €90,000.

*Table 5.11: Total additional costs internal scenario 2.2*

| **Non-Conformance Costs** | **Min amount [€]** | **Typical amount [€]** | **Max amount [€]** |
|---|---:|---:|---:|
| Repair | + 7,481 | + 9,181 | + 10,881 |
| Beer loss | - 1,985 | - 2,436 | - 2,888 |
| Operator | + 13,552 | + 16,632 | + 19,712 |
| Production loss | + 11,000 | + 10,313 | + 9,625 |
| | | | |
| **Conformance Costs** | | | |
| Introduction (once) | + 90,000 | + 90,000 | + 90,000 |
| Maintenance | + 7,500 | + 7,500 | + 7,500 |
| Finetuning (once) | - | - | |
| | | | |
| **Total cost per year** | **+ 41,518** | **+ 46,062** | **+ 50,605** |
| **Investment cost** | **+ 90,000** | **+ 90,000** | **+ 90,000** |

**Quality of conformance**
The quality of conformance of this scenario is similar to external sub-scenario 2.1 except for minor details. When the non-conformance costs of this scenario is compared to the other external sub-scenario, the same conclusion is drawn. Based on the similarities the EQL will also be at a 100% conformance level. Therefore, also for this scenario the optimal situation is reached when there is no unjustified rejection of kegs at the residual pressure check.

**Sensitivity analysis on operator costs**
For this scenario, the same reasoning applies to changes in hourly operator costs and the directly related production loss as it does to scenario 2.1. The difference is a decrease in operator time. The sensitivity analysis and therefore the impact of operator cost on the total annual non-conformance cost is shown in Table 5.12.

*Table 5.12: Sensitivity analysis on operator costs scenario 2.2*

| **Hourly operator costs [€]** | **Total operator time [Sec]** | **Total operator costs [€]** | **Extra downtime production loss [%]** | **Total production loss [%]** | **Total costs of production loss [€]** | **Total annual non-conformance costs [€]** |
|:-:|:-:|:-:|:-:|:-:|:-:|:-:|
| 27.5 | 105 | 12,197 | 0.60 | 0.475 | 13,063 | 25,259 |
| 32.5 | 105 | 14,414 | 0.55 | 0.425 | 11,688 | 26,102 |
| 37.5 | 105 | 16,632 | 0.50 | 0.375 | 10,313 | 26,944 |
| 42.5 | 105 | 18,849 | 0.45 | 0.325 | 8,938 | 27,787 |
| 47.5 | 105 | 21,067 | 0.40 | 0.275 | 7,563 | 28,630 |

From Table 5.12, it is observed that changes in hourly operator costs influences the total annual non-conformance costs similar as scenario 2.1. The total annual costs is mainly determined by the change in operator cost. Based on the total annual costs in Table 5.12, it is preferred to have an hourly operator cost of 27.5 €/hour for scenario 2.2.

**Sensitivity analysis on justified versus unjustified rejection ratio**

When the ratio between the justified and unjustified rejection is varied for scenario 2.2, the result is comparable with scenario 2.1. The total additional yearly costs are shown in Table 5.13. The total yearly costs of scenario 2.2 are marginally lower compared to scenario 2.1, and the cost versus rejection ratio shows a similar trend for scenario 2.1.

*Table 5.13: Sensitivity analysis on justified versus unjustified rejection ratio scenario 2.2*

| Justified rejection percentage [%] | Total additional yearly costs [€] |
|---:|---:|
| 10 | 46,062 |
| 20 | 37,750 |
| 30 | 34,977 |
| 40 | 33,591 |
| 50 | 32,759 |
| 60 | 32,205 |
| 70 | 31,809 |
| 80 | 31,512 |
| 90 | 31,280 |
| 100 | 31,096 |

### 5.1.3. Scenario Comparison

In this section, the different scenarios are compared based on the KPIs and the sensitivity analysis. First, all scenarios are compared based on justified versus unjustified rejection ratio. Next, the two internal scenarios are compared, followed by the two external scenarios. Finally, the best internal scenario is compared with the best external scenario.

#### Comparing all scenarios based on justified versus unjustified ratio

When comparing and evaluating the total additional costs for all scenarios based on the percentage of justified rejections, Table 5.14 shows that the costs decrease when the justified rejection percentage increases for all scenarios. For a lower justified rejection percentage, there can be a clear difference seen between the internal and the external scenarios based on Figure 5.1. The internal scenarios costs are a factor four higher compared to the external scenarios. When the justified rejection percentage is increasing, the difference between the four scenarios is decreasing. For a justified rejection percentage of 100%, the difference between the four scenarios becomes marginal. The internal scenario costs are more sensitive to variations in the justified rejection rate. For the external scenarios, there is almost no difference in cost for justified rejection percentages above 50%. For a justified rejection percentage of 10%, the external scenario would be preferably based on the annual cost. However, to implement the external scenarios an investment cost of €90,000 is necessary. This investment cost will be paid back after a period of eight months compared to the internal scenarios. For a higher justified rejection percentage of 50%, the payback period will increase significantly. It will change from eight months to six years. When the justified rejection is changed to 90%, the internal scenario becomes preferable. There is a minor difference in the additional annual cost of €1,250 between the internal and external scenario. The payback period for the external scenario for a justified rejection percentage of 90% would be 97 years.

Table 5.14: Total additional costs per year

| Justified rejection percentage [%] | Scenario 1.1 [€] | Scenario 1.2 [€] | Scenario 2.1 [€] | Scenario 2.2 [€] |
|---|---|---|---|---|
| 10 | 200,618 | 183,016 | 46,893 | 46,062 |
| 20 | 106,284 | 98,243 | 38,166 | 37,750 |
| 30 | 74,825 | 69,973 | 35,255 | 34,977 |
| 40 | 59,095 | 55,838 | 33,799 | 33,591 |
| 50 | 49,658 | 47,357 | 32,926 | 32,759 |
| 60 | 43,366 | 41,703 | 32,343 | 32,205 |
| 70 | 38,872 | 37,664 | 31,927 | 31,809 |
| 80 | 35,501 | 34,635 | 31,616 | 31,512 |
| 90 | 32,880 | 32,279 | 31,373 | 31,280 |
| 100 | 30,782 | 30,394 | 31,179 | 31,096 |

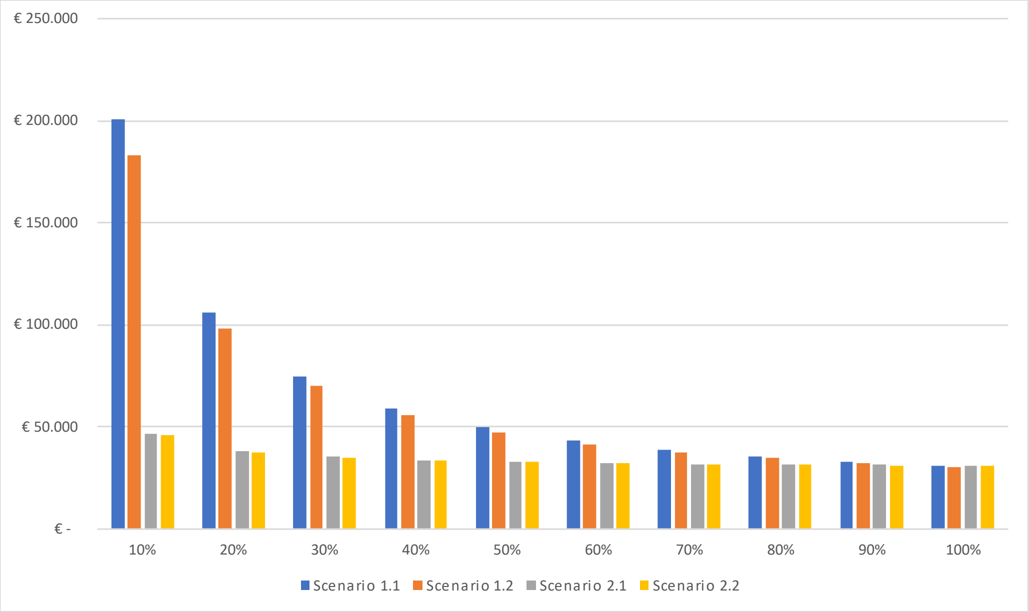


Figure 5.1: Sensitivity analysis on justified versus unjustified rejection ratio

### Comparing internal scenario 1.1 versus internal scenario 1.2

When evaluating the impact of the first internal scenario 1.1, where the rejected kegs are handled at the washing and filling machine versus the second internal scenario 1.2, where rejected kegs are handled at the scale, both scenarios present distinct influences on operator impact. There is less operator handling involved in scenario 1.2 compared to scenario 1.1, as the distance to return the kegs to the line is shorter. The difference in the cost of production loss is neglectable, since the difference in costs is minimal. For both scenarios, the repair costs and the costs of beer loss is similar. Table 5.15 shows the similarities and the differences expressed in the costs per year. Ultimately, scenario 1.2 would result in the lowest additional cost and would be the preferred option among the internal scenarios.

### Comparing external scenario 2.1 versus external scenario 2.2

When evaluating the impact of the first external scenario 2.1, where the rejected kegs are manually checked by operators versus the second external scenario 2.2, where the residual pressure check machine re-checks the rejected kegs, both scenarios are very similar with a few minor differences. The largest difference between these two scenarios is the operator handling. For scenario 2.2 there is less operator handling, which results in lower operator costs compared to scenario 2.1. Therefore, scenario 2.2 has the advantage over scenario 2.1 since the total cost is lower. A possible risk for scenario 2.2 is the throughput of the external residual pressure check since this implementation demands a higher throughput of the machine.

### Comparing internal scenario 1.2 versus external scenario 2.2

When considering the impact of internal scenario 1.2, where the residual pressure check is enabled on the current washing and filling machine versus external scenario 2.2, where a new machine is purchased for checking the residual pressures, both scenarios show advantages and disadvantages. The main disadvantage of the external scenario is the investment cost of €90,000, while the internal machine has only a cost of €2,500. The internal scenario has the advantage of requiring only a minor change to the current maintenance policy, while for the external scenario a new maintenance policy must be set up. Furthermore, the external scenario has a higher yearly maintenance cost.

