MASTER THESIS

INDUSTRIAL ENGINEERING & MANAGEMENT

UNIVERSITY OF TWENTE

A case study on improving the Machine Efficiency of Grolsch' keg line under continuous operation

Floor Veuger
February 2024

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Preface

This Master Thesis "A case study on improving the Machine Efficiency of Grolsch' keg line under continuous operation" concludes my Master Industrial Engineering and Management at the University of Twente. Executing the research and finalizing this Master Thesis was not possible without the help of others. I would like to take this opportunity to thank everyone who helped me realizing during this research.

First of all, I would like to thank Grolsch for the opportunity and the confidence in me to carry out the research within their brewery. A special thanks to **Peter Koel** for his daily support, weekly meetings, fruitful discussions and insights within the packaging lines. His insights and critical questions improved my analysis on the keg line and improved my professional skills.

Secondly, I would like to thank both my supervisors from the University of Twente. I would like to thank my first supervisor, **Matthieu van der Heijden** for his feedback sessions to improve the academic level of my Master Thesis. In addition, his in-depth suggestions improved the quality of my Master Thesis. I would also like to thank my second supervisor, **Wieteke de Kogel -Polak** for our conversations about Lean and production related issues. She gave me new insights and our conversations always led to new ideas for my Master Thesis.

Next, a word of thanks to the **operators** of the keg line, since they talked me through the line and took the time to answer all my questions. In addition, I would like to thank **Erich Brandes** and **Reinier Martens** for their help on implementing the suggestions for the improvement interventions within this research.

A special thanks to **Arjen Pille** and **Mark Snuverink** for having me in their office and the enjoyable moments we had. Also, a special thanks to all other employees of the **Packaging department** for guiding me through the brewery and for the fun talks during the Friday lunch as well as the walks during the break.

A lovely thanks to **Lisa Nonhof** for our biweekly buddy meetings. You were always there for me and supplied me with fresh energy after each meeting.

Of course, I would like to thank my friends and family for the support during the last period of my study. Finally, I want to thank the most special person to me, **Jantinus Wisman**. During moments of stress, you always cheered me up. You also ensured I took time to relax in the evenings and on weekends. Without you, I would not have been able to even start this master's degree let alone completed. Thanks for your everlasting support.

I wish you a pleasant reading.

Floor Veuger

Hengelo, February 2024

Management Summary

Problem description

In order to maintain competitiveness, Grolsch needs to continuously improve the efficiency of their packaging lines. This applies also to the keg line, where kegs are processed and filled with beer. The primary objective of this research is to increase the performance of the keg line, specifically the Machine Efficiency (ME). The current Machine Efficiency falls short of the target and the causes are divided in three categories: machine losses, speed loss and production stops. Preliminary research revealed speed loss accounts for the highest reduction in Machine Efficiency. However, the reasons for speed loss are not known and there is an absence of a standardized methodology in order to detect these issues in an early stage, ranking them and to overcome them. This leads to the following research question:

"What are the root causes for speed loss on the keg line, in what way could these issues have been revealed earlier to mitigate the impact and which implementation plans should be defined in order to decrease the speed loss on the keg line of Grolsch in order to increase the keg line ME?"

Approach

We conducted a CIMM (Continuous Improvement Maturity Model) scan at Grolsch in order to find the starting point for (Lean) improvement. The results showed a lack of standardization within Grolsch (9 out of 25 points), where standards and procedures form the basis of the continuous improvement process. Therefore, we developed a proactive standardized method for (early) detection, ranking/selection and solving the issues. In order to execute the standardized method for (early) detection, we developed flowcharts for:

1. Evaluating KPIs (machine capacities, cycle time bottleneck and downtime machines)
2. Operator Impact
3. Visual signals of waste

In addition, we determined the following criteria for the standardized ranking and selection method to assign the values:

1. Feasibility (time for problem investment/execution with amount of investment)
2. Impact Operator (total time per shift linked to issue)
3. Increase Production (when issue is solved)

After determining the values for these criteria, the product of the criteria values results in the Operational Improvement Potential, which determines the sequence of solving the issues. Lastly, the Small Group Activity (SGA) approach is most applicable to Grolsch, where Lean Six Sigma tools are proposed to use within each SGA step based on the root cause.

Results

The case study of applying the standardized method for proactive problem mitigation showed several issues on the keg line. Some of these issues became 'normal' during the last years and therefore were never solved. This was the case for 19.5l keg disruptions at the keg destacker which occurs since they began processing 19.5l kegs several years ago. We also detected several issues which did not affect the output of the line directly, but could cause issues in the future. This observation led to an early detection of a decreased transport processing time within the wash and filling station. As a result, actions were taken in order to overcome a significant effect of 1.73% ME on the output of the line on an annual basis.

The case study of the standardized method for an (early) detection of causes/issues and ranking/selection revealed a top five root causes. These have have the highest impact on the keg line ME and should be resolved first. These root causes are: unused space buffer capacity both in front and after the wash and filling station, 19.5l keg disruptions at the keg destacker, delay in transport speed within the wash and filling station and the speed of the empty keg turner.