When looking at the cost of production loss, the external scenario 2.2 has mainly advantages over the internal scenario 1.2 based on Table 5.15. Table 5.15 shows the range of cost for the scenarios for a justified rejection percentage of 10%. In the external scenario, the operator handling costs and production loss costs are nearly ten times lower compared to the internal scenario. This is mainly due to the fact that there is no introduced production loss when the kegs are rejected. Furthermore, the external scenario prevents the rejected kegs from entering the throughput bottleneck, which is the washing and filling machine. This will have a significant positive impact on the performance. For the internal scenario the rejected kegs at the scale must be repressurized to be able to re-enter the washing and filling machine. This is not applicable for the external scenario, which results in a lower operator handling costs. The cost due to beer loss and repair cost are for both scenarios the same. Based on the sensitivity analysis on the operator cost of the internal scenario, the operator cost must be as high as possible to have the lowest cost, while for the external scenario the operator cost must be as low as possible. This shows that the internal scenario is more dependent on the operator qualifications. The outcome of the sensitivity analysis on the justified versus unjustified rejection rate is that for justified rejection percentages lower than 50%, the external scenario is preferable. The investments costs for the external scenario will have a payback period of less than 6 years. For justified rejection percentage above 80%, the internal scenario become preferable since there is a minor difference in additional yearly costs. Due to this minor difference in costs, the payback period for the external scenario will increase to a worst-case period of 96 years.

*Table 5.15: Comparison of the scenarios on yearly additional cost*

| **Costs** | **Internal 1.1** | | **Internal 1.2** | | **External 2.1** | | **External 2.2** | |
|---|---|---|---|---|---|---|---|---|
| | Min [€] | Max [€] | Min [€] | Max [€] | Min [€] | Max [€] | Min [€] | Max [€] |
| **Non-conformance** | + 7,481 | + 10,881 | + 7,481 | + 10,881 | + 7,481 | + 10,881 | + 7,481 | + 10,881 |
| Repair cost | | | | | | | | |
| Operator cost | + 63,016 | + 91,660 | + 47,432 | + 68,991 | +14,229 | + 20,697 | + 13,552 | + 19,712 |
| Beer loss costs | - 1,985 | - 2,888 | - 1,985 | - 2,888 | - 1,985 | - 2,888 | - 1,985 | - 2,888 |
| Production loss costs | + 90,475 | + 130,350 | + 90,750 | + 130,625 | + 11,000 | + 9,625 | + 11,000 | + 9,625 |
| | | | | | | | | |
| **Conformance** | 0 | 0 | 0 | 0 | +90,000 | +90,000 | +90,000 | +90,000 |
| Introduction cost (once) | | | | | | | | |
| Maintenance cost | +1,250 | +1,250 | +2,500 | +2,500 | +7,500 | +7,500 | +7,500 | +7,500 |
| Finetune cost (once) | +2,500 | +2,500 | +2,500 | +2,500 | 0 | 0 | 0 | 0 |
| | | | | | | | | |
| **Total cost** | + 164,207 | + 237,029 | + 150,147 | + 215,885 | + 42,195 | + 51,591 | + 41,518 | + 50,605 |
| Annual cost | | | | | | | | |
| Once | +2,500 | +2,500 | +2,500 | +2,500 | +90,000 | +90,000 | +90,000 | +90,000 |

## 5.2. Leak Detection Machine

**Ratio of unjustified rejected kegs**
Based on different observations mentioned in chapter 2, there seems to be an issue that the leak detection machine rejects kegs unjustified. It is unclear what the exact amount of unjustified rejected kegs is at the leak detection machine. Therefore, several tests are performed to determine the percentage of unjustified kegs. The first test performed with the rejected kegs at the leak detection machine is testing if rejected kegs would be rejected a second time by the leak detection machine. This test showed that 98% of the rejected kegs were not rejected a second time. This implies that the working of the leak detection machine is not consistent over time, which leads to a decrease in trust in the quality inspection point.

The second test performed is monitoring the pressures of the rejected and accepted kegs over time. This test is done with a small number of kegs and the pressure of the kegs were measured manually with a pressure gauge. However, manually testing a small number of kegs leads to increased uncertainty and measurement inaccuracy. Manual measurements are prone to human error and inconsistency, which further undermines the reliability of the results. Therefore, instead of exact numbers, ranges are used to better interpret the results and to consider the inherent measurement inaccuracy. The accepted kegs which passed the leak detection machine show a maximum decrease in pressure in the range of 0.1 bar over the entire durations of the measurement. The rejected kegs are divided into two groups. The first group shows a similar maximum decrease in pressure compared to the accepted kegs of 0.1 bar. The second group shows a decrease in pressure of more than 0.2 bar. From the 21 rejected kegs, 4 kegs showed a decrease of more than 0.2 bar indicating that these are rejected justified. The other 17 kegs show a decrease of less than 0.1 bar in pressure, indicating that these are rejected unjustified. Based on this measurement, this would result in a percentage of unjustified rejected kegs of 81%. Due to the human aspect and the low number of kegs, this percentage is extended into a range from 76% to 86%. Based on this measurement, it is calculated what the rejection rate of the leak detection machine would be if there would only be no unjustified rejected kegs. Combining the current rejection rate of 1.39% and the unjustified percentage range from 76% to 86%, it would result in an optimal rejection rate range of 0.2 to 0.33%.

The manufacturer of the leak detection machine indicated that a rejection rate of 0.5% is normally observed at other breweries. The calculated optimal rejection rate range is slightly lower compared to this indicated, but in the same order of magnitude. The goal of the improvements is to reach the range of rejection rate from 0.2% to 0.33%.

**Root cause analysis**
In Section 2.4.3, several possible root causes have already been mentioned for the unjustified rejected kegs of the leak detection machine. Such as the minimal awareness of the maintenance needs for the leak detection machine and the lack of sufficient data to conduct a thorough data analysis. It is challenging to determine and resolve the root cause of unjustified rejections in the absence of comprehensive data. Therefore, information was collected through observations at the leak detection machine to determine where the root cause of the unjustified rejection may lie. From these observations and with interviews with operators, the following possible root causes have been observed for the unjustified rejections.

The setpoint of the leak detection machine is used to determine the limit of the difference in $CO_2$ levels. If the leak detection machine determines a difference between the keg headspace and the atmospheric $CO_2$ level of more than this setpoint, the keg is automatically rejected. This setpoint was set at 10%. This setpoint was implemented due to too many complaints from the market about leaking kegs. The impact of the change in setpoint was never determined within Grolsch. After consultation with the manufacturer of the leak detection machine, they advised a setpoint setting of 25%.

During monitoring the leak detection machine, it was observed that the $CO_2$ measurement levels were occasionally jumping. Which means that the measured $CO_2$ level of the keg was jumping above the setpoint and back, resulting in the keg being rejected unjustified. This was observed multiple times and has a significant impact on the unjustified rejection rate of the leak detection machine. This impact cannot be caused by the measurement of the keg itself, implying that this jump in $CO_2$ level is due to a mechanical error.

Furthermore, during the observations of the leak detection machine, it was found that the status of the machine was often unknown. For example, by observations it was found that there were loose wires or connections that were broken in or around the machine. The faulty situations do not result in direct error of the machine but can have a consequence for the performance of the leak detection machine. It was found that the operators of the machine do have a limited knowledge of the machine and the operation method. Due to the lack of knowledge, these more subtle faulty situations are not found.

As mentioned before, Grolsch has no maintenance policy in place for the leak detection machine. Due to this lack of maintenance policy, there is no stock of original spare parts for the machine. Whenever maintenance is needed, it is done with non-original parts since these are on stock with the maintenance engineer. In addition to the absence of a maintenance policy, there is also no cleaning procedure in place. During the weekly cleaning cycle, there is no structured plan on what should be cleaned within the leak detection machine. This can have an impact on the performance and the wear and tear of the machine.

An overview of the found possible root causes are shown in the Ishikawa diagram in Figure 5.2.

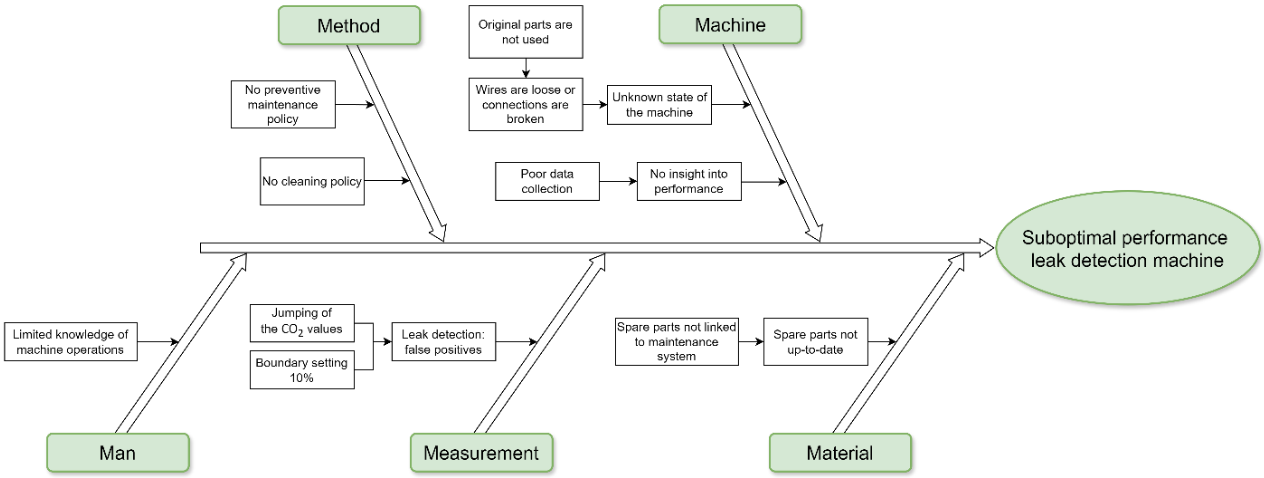


*Figure 5.2: Ishikawa diagram of suboptimal performance of the leak detection machine*

Using the Ishikawa diagram, the first issue to solve is determined by estimating the needed effort and the estimated impact. Determining the impact and effort for the root causes is based on the experience of employees who are directly involved in the processes. Through these interviews, the potential impact and effort required to address each root cause is assessed. The estimation for the different root causes are shown in Table 5.16.