The case study of solving the top five root causes showed an effective combination of SGA and Lean Six Sigma techniques. SGA ensured the step wise structure, where Lean Six Sigma tools are used within each SGA step resulting in a comprehensive analysis. Except for the first step of the SGA method (subject selection), we used our standardized method for (early) detection and selection. The results of the case study of solving the top five root causes are:

1. The buffer capacity in front of the wash and filling station is increased by a total of six spots by implementing an Input Rate Control for the conveyor, resulting in 37.1 extra kegs processed per day.
2. The buffer capacity after the wash and filling station is increased by a total of nine spots by relocating sensors, resulting in 66.5 extra kegs processed per day.
3. 19.5l keg disruptions at the keg destacker were resolved through adjustments to conveyor control, adjusting the iron frame and ensuring constant lubrication in order to minimize the operator impact: decrease from 8.8 to 1 on a scale of 1 to 10. It resulted in a success rate of the keg destacker of 99.53% per movement without a disruption.
4. Replacing a transport beam within the wash and filling station reduced transport time, with potential benefits in terms of a seven-month payback period and a 12% reduction in speed loss when replacing all transport beams.
5. Maintaining a 10% overcapacity of the empty keg turner contributed to a 0.37% increase in Machine Efficiency. Additionally, a comparison suggests a higher Machine Efficiency increase for a two second reduction in cycle time compared to one second.

Conclusion and recommendations

These five case studies join a total of €63,941 for investments and a total yield of €246,231 per year as shown in Table 0.1. There were no investment required for a buffer increase and eliminating the 19.5l keg disruptions at the keg destacker. All materials were available within Grolsch and since the costs of the mechanic and instrument technician are not investments, the investments for these three are determined as zero. For the increased speed of the empty keg turner we took into account the yield for an overcapacity of 10% for the empty keg turner. An ME increase is already realized within this research of 3.89% and an additional 0.37% ME increase for upcoming year can be realized by decreasing the cycle time of the empty keg turner of 1.4, 0.8 and 0.6 seconds for respectively 19.5l kegs, 30l kegs and 50l Grolsch kegs.

Table 0.1: Results five case studies towards ME increase (%), yield per year and investment

	Increase ME (%)	**Yield per year**	**Investment**
Increased buffer in front of wash and filling station	0.71	€ 41,003	€ 0
Increased buffer after wash and filling station	0.86	€ 49,665	€ 0
Eliminate 19.5l keg disruptions	0.59	€ 33,987	€ 0
Replacing transport beams	1.73	€ 100,026	€ 58,441
Increase speed empty keg turner	0.37	€ 21,550	€ 5,500
Total	**4.26**	**€ 246,231**	**€ 63,941**

In order to increase Grolsch' keg line ME further, all other issues found within this research should be solved and a Process Engineer should be responsible for both maintaining the issue list and executing the interventions. This Process Engineer should also be responsible for executing the standardized (early) detection method every week and one/two months (based on the predetermined criteria). In addition, the developed standardized method for proactive problem mitigation is developed in such a way that it can be applied to other manufacturing lines within Grolsch. We recommend to apply this method to all other manufacturing lines within Grolsch, starting with Line 2 since it is under performing.

Contents

Acronyms

CIMM Continuous Improvement Maturity Model
CL Control Limit
CTQ Critical To Quality

DPMO Defects Per Million Opportunities

EVOP EVolutionary OPeration

FE Factory Efficiency

KPI Key Performance Indicator

LCL Lower Control Limit

ME Machine Efficiency
MR Moving Range

OIP Operational Improvement Potential

PLC Programmable Logic Controller

SGA Small Group Activity
SKU Stock Keeping Unit

UCL Upper Control Limit

VOB Voice Of Business
VOE Voice Of Employee

1 Introduction

1.1 Company description

Grolsche Bierbrouwerij Nederland (Grolsch) is a Dutch brewery since 1615, which is a subsidiary of Asahi Group Holdings since 2016. Grolsch is known for their own brand Grolsch, but they also brew other brands such as De Klok, Kornuit and several other brands such as Peroni. Grolsch consist of several departments as Sales, Marketing, Finance & Commercial Services, Wholesale and Supply Chain & Logistics. Within the Supply Chain & Logistics department, the production and bottling of beers takes place in the sub departments Brewing and Packaging. The focus of this project is related to the Packaging department of Grolsch. Grolsch has three production halls where the bottling of different products takes place. Each hall consist of one or more different lines where each line fills bottles, cans or kegs. There is one line for kegs and this line will be researched during this project. There are three different sizes of kegs, which are 19.5, 30 and 50 liters. All these kegs can be filled with either Grolsch Pils, Grolsch Weizen, Peroni or several special beers, which results in more than 20 different SKUs. The kegs undergo several steps from arriving at the keg line, turning, exterior cleaning, inside cleaning, filling, turning and cap placement. A complete overview is given in Figure 1.1, where the wash and filling station consist of five parallel wash and filling lines with each eight heads: six for washing and two for filling.

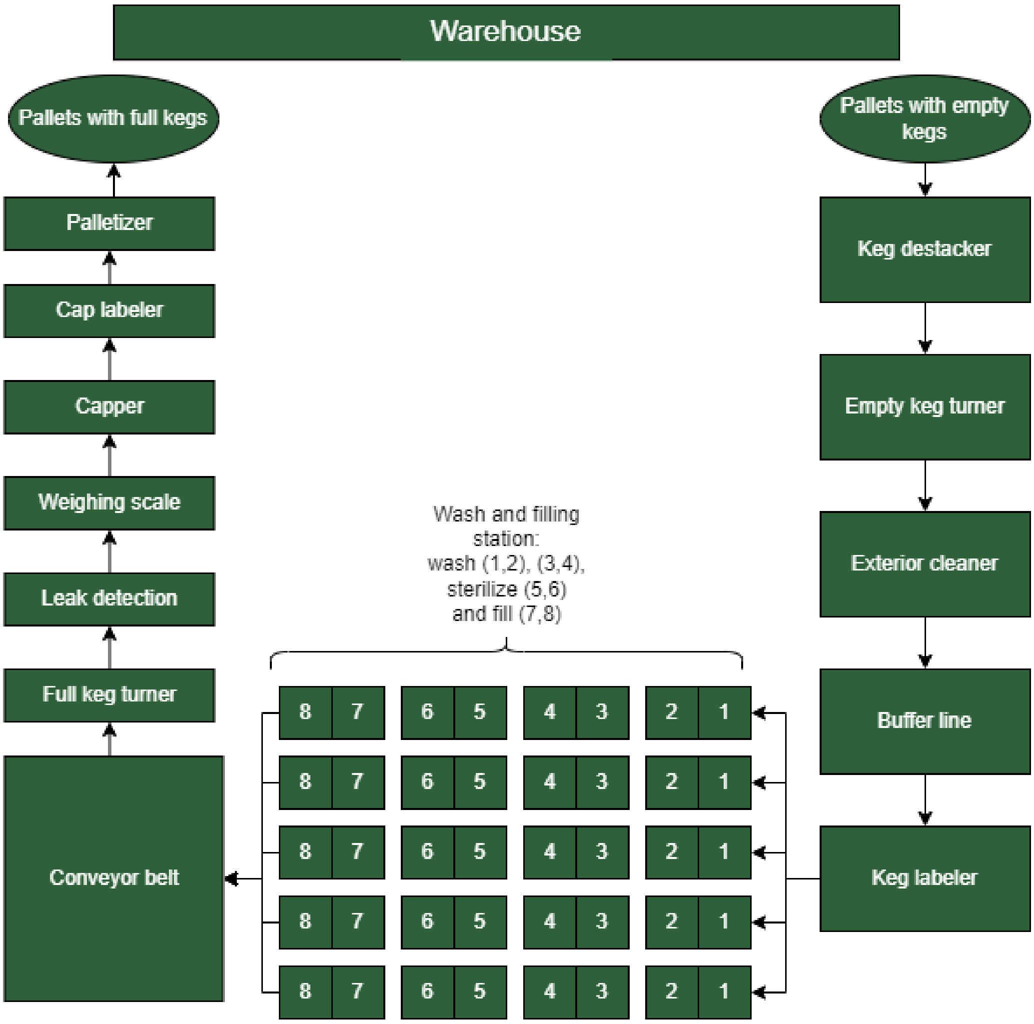


Figure 1.1: Automated keg production line with all machines

1.2 Research motivation

The goal of Grolsch is to create a meaningful connection between people, meet the demand and the expectations of the customers and to contribute to a sustainable future. This can be achieved by among other things continuously improving the performance of the processes. Several Key Performance Indicators (KPIs) are measured within Grolsch and since this research focuses on the operational side, the KPI efficiency will be the most important KPI. All packaging lines have inherent design and capacity limitations and any downtime translates into a loss of potential production output. In a beverage packaging environment like Grolsch, the maximum utilisation of installed capacity is critical to productivity, packaged product quality and the minimization of waste. Efficiency losses have an adverse effect on a plant's ability to meet sales demands and can impact on customer needs and expectations.

Asahi efficiency calculations are based on the use of two separate time frames: calendar hours (the hours a packaging line is physically available for use, irrespective of whether it is being used or not) and full production hours (the time it would take to produce a given volume of product with the line operating at rated speed). There are a number of different efficiency measures with each depicting a different aspect of equipment/plant performance. Most measures function on a time basis, using different defined times as a reference. These defined times are determined which allow for specific time losses that are inherent to the beverage packing process. Starting from the base of Calendar Hours, Figure 1.2 shows a graphic of how Grolsch defines the various defined times and time loss allowances used in efficiency calculations and depicts the relationship between them. This schematic of Grolsch is derived from the Overall Equipment Effectiveness (OEE) for measuring the manufacturing productivity as described by (He et al., 2018). Despite literature, Asahi and therefore Grolsch, calculate the Machine Efficiency and the Factory Efficiency of a packaging line instead of the OEE.

In order to make the figure comprehensible, each time loss will be explained shortly. Capacity Losses are hours where there are no paid operators at the line (weekends, stoppage weeks). Paid Factory Hours Adjustments means unscheduled idle time (adjustments of available production time outside the brewery's sphere of influence, as supply issues, legal stops or labor adjustments). Actual Maintenance and Cleaning (M&C) means preventive period maintenance and scheduled cleaning at the beginning and end of the week. Allowed Stops include startup time, shut down time, line converting, beer changes etc. At last, Service Stops is downtime caused by external factors as warehouse malfunctions or the absence of beer availability.

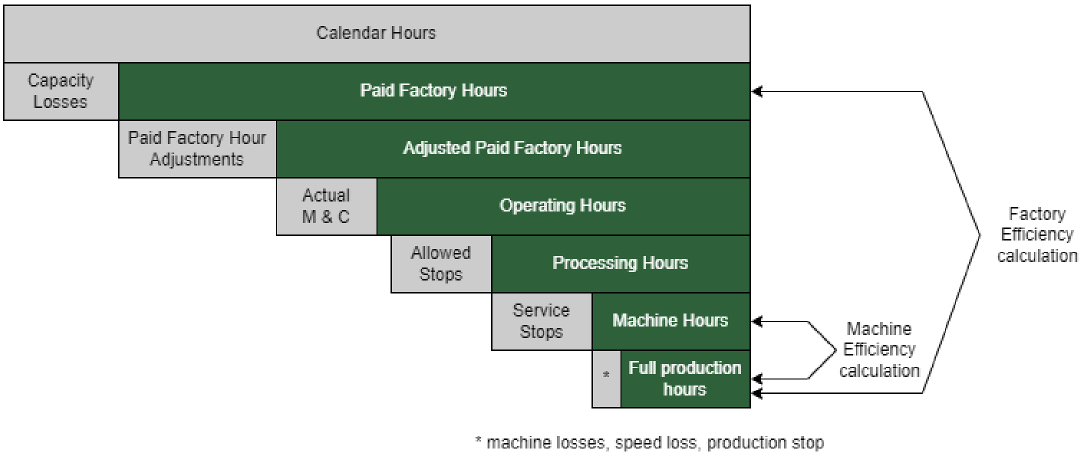


Figure 1.2: Factory Efficiency and Machine Efficiency calculation for a packaging line