*Table 5.16: impact/effort estimation for the potential root causes*

| Root cause | Impact | Effort |
|---|---|---|
| **Jumping of $CO_2$ values** | High | Medium/High |
| **Setpoint settings** | Medium | Low |
| **Limited machine knowledge** | Low | High |
| **No spare parts** | Low | Medium |
| **No maintenance policy** | Medium | High |
| **Unknown state of the machine** | Low | High |
| **No insights into performance** | None | Medium |

Several root causes are assumed to have a low impact on the amount of unjustified rejected kegs. For example, the limited machine knowledge, no spare parts and unknown state of the machine are estimated to have a low impact, since these causes do not have a direct impact but can cause issues on the long term. The insights into the performance will not change the performance of the machine itself but will provide possibilities to determine the main root cause. Due to the lack of a maintenance policy, crucial components of the machine can deteriorate without being noticed. The performance of the machine can decrease due to this deterioration. However, the implementation of a maintenance policy will take a lot of effort. There must be determined what are the crucial parts of the machine and how often maintenance needs to be performed. Since there is no data available of the rejected kegs by the leak detection machine, it is uncertain whether the implementation setpoint is correct. This can have an impact on measurements. However, since the implemented setpoint is tighter than the prescribed setpoint by the manufacturer, the impact would be medium. The highest impact is caused by the jumping of the $CO_2$ values, since they directly impact the correctness of the measurements. This phenomenon is clearly unwanted and should be resolved. Based on the frequency of the jumps in these values, the impact will vary.

Based on the impact and the effort, the priorities for resolving the issues are determined. The highest impact on the machine is to resolve the jumping of the $CO_2$ levels first. However, the effort to resolve this is medium to high. Therefore, we started with a low effort, medium impact action, namely the settings of the leak detection machine.

**Step 1: Setpoint update**
The setpoint of the leak detection machine was set in the past without any understanding what the impact was on the performance of the leak detection machine. When a keg is leaking, the measured value will shoot far over the setpoint. By setting the setpoint tight, the machine will get more prone to measurement errors and variation in the keg and will reject kegs unjustified. By changing the setpoint to the prescribed value, the expectation is that a part of the problem is solved. The expectation is that the rejection rate will be decreased by 0.2% to 0.3% by an update of the setpoint based on the experience within Grolsch.

The setpoint of the leak detection machine is a parameter within its system and can easily be adjusted by an engineer. The setpoint is returned to the prescribed value of 25% from the manufacturer. This prescribed value is based on extensive experience of the manufacturer at other breweries. The rejection rate is monitored for two weeks after the setpoint is adapted. Prior to the change of setpoint, the rejection rate of the leak detection machine was 1.39%. Within the following two weeks the rejection rate decreased to 0.81%. The change in setpoint resulted in an improvement of the rejection rate of 0.58%. The improvement exceeded the original expectation of an improvement of 0.2% to 0.3% due to an update of the setpoint. Since all data of the actual measured values by the leak detection machine is missing, this expectation was done on experience. Potentially leaking kegs could be missed with this setpoint and therefore a follow experiment was conducted. The measurement values, which are not stored in a system, are observed visually. The measurement value of a non-leaking keg is around 200 ppm. When a micro tear is measured, the measurement value is at least above 500 ppm. This indicates that the leaking kegs are still being rejected with this new setpoint. The main improvement is that the machine is less prone to keg variation and measurement inaccuracies. These variations are bigger than originally thought and can explain the higher obtained reduction in rejection rate. After this improvement the rejection rate decreased to 0.81%, which is still far from the goal for the rejection rate of 0.2% to 0.33%. Therefore, another improvement step is needed. The second improvement made is the jumping of the $CO_2$ values.

**Step 2: Jumping $CO_2$ values**

During visually monitoring the leak detection machine, it was observed that the $CO_2$ measurement levels were occasionally jumping above the setpoint and back. To be able to estimate the impact of this phenomenon, the number of times the $CO_2$ levels jumped are determined for a period of one hour. It was found that the $CO_2$ level jumped around ten times. During this period, a total of 350 kegs were processed by the leak detection machine. The jump of the $CO_2$ level did not always occur during a measurement and is therefore unrelated to the measurement of the keg. The expectation is that if this phenomenon is resolved, the rejection rate of the leak detection machine is in the optimal range. Therefore, a reduction in the current rejection rate of 0.5% is expected.

Based on the observation that a jump of the $CO_2$ levels is independent of the presence of a keg, the main suspect for the cause of this issue is the machine itself. Since the exact working of the machine is unknown by Grolsch, an escalation ladder was determined. This escalation ladder is used when Grolsch cannot solve this issue itself. The first step of the escalation ladder is the unit manager of the keg line within Grolsch. The second step of the ladder is the manufacturer of the leak detection machine. The final step is the manufacturer of a specific component of the leak detection machine. This final step is still unknown since it is not yet clear what component causes this issue.

Grolsch could not resolve the issue and therefore the manufacturer of the leak machine was contacted. The manufacturer conducted a maintenance cycle replacing critical components in the machine, but the indicated exact root cause could not be found. After this maintenance cycle, the rejection rate of the leak machine dropped to 0.205%. Based on the decreased rejection rate, the problem seemed to be resolved. To verify if the performance of the machine was as wanted, an observation of several days was performed. During this period, unwanted machine performance was detected. The leak detection machine has for each keg a total measuring time of five seconds. It was observed that the real measurement value was several times obtained after this period of five seconds. Since the measurement value was outside of the measurement period, the leaking kegs were not rejected anymore. A direct cause of this unwanted performance is the slow measurement time of the leak detection machine. The main component that influences the speed of the measurements are the water trap filters within the machine. Therefore, these are replaced with new original parts. After this machine update, the unwanted behavior was resolved.

Both the phenomena of the jumping $CO_2$ values and the slow measurements could be resolved by maintenance. For the slow measurements, the root cause is pinpointed to be the water trap filters within the leak detection machine. The exact root cause of the jump in $CO_2$ levels is still unknown. In the three weeks after the change in water trap filters, the rejection rate of the leak detection machine dropped to 0.32% and both phenomena are not observed anymore. With these improvements, the goal of the rejection rate is reached. Therefore, no further steps are taken regarding the reduction of the rejection rate of the leak detection machine.

**Impact on performance of the keg line**

The reduction of the rejection rate of the leak detection machine will have an impact on the KPIs and the performance of the keg line. The rejection rate has been reduced from 1.39% to 0.32%. To indicate the saved costs, the dataset from week 34 until 52 for 2023 is used. The original rejection rate of 1.39% is replaced by the newly obtained 0.32%. This results in the cost shown in Table 5.17.

*Table 5.17: Total cost of rejected kegs at the improved leak detection machine*

| **Leak detection machine** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Content keg [L]** | **Percentage rejected kegs [%]** | **Total rejected kegs [#]** | **Cost beer loss [€]** | **Repair cost [€]** | **Operator cost [€]** | **Cost of production loss [€]** | **Total cost [€]** |
| 19.5 | 0.32 | 355 | 344 | 2,041 | 555 | 667 | 3,607 |
| 30 | 0.32 | 162 | 242 | 933 | 254 | 305 | 1,733 |
| 50 | 0.32 | 817 | 2,033 | 4,699 | 1,277 | 1,536 | 9,546 |
| **Total** | **0.32** | **1,344** | **2,619** | **7,673** | **2,085** | 2,508 | **14,886** |

Based on Table 5.17 the total costs associated with the leak detection machine for a rejection rate of 0.32% for weeks 34 until 52 for 2023 would be €14,886. This is a reduction of €50,027 compared to the original situation with a rejection rate of 1.39%. When this reduction is extrapolated to estimate the savings on a yearly basis, the total reduction of costs due to the leak detection machine would be €144,523.

## 5.3. Conclusion

In this chapter the four different implementation scenarios for the residual pressure check are analyzed. All four scenarios will introduce yearly costs for Grolsch. However, the residual pressure check is essential according to the Asahi quality standards. Failure to perform this check could lead to a production stop. From all four scenarios, the external scenario 2.2 is the most optimal based on the KPIs. The main difference compared to the internal scenario is the operator cost and the cost due to production losses. After only 8 months the external scenario would be preferable over the internal scenario. Scenario 2.2 would require an investment of €90,000 and introduces a yearly cost of €46,062. For all four scenarios the EQL point is determined. The most cost efficiency point is when the quality of conformance is 100%. However, this cannot be reached in the current situation due to justified rejected kegs by the residual pressure check. This implies that the unjustified rejected kegs must be kept to a minimum.

Furthermore, a root cause analysis for the too high rejection rate of the leak detection machine is conducted. The result of this root cause analysis is shown in an Ishikawa diagram. Based on this Ishikawa diagram the priorities for resolving the root causes to obtain a wanted rejection rate of 0.2% to 0.3% is determined. The two root causes which resolved the too high rejection rate were the setpoint settings and the jump of $CO_2$ levels within the leak detection machine. The root cause of the jump of $CO_2$ levels is still unknown, however, it is resolved by performing a maintenance cycle. With these two updates, the resulting rejection rate of the leak detection machine is 0.32%, which is in the wanted rejection rate range. This reduction in the rejection rate saves on a yearly basis a total cost of €144,523.

# 6. Implementation Plan & Recommendations

In this chapter, the implementation plan and recommendations for Grolsch are discussed for the residual pressure check in the keg line and maintaining an optimal rejection rate of the leak detection machine.