In this research, the most important KPIs are Factory Efficiency (FE) and the Machine Efficiency (ME) of the keg line. FE is a measure of how efficient a line has performed relative to the time period available for production and/or maintenance work on the line (Asahi, 2022). It is calculated by the full production hours divided by the Factory Paid Hours, which equals the time a production line runs compared to the available time of personnel for production. ME is a measure of how efficiently the line has performed relative to the time period available once adjustments for actual Maintenance & Cleaning time and actual allowed stops/service stops have been made (Asahi, 2022). It is calculated by the Full Production Hours divided by the Machine Hours, which equals the time a line is truly operating.

1.3 Problem description

As described in the previous section, ME is an important KPI for the different packaging lines at Grolsch. The ME of Grolsch' keg packaging line drops behind with regard to the ambition and is also lower in 2023 in comparison with 2022. Figure 1.3 shows the ME performance of 2022 and January until and including August 2023, where the light green line shows the ambition for producing kegs and the dark green histogram shows the realized ME per month. The ME ambition per packaging line of the following year is always determined at the end of last year. Additionally, other breweries from Asahi are performing around $X\%$ while the keg line of Grolsch is performing around $X\%$.

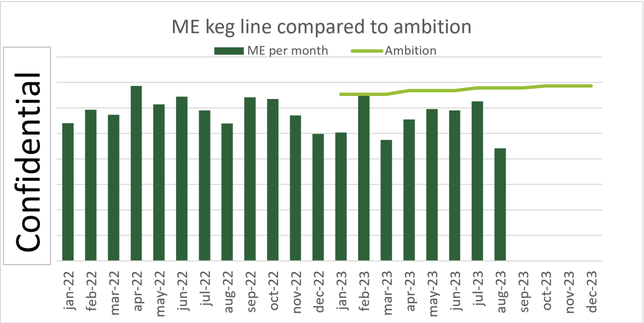


Figure 1.3: ME keg line compared to ambition

Figure 1.4 shows the three categories for losses towards the ME, which are machine losses (machine malfunctions), speed loss (lower speed filling machine due to other malfunctions on the line/disapprovals) and production stops (production stops for no technical reasons, such as shortage of personnel). At the end of this section, we explain the reason for the green circle around the speed loss category.

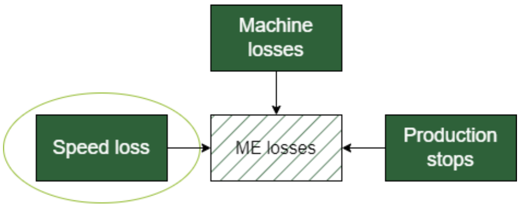


Figure 1.4: ME losses categories

In order to determine on which of the three categories the research will focus, a first analysis is conducted in order to find the distribution of the losses towards ME. The available data of January 2022 till August 2023 is used for this analysis and the results are shown in Figure 1.5. It shows ME losses for different categories, as shown in Figure 1.4, where ME losses per machine are shown separately. To increase readability, machine names are dropped and replaced by machine numbers (1-35). This analysis shows speed loss accounts for 34.5% and 35% of the total losses according to respectively 2022 and the first eight months of 2023. Besides, the machine losses per machine are known and directly linked to the machine on the keg line and therefore the cause of which machine is malfunctioning and the reason is generally known. However, speed losses are calculated afterwards and not specified, resulting in an unknown reason for speed loss.

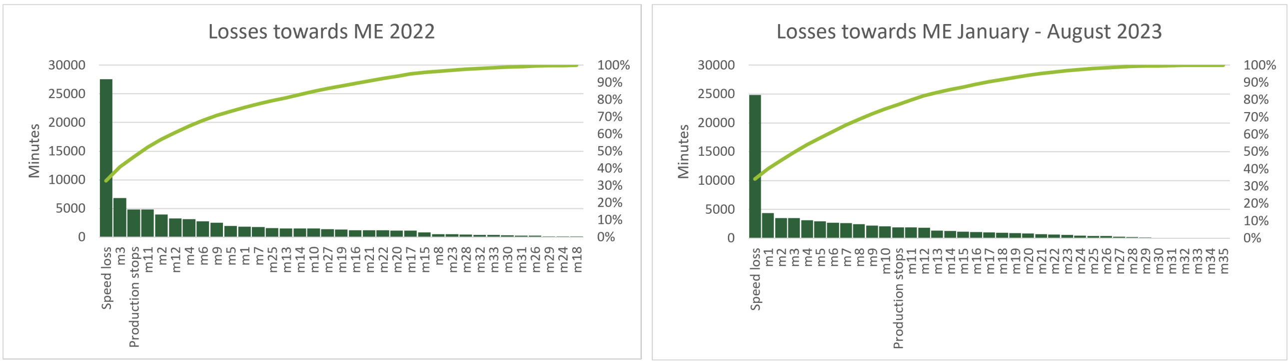


Figure 1.5: ME losses in minutes per category for 2022 and January - August 2023

The keg line stoppages can also be calculated towards the Paid Factory Hours. This means that the number of minutes for the specific stoppage is divided by the Paid Factory Hours (for the specific period). An analysis is executed for the keg line with data from 2022 and the first eight months of 2023. This analysis includes 35 stoppages, but in order to increase the readability, only a selection of the five highest categories of 2022 and the first eight months of 2023 are visualized in Table 1.1 and 1.2 respectively. The results from this analysis show a structural high speed loss around 10% where all other 35 stoppages have a average percentage of 0.54% towards the Paid Factory Hours.

Table 1.1: Stoppages with regard to the Paid Factory Hours 2022

Category	***2022***
Speed loss	9.7%
Palletizer (m3)	2.4%
01 KEG line (m11)	1.7%
Steam generator (m2)	1.4%
Empty keg conveyor belt (m12)	1.2%

Table 1.2: Stoppages with regard to the Paid Factory Hours January - August 2023

Category	***2023***
Speed loss	10.2%
Wash and filling station (m1)	1.9%
Leak detection (m4)	1.7%
Palletizer (m3)	1.6%
Steam generator (m2)	1.5%

The combination of the results from these two analysis show the speed loss has a significant influence on the keg line and due to the fact the reasons for speed loss are unknown, the focus of this research will be on the ME speed loss of the keg line as visualized by the circle in Figure 1.4. From this first data analysis and the problem description, the following problem statement is defined:

"The speed loss has a considerable effect on the overall ME losses of the keg line and the root causes of the speed loss are unknown. In addition, there is no standardized method within Grolsch in order to detect these issues in an early stage to mitigate the effects, ranking the issues even as a standardized method to overcome these issues."

1.4 Research objective

Based on the problem description and the problem statement, the goal of this research is to find root causes of speed loss on the keg line of Grolsch and define implementation plans for interventions in order to decrease the speed loss and improve the keg line ME. With the problem description and research objective in mind, the main research question has been formulated as follows:

What are the root causes for speed loss on the keg line, in what way could these issues have been revealed earlier to mitigate the impact and which implementation plans should be defined in order to decrease the speed loss on the keg line of Grolsch in order to increase the keg line ME?

In order to answer the main research question and propose a solution to the problem, it is convenient to list the deliverables that are obtained during this research:
Context study: This study shows the current process of the keg line including the machines and an identification of the different SKUs on the keg line. This section will also include an in depth analysis on the ME speed loss.

Literature study: This study shows the methods available in literature to detect causes in an early stage and how to approach them. Within this study, we also elaborate on the elements which should be used in the method which will developed to find root causes within a manufacturing process. It also contains the methods for implementation plans and case studies on which steps have to be taken in order to overcome the found causes.

Case study: In this study, the root causes for speed loss and a decrease in ME are found and explained. This case study also shows the root causes which are solved in order to increase the ME of Grolsch' keg line. At last, it is important to include the control phase of the interventions to guarantee the results and prevent relapse.

1.5 Research questions and approach

To answer the research question stated in the previous section, several sub-questions are needed. These sub-questions are answered in different chapters to answer the research question. The questions are subdivided in several chapters.

Chapter 2: Context study
1.1 How is the keg line designed and how are kegs processed?
1.2 How is the keg line currently performing according to speed loss?

To answer these sub-question, several Gemba walks (visiting the workplace you want to improve) will be executed on the keg line to assess the performing and get a first impression of the losses on the keg line. Conversations will be held with operators and also with Technical Service to understand the error messages and have conversations about issues that occur frequently on the keg line. In addition, we will analyse the speed losses in depth. Also, a flow chart of the keg line will be developed including all the machines and several checks where after these machines will be explained in order to understand the process.

Chapter 3: Literature study
2.1 How is speed loss characterized in literature?
2.2 Which lean methods are used in literature to improve performance?
2.3 Which assessments are available in literature for determining organizations' maturity level?
2.4 Which methods are available in literature to find root causes in a production line in an early stage?
2.5 Which methods and tools are used in literature for developing implementation plans/case studies?

This study shows the different approaches which are available in literature in order to detect causes and how to approach them. This study also shows the different assessments which can be used in order to find the Maturity level of an organization towards Lean and which is most applicable for Grolsch. In addition, we dive deeper into the elements which can be used for an early detection of issues. At last, we elaborate on the methods for implementation plans/case studies to deduct the highest impact causes on ME.

Chapter 4: Method
3.1 How should the (early) detection method be designed in order to detect root causes in an early stage?
3.2 In what systematic way (ranking and selection) should the root causes be prioritized to ascertain the addressed sequence?
3.3 How should the design for the root causes be developed to decrease the time between detection and solving?

3.4 Which systematic approach is suitable to perform case studies for interventions to overcome the root causes?

This section shows the method, which can be used in order to find root causes within an automated manufacturing process in an early stage. Additionally, the standardized method to prioritize the root causes are elaborated. At last, we elaborate on the systematic approach which is suitable to perform case studies of the causes which have the highest score according to this standardized method.

Chapter 5: Process improvement case study
4.1 What are the root causes for speed loss on the keg line?
4.2 Which interventions are feasible and selected to develop implementation plans for?
4.3 What are the (first) results of the interventions?
4.4 Which steps have to be taken in order to guarantee the results and prevent relapse?

This chapter shows a case study on the keg line of Grolsch by the application of the methods described in Chapter 4. Chapter 5 elaborates on the root causes for speed losses which effect the ME the most. In addition, the interventions are selected by applying the method described in Chapter 4 in order to develop implementation plans and solve the root causes. Next, the steps on how to implement interventions which are shown in the literature study will be applied. At last, the results, as far as possible, are shown in this chapter. In order to prevent a relapse, this chapter contains a plan on how the realized improvement interventions can guarantee reduced speed loss and an increased ME in the future and prevent relapse.