## 6.1. Residual Pressure Check

**Implementation plan**

The best and most suitable implementation scenario for the residual pressure check is implementing an external residual pressure check machine according to scenario 2.2 in Section 4.1. For introducing this implementation scenario, adjustments need to be made to the keg line. First, a new residual pressure check machine needs to be purchased and space needs to be created in the current keg line. The recommended position is after the exterior cleaner and before the washing and filling machine. Within the investment, it is considered that several adaptations to the keg line must be made like providing the needed electricity. Therefore, this installation should be done in close cooperation with the technical department within Grolsch. To provide sufficient space, a part of the conveyor belt needs to be removed. The rejected kegs by the residual pressure check needs to be stored to perform the extra tests. For this, sufficient space should be created to perform these measurements efficiently. At the place where the rejected kegs are stored, there needs to be a way to repressurize and mark the kegs. The kegs are repressurized using compressed air and a dedicated fitting. Within the keg line there are several places where the compressed air is available. There needs to be checked if this is already in place at the external residual pressure machine. Furthermore, an effective method for marking the kegs should be determined. Within this method, several parameters should be kept into mind. Not all marked kegs are rejected a second time by the residual pressure check and will enter the market with the marking. Therefore, this marking should not impact the handling of the customers. The operator should be able to mark this keg within seconds and should not have to remove the marking to prevent an impact on the operator handling.

The introduction of a new machine within a production line will have an impact on several factors like operator handling and the maintenance cycle. There are several aspects for the operator handling which should be updated or developed. First and foremost, new work instructions must be made for the operator on how to handle the new machine and the rejected kegs. Dedicated training modules must be developed to prevent start-up inefficiency. These work instructions need to include the error indications of the machine, the cleaning cycle of the machine and dedicated needed handling actions. Besides the interaction with the machine, the operator will need to perform several steps manually, like removing kegs from the conveyor belt and repressurizing the kegs. After a dedicated period, the kegs must re-enter the keg line. A guideline for this process must be set up. The final and most critical part of the work instructions is the detailed explanation of the kegs that must be shipped for repair. The work instruction for the rejected kegs must be adapted to inform the operators of the change in handling the rejected kegs. The change should indicate that rejected kegs should re-enter the keg line after the residual pressure check machine. Within literature several consequences of performing no maintenance on a quality inspection point are indicated. To prevent the negative consequences mentioned in Section 3.3, a maintenance cycle should be developed.

Besides the practical implementation of the machine, several parameters within the machine must be set. The most important parameter of the residual pressure check is the setpoint. From other breweries it is learned that approximately 90% of the rejected kegs are unjustified with a setpoint of 0.5 bar. As was described in Section 5.1.2, the optimal EQL point is at 100% quality of conformance level or a justified rejection percentage of 100% when there are no more unjustified rejections from the residual pressure check. With the setpoint of the machine, only the amount of unjustified rejected kegs could be changed. To reduce this and get close to the EQL point it is necessary to adjust the setpoint. It is therefore recommended to investigate the optimal setpoint of the residual pressure check. A possible method to determine the optimal setpoint is discussed next. Since there is currently no data available regarding the pressures of correct and/or leaking kegs, the first step is to gather this data. The assumption within Grolsch is that manipulated or leaking kegs will gradually move towards a pressure of 0 bar. However, not all leaking kegs had enough time to return to 0 bar and will have some residual pressure left inside the keg. Based on the data of the residual pressure of all measured kegs, a range of pressures where the expected optimal setpoint lies can be determined. This range of pressures is presumably lower than the current setpoint at other breweries which is 0.5 bar.

To gain more insight into the state of a keg, the following measurement needs to be conducted. Several kegs within the previously determined range of pressures should be put aside and repressurized. These repressurized kegs should be put aside for a week and after this week the pressure of the keg should be remeasured. When the pressure has dropped substantially in this period of a week, it is assumed that this keg is manipulated or leaking. The number of kegs used for this measurement should be large enough to do data analysis and to be representative for the keg line. Based on the combination of the residual pressure at the start and at the end of the measurement, it can be concluded if the keg arrived in the correct state at Grolsch.

Based on the data of the pressures of the keg measured by the residual pressure check and the measurement indicating if a keg should be rejected or accepted, an optimal setpoint is determined. Within Grolsch, the quality of the kegs has a higher priority than the additional costs. Therefore, the optimal setpoint should guarantee that all manipulated or leaking kegs are rejected. This could result in some unjustified rejection of good kegs. Therefore, the optimal setpoint would reject all manipulated and leaking kegs and keep the unjustified rejection of good kegs to a minimum.

**Recommendations**

The implementation of scenario 2.2 is based on several assumptions like the handling time of an operator for each step, production loss and the reject and repair rate. These assumptions should be checked when the machine is implemented and made operational. Based on the verification of these assumptions the actual impact on the performance of the line is determined.

The used costs in the implementation scenario to estimate the performance and the impact on the keg line is limited to the used KPIs. By limiting the scope of the model, several impacts are not considered. To get even more insights into the impact of the implementation of the external residual pressure check, these factors should be included. Two of the factors that should be included are the needed cleaning time of the machine and the throughput impact due to a difference in the buffer spaces of the kegs between machines. Based on the quality of conformance analysis of implementation scenario 2.2, the rejection rate of the residual pressure check should be as low as possible. In this research a method is described for the reduction of unjustified rejected kegs within the residual pressure check. When the unjustified rejected kegs is limited, the main cost driver will be justified rejected kegs. To reduce costs even further, it would be advised to reduce the amount of manipulated or leaking kegs due to customer or transport handling. This reduction in manipulated or leaking kegs can be achieved with different approaches. The design of the kegs can be improved to be less susceptible to misusage. Furthermore, the information on the operating principle of a keg can be extended towards a customer to prevent this wrong usage. Finally, the transport method can be evaluated to determine if improvements can be made to prevent damage during transport.

Based on the sensitivity analysis of scenario 2.2, the operator costs should be minimized. However, since there are no dedicated operators for solely the residual pressure check machine, lowering the operator costs will impact the performance of the complete keg line. The effect of a change in operator costs for the complete keg line is currently unknown. It is therefore not possible to advise on lowering or increasing the operator cost for the performance of the complete keg line.

## 6.2. Leak Detection Machine

**Implementation plan**

The results in Chapter 5 show that the issue of a too high unjustified rejection of the kegs is resolved by performing a maintenance and cleaning cycle. This will resolve the issue for a period of time. However, when there are no changes made to the maintenance cycle within Grolsch, it is very likely that these or similar problems will return in time. A proactive maintenance cycle is therefore advised to be performed by Grolsch. Several proactive maintenance cycles are described in literature. The maintenance strategy advised is a combination of preventive and predictive maintenance. There are several parts like the measurement head which are used a lot and are sensitive to wear and tear. For this type of component, a preventive maintenance strategy is advised. A large part of this preventive maintenance strategy involves cleaning the parts during downtime of the machine. The predictive maintenance strategy is advised for crucial components which are harder to reach or more expensive to replace. However, in the current situation the predictive maintenance strategy cannot be implemented within Grolsch due to the lack of available data from the leak detection machine. To be able to implement the predictive maintenance strategy, the following types of data should be stored within the system.

The measurement of the $CO_2$ level for each keg should at least be stored. It would be preferred to include the variation in the $CO_2$ level over time during the measurement. The $CO_2$ levels of the leak detection machine should be stable over time when no keg is being measured. Based on $CO_2$ level data from the leak detection machine, a jump in stationary $CO_2$ levels is made visible. This jump in $CO_2$ level is either positive or negative. When a detection method for this $CO_2$ level jump is implemented in the data monitoring of the leak detection machine, a maintenance cycle needs to be scheduled when the system detects multiple $CO_2$ jumps within a certain period. The detection method should consider that when a keg is being measured, a positive jump in $CO_2$ indicates a leaking keg. This jump in $CO_2$ level due to a leaking keg should not result in a warning for a maintenance cycle. During the weekly cleaning and maintenance cycle, the leak detection machine is disabled for a certain period. During this period, the leak detection machine may be enabled, and the $CO_2$ level can be monitored for a long period. Based on this longer stationary run, it is determined with more accuracy if unwanted jumps in $CO_2$ levels are observed. This detection method can be used to determine if the water trap filters are in need for a maintenance cycle.

During the measurement of the leak detection machine, a keg is rejected on one of the two heads. To be able to detect faulty measurements of one head, the system must be capable to have a separate data storage of the $CO_2$ levels measured and the amount of processed and rejected kegs of both heads. Based on this data, it is analyzed if the kegs are correctly rejected due to a jump in $CO_2$ levels. Furthermore, the amount of rejected kegs between the two heads can be monitored. A big gap in the amount of rejected kegs between the two heads can indicate that one of the two heads is faulty, and a maintenance cycle for the faulty head is necessary.

Furthermore, it was observed that the count of the processed kegs is unreliable due to the negative number of processed kegs, which can result in a wrong rejection rate. This negative number of processed kegs should be resolved to be able to monitor the trend in rejection rate over time.

The root cause of the jumping $CO_2$ levels within the leak detection machine was not found. Therefore, it is unclear how to implement a suitable maintenance cycle to prevent this problem. To improve the maintenance cycle further, a root cause study must be performed by the manufacturer regarding the root cause of this issue.

Within Grolsch there is no logging of the maintenance activities performed on the leak detection machine. This should be extended to improve the predictability of the maintenance needed for the leak detection machine. Based on the performed maintenance, the interval between dedicated actions can be determined and implemented within the predictive maintenance strategy.

**Recommendations**

The initial set goal for the rejection rate is reached. However, it is uncertain if all rejected kegs are now justified for the improved situation. To determine whether all rejected kegs are justified by the leak detection machine, we recommend an extra test. Manual measurements are prone to human error and inconsistency, which undermines the reliability of the results. Therefore, the recommendation is to use the available $CO_2$ level data as described in the implementation plan. This data can be used to accurately determine whether each keg is rejected due to a change in $CO_2$ level. If all kegs rejected by the leak detection machine had a positive jump during the measurement, the keg is rejected justified. This monitoring of the rejected kegs versus its $CO_2$ level should be done periodically.