1.6 Scientific contribution

This research will execute a case study on finding root causes of speed loss in a keg production line and select, which improvement interventions have the most potency/feasibility in order to increase the ME. Existing information on finding root causes and how to execute improvement interventions are mostly superficial and not in depth based on the preliminary literature research by the researcher. This research will show both the methods as the steps for executing improvement interventions with a case study on the keg line. This method can be used by the Packaging department of Grolsch to identify root causes and execute improvement interventions on other packaging lines. After the research is conducted, the method can also be applied on other manufacturing processes, since it will be made for all automated manufacturing processes. This method can therefore be used as red line approach for other production lines outside the walls of Grolsch.

1.7 Scope

The focus of this research lies on the speed loss of the keg production line of Grolsch according to the application of the developed method for early problem detection and mitigation, and for the case studies for improving ME. The case study only applies to the keg line of Grolsch and all other Packaging lines of Grolsch are excluded for this part. The method will be formulated in a way that ensures its applicability to all other packaging lines within Grolsch and can be applied by other automated manufacturing lines. In the time frame of the execution of this research, physical changes will be made in the keg line. The pallet destacker and the palletizer which respectively separates the pallets with kegs and stacks kegs on pallets are replaced by new machines. Due to these changes in the beginning and at the end of the keg line, the focus on these machines are excluded from this research.

2 Context analysis: Production and process description

Section 2.1 elaborates on the different produced SKUs on the keg line. These kegs undergo several processes and in order to understand these steps a flow chart is developed, which is shown and explained in Section 2.2. In between the machines on the keg line, buffers are used to absorb minor disruptions which are explained in Section 2.2.1. An in depth analysis of the speed loss for the different kegs is conducted and the results are shown in Section 2.3. At last, 2.4 already shows the root causes of speed loss which will be solved within Section 5.4-5.7.

2.1 SKUs of the keg line

The keg line of Grolsch only fills kegs of 19.5, 30 and 50 liters (Figure 2.1) with several different beers, such as Grolsch Pils, Herfstbok, IPA, Tripel, Zomerbok, Radler and Peroni, which results in over 20 different SKUs. In order to determine the distribution between the three different keg sizes, data from January till and including August 2023 is analyzed according to the produced hectoliters, machine hours, Paid Factory Hours and number of kegs according to the total amount produced. The analysis shows that the distributions for the three kegs sizes are equal according to the produced hectoliters, machine hours, Paid Factory Hours and number of kegs. Therefore, Table 2.1 only displays the distribution for the Paid Factory Hours per keg size. The analysis shows the highest proportion is attributed to 50 liter kegs and the second highest proportion is 19.5 liter kegs for all different analysis (produced hectoliters, machine hours, Paid Factory Hours and number of kegs). In February 2023 Grolsch started to fill kegs with Peroni in 19.5 and 50 liter kegs and the production will be up scaled in the upcoming periods, where the increase of production numbers is even higher for the 50 liters compared with the 19.5 liters.

Figure 2.1: 19.5, 30 and 50 liter keg respectively

Table 2.1: Keg distribution over January - August 2023

Keg	*Paid Factory Hours*
19.5 liter	33.9%
30 liter	18.3%
50 liter	47.8%
Total	**100%**

2.2 Production process

In order to convert the empty dirty kegs into clean kegs filled with beer, a keg undergoes several process steps as shown in Figure 1.1. The keg manufacturing line is arranged according the U-line principle, where the U-shape line organizes machines along an U-shaped configuration corresponding to the sequential order of production operations. It satisfies the flow manufacturing principle, where operators must be multi-skilled to operate several different machines within the production process (Miltenburg, 2001).

The process steps of the keg line are visualized in the flow chart of Figure 2.2 and will be explained below. Machine figures of the keg line are shown in Appendix A to increase the readability of this section. Subsequent to the explanation of each machine in this section, a letter is provided to denote the corresponding figure in Appendix A.