The machine is operated by several operators. However, the knowledge of the leak detection machine is poor. This can be improved by providing an extensive training into the details of the way of working of the machine and the different error conditions. Within this training, the focus should be placed on the different possible faults within the machine and on how to resolve those. Furthermore, there are no work instructions for the leak detection machine. The work instructions should be developed and the specified repair activity for a certain fault situation should be included.

During the maintenance cycle performed by the manufacturer there was indicated that not all parts were original. Grolsch was not capable of performing certain maintenance cycles due to the obsolescence of certain machine parts. It is advised to improve both topics to prevent unwanted downtime of the keg line and incorrect behavior of the leak detection machine.

# 7. Conclusion

This final chapter summarizes and discusses the main findings of this research. Section 7.1 provides an overview of the main results, Section 7.2 discusses the limitations of the research, and Section 7.3 provides recommendations for future research.

## 7.1. Conclusion

Within Grolsch there are two problems identified for the keg line. Firstly, the percentage of rejected kegs of the leak detection machine within the keg line is higher than desirable. Secondly, to comply with the quality standards of Asahi a residual pressure check shall be enabled, resulting in a high unjustified rejection rate. Based on these two problems the following main research question is formulated:

***What improvements can be made to the keg line in order to decrease the cost of rejected kegs?***

In order to be able to find the root causes of the two issues, the processes and performance of the keg line must be determined. The introduction of the residual pressure check is an improvement in quality based on the current situation and cannot be taken along in the analysis of the current situation. The analysis is done based on the KPIs, which are throughput, production costs and the quality of the production process and end products. The total yearly costs due to the rejection of kegs within the keg line is €434,197. The main cost driver is the leak detection machine, due to the high repair cost, with a total yearly cost of €187,527. The main factor impacting the total cost of the keg line is the high unjustified rejection of the leak detection machine. The unjustified rejection at the leak detection machine is due to wrong measurements and the lack of maintenance. To improve the performance of the keg line by decreasing the cost of rejected kegs, there is focused on the reduction of the rejection rate of the leak detection machine and an implementation scenario for the residual pressure check with the lowest possible rejection cost.

A literature review has been conducted to get more insights into the different costs associated with quality and quality inspections. The Cost of Quality approach provides a method to balance two competing objectives, which are achieving high-quality while minimizing expenses. Furthermore, within literature different maintenance strategies are studied together with the impact of maintenance on quality inspection. When no maintenance is performed on quality inspection machines, the machine will deteriorate over time and the quality of the product cannot be guaranteed anymore. Maintenance strategies can be divided into reactive and proactive maintenance strategies like preventive and predictive. The main advantage of proactive maintenance is that it prevents a reduction in performance due to deterioration.

Several different implementation scenarios are developed on how to implement the residual pressure check. These four scenarios are quantitatively analyzed based on the KPIs and sensitivity analyses regarding the operator costs and the justified versus unjustified rejection ratio were performed. Based on these analyses, the internal scenario where the residual pressure check was implemented in the washing and filling machine would result in a yearly cost of €183,000 for a justified rejection ratio of 10%. Whereas the external scenario, where a new residual pressure check machine is introduced would result in a yearly cost of €46,000 with an investment cost of €90,000. For a justified rejection ratio below 60% the external scenario is recommended based on the cost and the payback period. Between a justified rejection ratio of 70% and 80% there is a crossover point between the internal and external scenarios. Above a justified rejection ratio of 80%, the internal scenario is recommended due to the payback period of the external scenario. Based on the current situation with a justified rejection ratio of 10%, the external scenario is recommended. In the implementation plan it is specified which practical aspects need to be considered for the installation and operation of the new residual pressure check machine. Furthermore, an extended study regarding the setpoint of the machine is described to be able to implement an optimized setpoint.

A root cause analysis is performed to determine the possible root causes of the too high rejection rate of the leak detection machine. With the use of an Ishikawa diagram and an impact and effort estimation, a prioritization is done. After improving the boundaries setting, the rejection rate dropped to 0.81%. Furthermore, by performing a maintenance cycle, the root cause for the jumping $CO_2$ values and the slow measurements was resolved. After both these steps had been taken, the obtained rejection rate of 0.32% of the leak detection machine was in the expected optimal range of 0.2% to 0.33%. By reducing the rejection rate of the leak detection machine from 1.39% to 0.32%, an estimated cost of €144,523 is saved on a yearly basis. To prevent the deteriorating performance over time of the leak detection machine, a combination of a preventive and predictive maintenance strategy was advised.

The goal of this research was to reduce the cost due to the rejection of kegs for the two focus areas. For the residual pressure check, a cost-optimal scenario was obtained which meets the requirements from the quality standards of Asahi. The rejection rate of the leak detection machine decreased by over one percentage point resulting in a cost reduction of €144,523 on a yearly basis.

Within this research the rejection rate of the keg line is reduced. Furthermore, this research provides more insights into the performance and the way of working of the keg line. Using these insights regarding the performance of the keg line, several improvements like a maintenance strategy are described. Besides the advised improvements, Grolsch can determine new areas of interest to improve the performance even further. This research presents a methodology and framework to conduct further investigations and improvements. The currently used KPIs can be extended to get a deeper understanding of the keg line. This research present a framework based on the CoQ and shows a practical implementation of the CoQ. This practical implementation of the CoQ can be extended to cover the other costs in more detail, namely Prevention, Appraisal, Internal and External Failure.

### 7.2. Limitations

Several limitations were found during this research. First and foremost, there are a lot of inconsistencies with the data storage within Grolsch. Due to these inconsistencies, there are some uncertainties regarding the used data like the total throughput or the rejection rate of the current situation. Due to these uncertainties, the indicated cost within this research can vary in reality. Furthermore, during this research the amount of incoming manipulated or leaking kegs was considered fixed. In a real case scenario, this amount will vary and therefore also the rejection rate of the residual pressure check and the leak detection machine. The amount of faulty incoming kegs has a significant influence on the yearly cost due to rejected kegs.

Another limitation arose during the estimation of the operator costs. The time an operator is handling a rejected keg in the keg line is based on assumptions and it is assumed that every second of handling a keg is resulting in a rise in operator costs. In practice, there are always two or three operators present and therefore the operator costs are fixed. Within Grolsch there is currently unknown how much time the operator is idle during its work shift. Therefore, it is unknown if the operator can handle more workload. The only difference in operator cost will be achieved when an extra operator is needed, or one operator can be saved.

Within this research the KPIs throughput, production costs and the quality of the production process and end products are used. Within the CoQ framework used in this research, the focus is on a part of the prevention and the internal failure cost. The maintenance cost are a part of the prevention costs and the cost due to rejected kegs are part of the internal failure cost. However, within the CoQ there are many more costs regarding the quality of products, such as appraisal cost, external failure costs and other prevention costs. These were excluded from this research and therefore influenced the outcome of the CoQ. For example, the external failure cost are influenced by the number of manipulated or leaking kegs on the market. By introducing the residual pressure check the number of manipulated or leaking kegs entering the market is reduced. The assumption is made that in this research the manipulated or leaking kegs are not found by the leak detection machine but are found by the customer. This will lead to a lower customer satisfaction and the kegs are returned to Grolsch. The costs due to these leaking kegs are currently excluded. When the leaking kegs are prevented from entering the market, the customer satisfaction will rise over time and the cost due to returned kegs will decrease.

Within the internal failure costs, the costs due to machine operation, wear and tear and storage are excluded. All machinery within the production line use several resources like electricity, water and air pressure. These costs due to the machines are not included within the calculation of the internal failure costs. Each keg handled by a machine will contribute to the wear and tear for the machine resulting in higher maintenance costs. Lastly, every keg that needs to be sent for repair needs to be temporarily stored within the keg line and/or the warehouse. When the kegs are stored within the keg line, it can result in a lower efficiency of the operators due to less efficient walking routes. To store the kegs within the warehouse, a dedicated area needs to be reserved. A change in the number of kegs for repair can vary the efficiency of the operators and the area needed in the warehouse.

## 7.3. Future Research

For future research, it is recommended to study the correlation between the residual pressure check and the leak detection machine. The current assumption is that the kegs rejected by the residual pressure check would not be detected by the leak detection machine. Both machines will detect if a keg is leaking. The only difference being the method used to perform this measurement. The leak detection machine will detect the $CO_2$ level of the keg directly after it is filled. The residual pressure check machine will detect the residual pressure within a keg before the filling process. If a keg is leaking, the residual pressure of a keg is gradually decreasing. To improve the understanding of the behavior of the keg line it is advised to study the relation between the rejection at the residual pressure check and the leak detection machine. This relation can be studied after finetuning the setpoint of the residual pressure check. The study is based on executing a test with kegs that are rejected by the residual pressure check. The rejected keg should be filled with beer and afterwards measured by the leak detection machine. Based on this test, the number of kegs can be determined which are rejected by both the leak detection machine and the residual pressure check. Based on this number of rejected kegs, the reduction in rejection rate for the leak detection machine can be estimated. The expectation is that by implementing the residual pressure check, the leak detection machine rejection will decrease below the current 0.32%. By applying Statistical Quality Control, the inspection points can be monitored to identify variability and deviations. This gives an extra understanding of the correlations and trends between the inspections points and provides valuable insights into the process (Montgomery, 2012). By using this method, the implemented setpoint of the residual pressure test can be monitored.

For the implementation of the residual pressure check, an external machine is advised to be implemented. This external scenario considers the optimal implementation of the machine. However, to be able to reach this optimal implementation several factors should be analyzed more deeply. The placement of the machine has an impact on the length of the conveyer belt in front and behind the machine. The conveyer belts within Grolsch act like a buffer enabling an optimal operation of the machinery. The impact of the placement of the machine on the buffers and thereby the throughput of the keg line should be studied. Furthermore, the current walking routes of the operators need to be adapted to be able to implement the new machine. A study on how to optimize these walking routes can be conducted to reduce the impact on operator handling of the total keg line. These two studies can be conducted through a simulation study. The current research is conducted based on several KPIs, however for the simulation study, these KPIs should be extended with factors like buffer spaces. Based on these KPIs several scenarios regarding the placement of the new residual pressure machine and the walking routes of the operators can be developed. The impact of the scenarios regarding the KPIs can be determined and compared using a simulation model. Based on the impact the most suitable scenario for the placement of a new residual pressure check can be implemented within Grolsch.

By performing the sensitivity analysis on the internal and the external scenarios for the residual pressure check, it was found that for the internal scenarios the operator qualification should be raised. For the external scenario the operator qualification should be decreased to reduce the total cost due to the residual pressure check machine. Within Grolsch all operators have a similar qualification level. This raises the question whether the current operator qualification within Grolsch is optimal. A study can be conducted to determine the operator cost for the complete keg line and perform a sensitivity analysis to determine the optimal operator qualification. Several scenarios can be considered during this sensitivity analysis like increasing the qualification level of both operators or decreasing the qualification level of one operator while raising the other. Based on this sensitivity analysis, a cross-over point can be determined when it would be beneficial to create a distinction in operator qualification level.

This research focuses on the rejection rate of the residual pressure check and the leak detection machine. However, there are also other locations where kegs are rejected, such as the washing and filling machine and scale which also causes extra operator handling, cost of beer loss, and cost of production loss. Reducing these rejection rates are excluded from this research because the leak detection machine and the residual pressure check had higher priority. However, based on the analysis on the current situation and Appendix B, the washing and filling machine is contributing to the unjustified rejection ratio of the keg line. By performing a root cause analysis on the keg line, other sources of rejections can be further analyzed, and it can be determined if these rejection rates can also be reduced.

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# Appendices

## A. Machine Park

*Figure A.1: Dry area*

*Figure A.2: Full keg turner robotic arm*

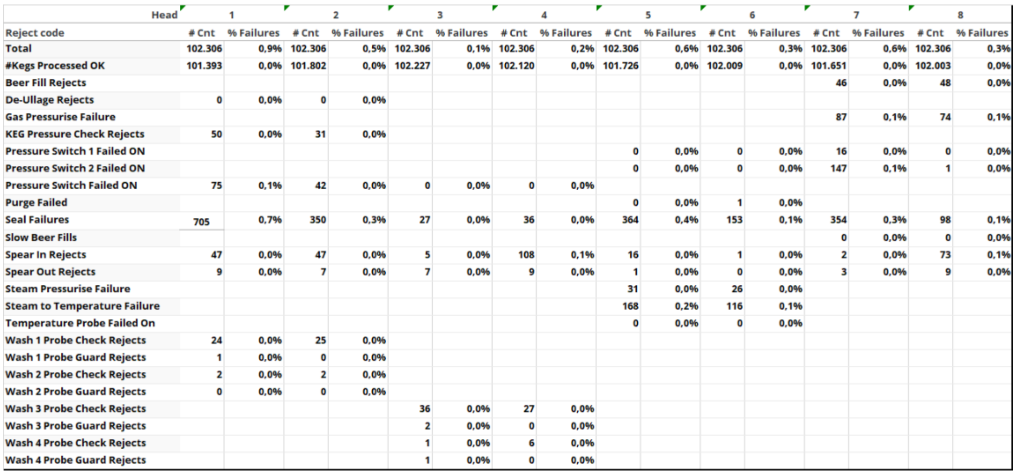
*Figure A.3: Exterior cleaner*

Figure A.4: Washing and filling machine

Figure A.5: Leak detection machine

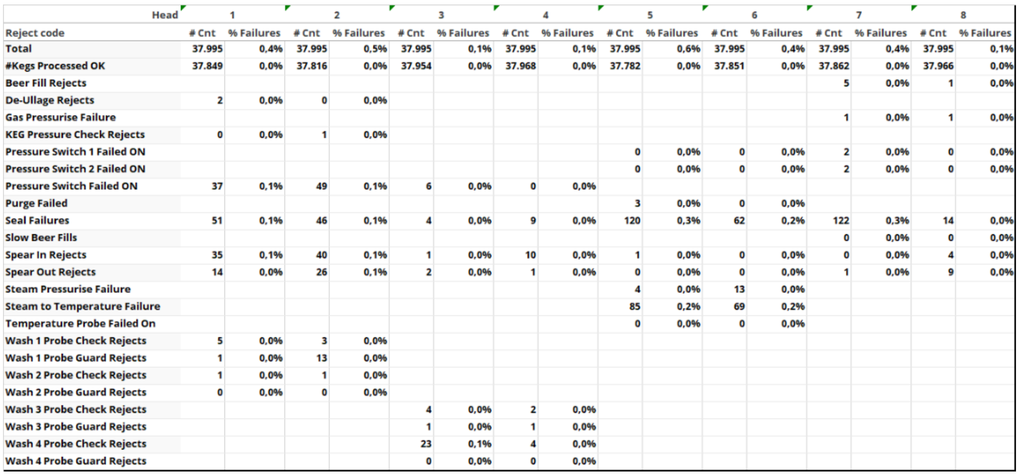
Figure A.6: Capper

# B. Rejection Figures and Percentages: Washing and Filling Machine



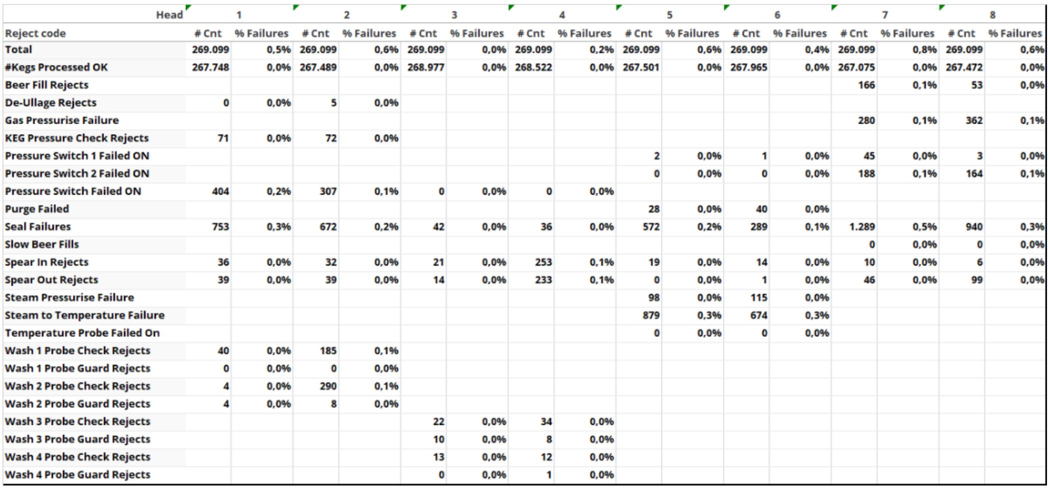
| Head | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reject code | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures |
| Total | 102.306 | 0,9% | 102.306 | 0,5% | 102.306 | 0,1% | 102.306 | 0,2% | 102.306 | 0,6% | 102.306 | 0,3% | 102.306 | 0,6% | 102.306 | 0,3% |
| #Kegs Processed OK | 101.393 | 0,0% | 101.802 | 0,0% | 102.227 | 0,0% | 102.120 | 0,0% | 101.726 | 0,0% | 102.009 | 0,0% | 101.651 | 0,0% | 102.003 | 0,0% |
| Beer Fill Rejects | | | | | | | | | | | | | 46 | 0,0% | 48 | 0,0% |
| De-Ullage Rejects | 0 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Gas Pressurise Failure | | | | | | | | | | | | | 87 | 0,1% | 74 | 0,1% |
| KEG Pressure Check Rejects | 50 | 0,0% | 31 | 0,0% | | | | | | | | | | | | |
| Pressure Switch 1 Failed ON | | | | | | | | | 0 | 0,0% | 0 | 0,0% | 16 | 0,0% | 0 | 0,0% |
| Pressure Switch 2 Failed ON | | | | | | | | | 0 | 0,0% | 0 | 0,0% | 147 | 0,1% | 1 | 0,0% |
| Pressure Switch Failed ON | 75 | 0,1% | 42 | 0,0% | 0 | 0,0% | 0 | 0,0% | | | | | | | | |
| Purge Failed | | | | | | | | | 0 | 0,0% | 1 | 0,0% | | | | |
| Seal Failures | 705 | 0,7% | 350 | 0,3% | 27 | 0,0% | 36 | 0,0% | 364 | 0,4% | 153 | 0,1% | 354 | 0,3% | 98 | 0,1% |
| Slow Beer Fills | | | | | | | | | | | | | 0 | 0,0% | 0 | 0,0% |
| Spear In Rejects | 47 | 0,0% | 47 | 0,0% | 5 | 0,0% | 108 | 0,1% | 16 | 0,0% | 1 | 0,0% | 2 | 0,0% | 73 | 0,1% |
| Spear Out Rejects | 9 | 0,0% | 7 | 0,0% | 7 | 0,0% | 9 | 0,0% | 1 | 0,0% | 0 | 0,0% | 3 | 0,0% | 9 | 0,0% |
| Steam Pressurise Failure | | | | | | | | | 31 | 0,0% | 26 | 0,0% | | | | |
| Steam to Temperature Failure | | | | | | | | | 168 | 0,2% | 116 | 0,1% | | | | |
| Temperature Probe Failed On | | | | | | | | | 0 | 0,0% | 0 | 0,0% | | | | |
| Wash 1 Probe Check Rejects | 24 | 0,0% | 25 | 0,0% | | | | | | | | | | | | |
| Wash 1 Probe Guard Rejects | 1 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Wash 2 Probe Check Rejects | 2 | 0,0% | 2 | 0,0% | | | | | | | | | | | | |
| Wash 2 Probe Guard Rejects | 0 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Wash 3 Probe Check Rejects | | | | | 36 | 0,0% | 27 | 0,0% | | | | | | | | |
| Wash 3 Probe Guard Rejects | | | | | 2 | 0,0% | 0 | 0,0% | | | | | | | | |
| Wash 4 Probe Check Rejects | | | | | 1 | 0,0% | 6 | 0,0% | | | | | | | | |
| Wash 4 Probe Guard Rejects | | | | | 1 | 0,0% | 0 | 0,0% | | | | | | | | |