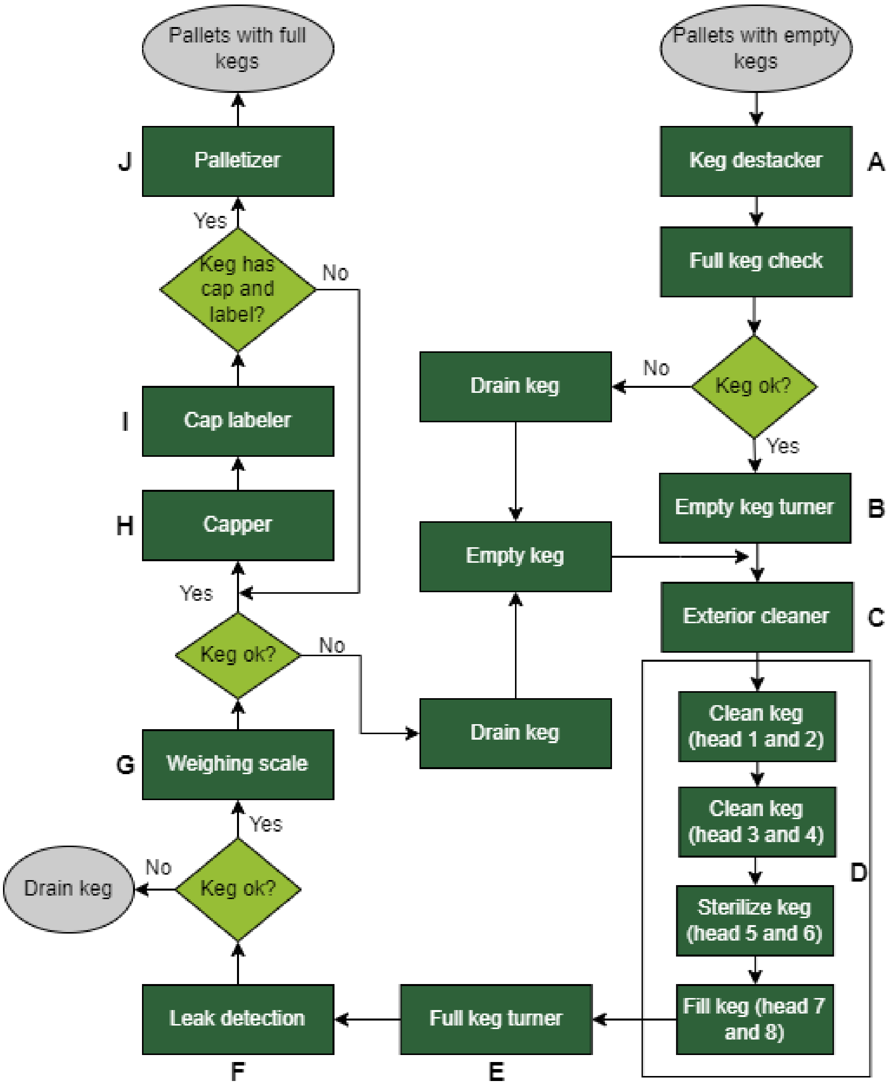


Figure 2.2: Flowchart of the process steps on the keg line

Empty kegs are delivered by the warehouse to the keg line by an automated system (Swisslog). The keg destacker (A) segregates pallets and transfers kegs onto the conveyor belt, with the right side up (fitting on top). However, kegs are filled upside down. Upside down inside cleaning guarantees the keg is fully drained and filling upside down prevents an excessive amount of foam production. For this purpose, two kegs are turned upside down simultaneously (B) and placed on the conveyor belt. As mentioned in Section 2.1, kegs of different sizes are filled with beer. Figure 2.1 shows a smaller circumference for a 19.5 liter keg compared with a 30 and 50 liter keg. In order to process the 19.5 liter kegs in the same way as the 30 and 50 liters, which have the same circumference, 19.5 liter kegs are positioned in a dummy, as shown in Figure 2.3 and Figure 2.4, when turned upside down. When the kegs are turned upside down, they are transported by a conveyor belt into the exterior cleaner (C). This is a 20 meter long machine where kegs are transported by a conveyor belt through the cleaner in order to remove stickers and labels. Clean kegs are then transported by a conveyor belt to the wash and filling station (D).

The wash and filling station consist of five parallel wash and filling lines with each eight heads. The kegs are cleaned at head one and two with compressed air, water and lye. Head three and four also have the purpose of washing, but then with acid, air and water. Head five and six ensure keg sterilisation with steam before the kegs are filled with beer at head seven and eight. Two kegs arrive simultaneously at one of the five wash and filling lines and therefore it is important to mention that a keg is processed by either head 1, 3, 5 and 7 or head 2, 4, 6 and 8 i.e. kegs are passing through the wash and filling station in groups of two. Consequently, a keg always skips a spot which is possible due to the fact that head 1&2 have the same function. This applies also for the combination of head 3&4, head 5&6 and head 7&8. After the kegs are filled at head 7 and 8, two full kegs are rejected from the wash and filling station and transported by a conveyor to the keg turner (E). Turned kegs (fitting on top), are checked on leakages (F). A leak keg is emptied and undergoes revision at an external Grolsch facility. If there are no leakages, kegs are transported to the weighing scale (G) in order to check if the keg is full. The keg is full when the weight of the keg is above a predefined level. Next, a cap is placed (H) to protect the keg valve from mold and dirt. Figure 2.2 shows the process step labelling, which means that the best before date is printed on the cap (I). This only applies to the kegs sold in the Netherlands with an exception of Weizen. All other caps, for Grolsch export and Peroni for example, the best before date is pre-printed on the caps and therefore the kegs are transported through the keg labeler without being processed. The last step in the process, is stacking the kegs on pallets (J) for distribution to the customer.

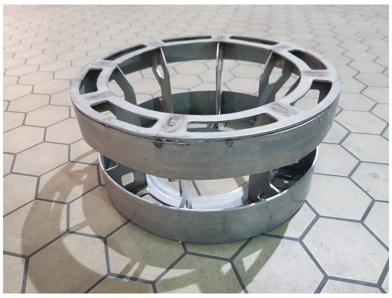


Figure 2.3: Dummy

Figure 2.4: Dummy with 19.5 liter keg

2.2.1 Buffers

Grolsch' keg line is designed around the critical machine (bottleneck), which is the slowest and typically the most expensive item on the line, the wash and filling station. The wash and filling station is also the most important machine on the line, because it performs the primary function of the line: filling the kegs with beer. The performance of this machine, which determines whether the line is operating or not, is used to measure the performance of the line also called the bottleneck of the line. In other words, if the wash and filling station is running, the line is running but when the wash and filling station is processing at a lower speed, there is speed loss. In general, the core machine of the line should be running as much as possible and starvation and blocking of this machine should be prevented. The machines on the keg line are connected by conveyors and transport the kegs from one machine to another. The conveyors are transport systems, not storage systems due to the fact the kegs are in line and cannot pass each other on the conveyors. This is also called dynamic accumulation according to Härte (1997). The conveyors also have another function: to create buffers to absorb small breakdowns on the line. Buffers between the machines in front of the wash and filling station are present in order to absorb small breakdowns of upstream machines causing the wash and filling station to produce a little longer compared with a situation without buffers. These buffers are called anti-starve buffers. On the other hand, anti-block buffers are present downstream of the wash and filling station and have the purpose to prevent the wash and filling station is blocked by full kegs and therefore not able to transport full kegs out of the wash and filling station. In an ideal situation, the buffers in front of the wash and filling station are full and the buffers after the wash and filling station are empty. Within this ideal situation, the critical machine has a continuous supply of kegs and enough space to transport kegs to the next station. In essence, there is no difference in the number of spots for the different SKUs, since the dummies ensure an equal circumference of 19.5l kegs compared with 30 and 50 liter kegs.