*Figure B.7: Rejection figures and percentages 19.5-liter kegs*



| Head | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reject code | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures |
| Total | 37.995 | 0,4% | 37.995 | 0,5% | 37.995 | 0,1% | 37.995 | 0,1% | 37.995 | 0,6% | 37.995 | 0,4% | 37.995 | 0,4% | 37.995 | 0,1% |
| #Kegs Processed OK | 37.849 | 0,0% | 37.816 | 0,0% | 37.954 | 0,0% | 37.968 | 0,0% | 37.782 | 0,0% | 37.851 | 0,0% | 37.862 | 0,0% | 37.966 | 0,0% |
| Beer Fill Rejects | | | | | | | | | | | | | 5 | 0,0% | 1 | 0,0% |
| De-Ullage Rejects | 2 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Gas Pressurise Failure | | | | | | | | | | | | | 1 | 0,0% | 1 | 0,0% |
| KEG Pressure Check Rejects | 0 | 0,0% | 1 | 0,0% | | | | | | | | | | | | |
| Pressure Switch 1 Failed ON | | | | | | | | | 0 | 0,0% | 0 | 0,0% | 2 | 0,0% | 0 | 0,0% |
| Pressure Switch 2 Failed ON | | | | | | | | | 0 | 0,0% | 0 | 0,0% | 2 | 0,0% | 0 | 0,0% |
| Pressure Switch Failed ON | 37 | 0,1% | 49 | 0,1% | 6 | 0,0% | 0 | 0,0% | | | | | | | | |
| Purge Failed | | | | | | | | | 3 | 0,0% | 0 | 0,0% | | | | |
| Seal Failures | 51 | 0,1% | 46 | 0,1% | 4 | 0,0% | 9 | 0,0% | 120 | 0,3% | 62 | 0,2% | 122 | 0,3% | 14 | 0,0% |
| Slow Beer Fills | | | | | | | | | | | | | 0 | 0,0% | 0 | 0,0% |
| Spear In Rejects | 35 | 0,1% | 40 | 0,1% | 1 | 0,0% | 10 | 0,0% | 1 | 0,0% | 0 | 0,0% | 0 | 0,0% | 4 | 0,0% |
| Spear Out Rejects | 14 | 0,0% | 26 | 0,1% | 2 | 0,0% | 1 | 0,0% | 0 | 0,0% | 0 | 0,0% | 1 | 0,0% | 9 | 0,0% |
| Steam Pressurise Failure | | | | | | | | | 4 | 0,0% | 13 | 0,0% | | | | |
| Steam to Temperature Failure | | | | | | | | | 85 | 0,2% | 69 | 0,2% | | | | |
| Temperature Probe Failed On | | | | | | | | | 0 | 0,0% | 0 | 0,0% | | | | |
| Wash 1 Probe Check Rejects | 5 | 0,0% | 3 | 0,0% | | | | | | | | | | | | |
| Wash 1 Probe Guard Rejects | 1 | 0,0% | 13 | 0,0% | | | | | | | | | | | | |
| Wash 2 Probe Check Rejects | 1 | 0,0% | 1 | 0,0% | | | | | | | | | | | | |
| Wash 2 Probe Guard Rejects | 0 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Wash 3 Probe Check Rejects | | | | | 4 | 0,0% | 2 | 0,0% | | | | | | | | |
| Wash 3 Probe Guard Rejects | | | | | 1 | 0,0% | 1 | 0,0% | | | | | | | | |
| Wash 4 Probe Check Rejects | | | | | 23 | 0,1% | 4 | 0,0% | | | | | | | | |
| Wash 4 Probe Guard Rejects | | | | | 0 | 0,0% | 0 | 0,0% | | | | | | | | |

*Figure B.8: Rejection figures and percentages 30-liter kegs*



| Head | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reject code | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures | # Cnt | % Failures |
| Total | 269.099 | 0,5% | 269.099 | 0,6% | 269.099 | 0,0% | 269.099 | 0,2% | 269.099 | 0,6% | 269.099 | 0,4% | 269.099 | 0,8% | 269.099 | 0,6% |
| #Kegs Processed OK | 267.748 | 0,0% | 267.489 | 0,0% | 268.977 | 0,0% | 268.522 | 0,0% | 267.501 | 0,0% | 267.965 | 0,0% | 267.075 | 0,0% | 267.472 | 0,0% |
| Beer Fill Rejects | | | | | | | | | | | | | 166 | 0,1% | 53 | 0,0% |
| De-Ullage Rejects | 0 | 0,0% | 5 | 0,0% | | | | | | | | | | | | |
| Gas Pressurise Failure | | | | | | | | | | | | | 280 | 0,1% | 362 | 0,1% |
| KEG Pressure Check Rejects | 71 | 0,0% | 72 | 0,0% | | | | | | | | | | | | |
| Pressure Switch 1 Failed ON | | | | | | | | | 2 | 0,0% | 1 | 0,0% | 45 | 0,0% | 3 | 0,0% |
| Pressure Switch 2 Failed ON | | | | | | | | | 0 | 0,0% | 0 | 0,0% | 188 | 0,1% | 164 | 0,1% |
| Pressure Switch Failed ON | 404 | 0,2% | 307 | 0,1% | 0 | 0,0% | 0 | 0,0% | | | | | | | | |
| Purge Failed | | | | | | | | | 28 | 0,0% | 40 | 0,0% | | | | |
| Seal Failures | 753 | 0,3% | 672 | 0,2% | 42 | 0,0% | 36 | 0,0% | 572 | 0,2% | 289 | 0,1% | 1.289 | 0,5% | 940 | 0,3% |
| Slow Beer Fills | | | | | | | | | | | | | 0 | 0,0% | 0 | 0,0% |
| Spear In Rejects | 36 | 0,0% | 32 | 0,0% | 21 | 0,0% | 253 | 0,1% | 19 | 0,0% | 14 | 0,0% | 10 | 0,0% | 6 | 0,0% |
| Spear Out Rejects | 39 | 0,0% | 39 | 0,0% | 14 | 0,0% | 233 | 0,1% | 0 | 0,0% | 1 | 0,0% | 46 | 0,0% | 99 | 0,0% |
| Steam Pressurise Failure | | | | | | | | | 98 | 0,0% | 115 | 0,0% | | | | |
| Steam to Temperature Failure | | | | | | | | | 879 | 0,3% | 674 | 0,3% | | | | |
| Temperature Probe Failed On | | | | | | | | | 0 | 0,0% | 0 | 0,0% | | | | |
| Wash 1 Probe Check Rejects | 40 | 0,0% | 185 | 0,1% | | | | | | | | | | | | |
| Wash 1 Probe Guard Rejects | 0 | 0,0% | 0 | 0,0% | | | | | | | | | | | | |
| Wash 2 Probe Check Rejects | 4 | 0,0% | 290 | 0,1% | | | | | | | | | | | | |
| Wash 2 Probe Guard Rejects | 4 | 0,0% | 8 | 0,0% | | | | | | | | | | | | |
| Wash 3 Probe Check Rejects | | | | | 22 | 0,0% | 34 | 0,0% | | | | | | | | |
| Wash 3 Probe Guard Rejects | | | | | 10 | 0,0% | 8 | 0,0% | | | | | | | | |
| Wash 4 Probe Check Rejects | | | | | 13 | 0,0% | 12 | 0,0% | | | | | | | | |
| Wash 4 Probe Guard Rejects | | | | | 0 | 0,0% | 1 | 0,0% | | | | | | | | |

*Figure B.9: Rejection figures and percentages 50-liter kegs*

# C. Research Methodology

## C.1. Quality improvement

To survive the competitive market, improving the quality and productivity of a product or process is necessary for any company. A methodological way to assist with this is through quality improvement. De Mast (2004) defines quality improvement as '*a coherent series of concepts, steps (phases), methodological rules and tools, that guide a quality professional in bringing the quality of a process or product to unprecedented levels'.* Quality improvement goes beyond identifying defects or errors; it also involves taking proactive steps to prevent defects or errors from happening, optimizing processes to reduce waste, and aiming for better performance levels. Quality improvement activities are typically conducted in projects (de Mast, 2004). Depending on the purpose of a particular improvement project, the right methodology can be selected, or a combination of methods can be chosen. The improvements made within continuous quality improvement are done by means of a variety of tools and techniques, in Section C.2 these various improvement methods are further explained to provide structured frameworks and tools for systematically addressing quality issues and optimizing processes.

## C.2. Improvement Methodologies

Within literature, several methodologies are described by researchers and practitioners to use for quality improvement of production processes. Lean six sigma techniques such as DMAIC and the PDCA-cycle of TQM are methods which are widely used for improving production processes and reducing defect rates. Although there are some differences between these methodologies in terms of tools, terms and approaches, there are also a lot of resemblances between these methodologies. In this section these methods are further explained and compared. Within Grolsch, often the Small Group Activity (SGA) method is used for improvement projects, therefore, this method is included and compared with the commonly used methods in the literature.

**Total Quality Management**

Total Quality Management (TQM) is a management approach, which uses Deming's concept of Plan-Do-Check-Act (PDCA) (Salah et al., 2010). The PDCA method is a continuous-improvement technique, which represents the repeated and continuous nature of continuous improvement. This allows for the evaluation of all implemented and applied solutions, serving as an indicator for further improvement activities. PDCA is more than just a quality tool, as organizations take the philosophy of continuous improvement into their culture, see Figure C.10 (Sokovic et al., 2010).

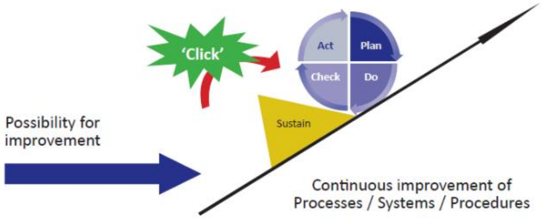


*Figure C.10: PDCA cycle*

The PDCA cycle is often used in small improvement projects (Theisens, 2021). In Table C.1 the four phases of the PDCA framework are further explained.

Table C.1: PDCA framework

| | |
|---|---|
| Plan | Define the problem and objectives. Analyze the problem and possible causes using quality tools like the Ishikawa diagram or 5-whys. Generate a solution and create an implementation plan. |
| Do | Execute the implementation plan and apply solutions to address the root cause. Collect data of the improved process. |
| Check | Compare data of improved process with the initial data to measure the effect of the solution. Verify if the root cause has been eliminated and if the output meets expectations. |
| Act | If the plan did not have the desired effect, the PDCA cycle must be repeated. If the plan did work, the focus is on sustaining the improvement to ensure the process performance does not deteriorate over time. This phase is the wedge in Figure C.10. |

**Small Group Activity**

Small Group Activity (SGA) is ideal for smaller, team-oriented improvements that can be implemented quickly as it solves problems in a relatively short period of time. SGA is a useful technique that is suitable for every company to solve problems and improve employee involvement (Ejsmont & Łyjak, 2016). The SGA approach is based on the PDCA approach, however, the plan phase of the PDCA approach is divided into five steps, see Figure C.11. The five steps are subject selection, determination of the goal, problem investigation, create the solution, and making a plan (de Groot et al., 2006).

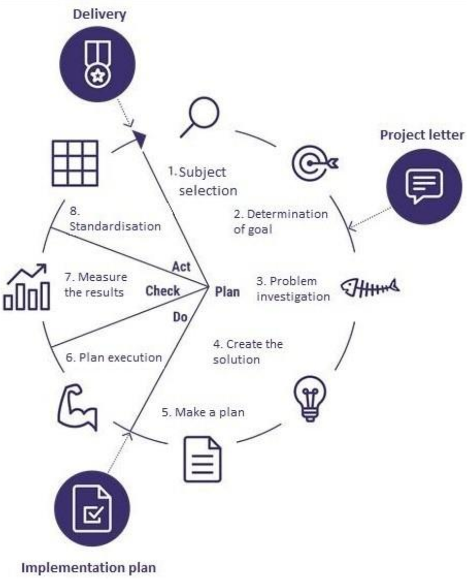


Figure C.11: SGA cycle

In Table C.2 the frequently used tools within the mentioned steps of the SGA cycle are shown.

Table C.2: Frequently used tools within a step of SGA cycle

| **Tools** | **Step in SGA cycle** |
|---|---|
| Ishikawa diagram, 5-Why, 5W + 1H | 3, Problem investigation |
| Check sheet, graph of the variable in time, use of existing data | 4, Create the solution |
| Pareto analysis, histogram, scatter diagram, control chart | 5, Make a plan |

### Lean Six Sigma

Lean Six sigma (LSS) is a frequently used methodology for quality improvement as it is a broad framework for company-wide quality improvement, with various tools and techniques (de Mast, 2004). Within LSS, there is the DMAIC cycle which focusses on the improvement of production through combining lean and six sigma, where lean focusses on reducing waste and six sigma on control over the process (Salah et al., 2010). DMAIC is a structured data-driven life-cycle approach that investigates the root causes of defects and offers ways to reduce them through each of the iterative cycles. DMAIC is ideal for complex, process-oriented improvement projects that require detailed data analysis. The approach is divided into five phases, namely Define, Measure, Analyze, Improve, and Control. Table C.3 gives the definitions of each phase (Setiawan et al., 2021). The approach of DMAIC is set up in a way that it can be applied to a range of areas, from manufacturing to services.

*Table C.3: DMAIC framework*

| | |
|---|---|
| **Define** | Define the problem statement, specific goals, project scope and establish the timeline. This phase aims to clarify the significance of the problem, often by quantifying its financial impact. The Critical to Quality (CTQ) factors are determined. |
| **Measure** | Identify difference between the current and required performance. Establish data collection procedures, determine key metrics and measurement methods. |
| **Analyze** | Identify the primary causes and critical factors that influence the process. |
| **Improve** | Implement changes, optimize performance, and verify the solutions to the problem. |
| **Control** | Document and standardize validated improvements, ensuring sustainability of the results. Continually monitor improvements to ensure long-term success. |

Within each phase of the DMAIC, several tools and techniques are available to use which depends heavily on the type of project. In Figure C.12 the various tools and techniques per phase are shown, which can help with specific aspects of the process improvement (Swarnakar & Vinodh, 2016).

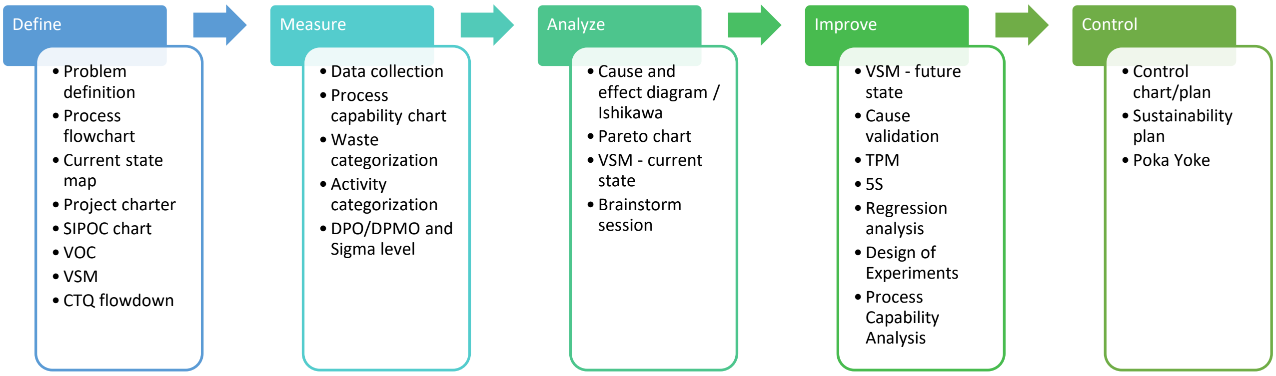


*Figure C.12: DMAIC tools*

### Comparison methodologies

SGA is a distinct method frequently applied within TQM frameworks. TQM and LSS share many values and objectives and are highly compatible, as both frameworks depend on statistical methods. TQM offers a holistic approach which is company-wide and involves all stakeholders, while LSS provides a framework for rapid process improvements (Salah et al., 2010). While LSS and SGA use different tools and techniques, they both can be used in process improvement projects. Figure C.13 shows the relationship between the PDCA cycle, DMAIC and SGA improvement methods.

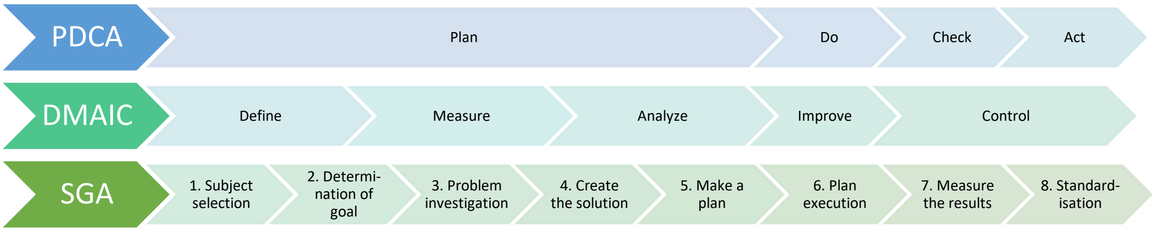


*Figure C.13: PDCA cycle vs. DMAIC vs. SGA*

Table C.4 provides a comparison of the Lean Six Sigma, TQM, and the SGA methodologies across various variables, highlighting their differences and similarities in terms of methodology, nature of problem, focus, tools and techniques, level of implementation, involvement, and timeline (de Groot et al., 2006; Ejsmont & Łyjak, 2016; Sokovic et al., 2010; Swarnakar & Vinodh, 2016; Theisens, 2021).

*Table C.4: Comparison of the LSS, TQM, and SGA strategies.*

| | **Strategy** | | |
|---|---|---|---|
| **Variable** | **LSS** | **TQM** | **SGA** |
| Method | DMAIC methodology | PDCA cycle | Group-based problem-solving with use of PDCA framework |
| Nature of problem | Complex problems, focus on data-driven analysis and statistical tools | Immediate and systematic problems | Problems that can be solved through knowledge and experience of frontline employees |
| Focus | Reducing variation, eliminating defects, and improving process efficiency | Meeting customer needs, continuous improvement, and improving organizational culture | Quick wins, visible improvements, engaging frontline employees |
| Tools / techniques | Statistical tools and techniques | Quality management tools | Problem-solving tools and techniques, such as brainstorming, root cause analysis, and 5-whys |
| Level of implementation | Both organization-wide and process levels | Organization-wide implementation | Typically implemented at process level, focusing on specific areas, processes or machines |
| Involvement | Project teams or specialists in process improvement methodologies | All levels of the organization | Small groups of frontline employees or cross-functional team |
| Timeline | Structured, time-bound improvement projects with defined milestones | Ongoing and gradual improvement efforts integrated into daily operations. | Rapid and visible improvements with short implementation timelines, often around 3 months |

### C.3. Choice of Method

The choice between the Lean Six Sigma, TQM, or SGA method depends on factors such as the complexity of the problem, available resources, and the level of involvement desired from employees. DMAIC is often used for in-depth analysis of root causes, PDCA more for iterative testing of solutions, and SGA for engaging frontline workers in implementing improvements.

The main focus of this research is identifying the issues and potential root causes regarding the processes of the keg line to reduce the costs due to rejected kegs. This scope of the research is best represented by the DMAIC method. However, the final steps of the DMAIC method (Improve and Control) are out of scope for this research. The DMAIC approach is often mentioned for quality improvement and for reducing the rejection rate within a manufacturing company. In conclusion, the DMA phases of the DMAIC method is used for this research to reduce the costs due to rejected kegs.