2.3 Variation in keg speed loss

Speed loss is already shortly explained in Section 1.3, but this section shows a better understanding of the keg line speed loss. Speed loss can be described as the production speed is lower than the line rating of the wash and filling station as a result of several malfunctions or disapprovals on the line. These malfunctions or disapprovals occur at several spots on the line, for example in front of the wash and filling station, within the wash and filling station or after the wash and filling station. The malfunctions or disapprovals relate to several sub processes on the keg line and even can be related to specific SKUs. For example, stainless steel kegs are of poor quality compared with the black plastic kegs and cause issues on the line such as falling of a pallet. Another example relates to the 19.5 liter kegs with dummies: a lack in the supply of dummies causes delays in front of the wash and filling station. A fell keg in one of the lines of the wash and filling station results in a malfunction and therefore downtime of that specific line. A sign of a leak keg emerge at the leak detection, causing a rejected keg. Even if the wash and filling station has no issues, a leak keg is rejected and therefore does not count towards the production output causing speed loss. Only with these four examples, the lower speed or malfunctions occur at different sections of the keg line. In order to increase the clarity of the future analysis, we already divided the causes in four categories:

1. Speed loss in front of wash and filling station
2. Speed loss within wash and filling station
3. Speed loss after wash and filling station
4. Rejected kegs

We did not made a separate analysis for these four categories based on 19.5l, 30l and 50l, since most causes affect the speed loss for all different SKUs. Therefore, the causes based on 19.5l, 30l and 50l are not separated, but compared within the causes. If a root cause only affects the speed loss due to the volume of the keg, it is appointed separately. In order to gain insight into the speed loss for the different kegs of 19.5, 30 and 50 liters, the speed loss is calculated for each month (January 2022-August 2023) according to Equation 1.

$$\text{Speed loss in month n per keg capacity} = \frac{\sum_{i=0}^{I} S_{in}}{\sum_{i=0}^{I} S_{in} + \sum_{i=0}^{I} P_{in}} \tag{1}$$

where,
i: the number of SKUs being considered which are different for each keg capacity (19.5l, 30l and 50l)
S_{in}: speed loss in month n in minutes for SKU i
P_{in}: full Production Hours in month n in minutes for SKU i

Applying Formula 1 on the data set of 2022 and the first eight months of 2023 results in Figure 2.5. As shown in the figure, there is no speed loss for 30l kegs in December 2022 as a result of zero production hours for 30l kegs. These graphs show a higher speed loss for 30l and 50l in comparison with 19.5l kegs. This is due to the fact that Weizen is mostly produced in 19.5l kegs and the lead time in the wash and filling station takes longer for Weizen, so the line rating of the wash and filling machine is determined lower for 19.5l in comparison with 30l and 50l kegs.. When Peroni is filled in 19.5l kegs, the speed loss is lower, since the difference between line rating and the real speed of the wash and filling station is smaller resulting in a lower speed loss compared with the production of 19.5l Weizen.

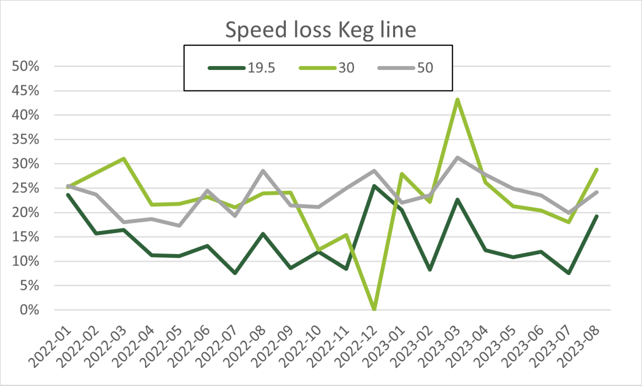


Figure 2.5: Speed loss per month for 19.5, 30 and 50 liters

Investigating the speed loss per month reveals variations when analyzing the same keg size (19.5l, 30l and 50l kegs), but there is no decreasing trend over time. It can be concluded that the speed loss ratio is high for each keg size and the causes should be investigated for both 19.5l, 30l and 50l kegs. Therefore, none of the three kegs are excluded from this research and we focus on 19.5l, 30l and 50l kegs.

2.4 Root causes of speed loss

Within this research we found the top five root causes of speed loss and a decreased ME by the methods developed in Section 4.2 and 4.3. Section 4.4 shows a standardized method in order to solve the top five issues. In order to fill this standardized method and find the right literature, we will elaborate shortly on the top five root causes found within this research within this section. The top five root causes are determined based on the methods described in Section 4.2 and 4.3, which are applied in respectively Section 5.1 and 5.2. The method for solving these root causes will be explained in Section 4.4 and the application of this method is explained in Section 5.4-5.7. The top five root causes are explained below in comparison with quantitative data.

Root cause 1: Delay in transport speed

First, we will focus on the delay in transport speed within the wash and filling station. The researcher performed two measurements per line per SKU resulting in 50 measurements where the results are shown in the boxplot of Figure 2.6. These measurements are used as indication for the transport speed and the measurements will be extended further on in this research (Section 5.1).

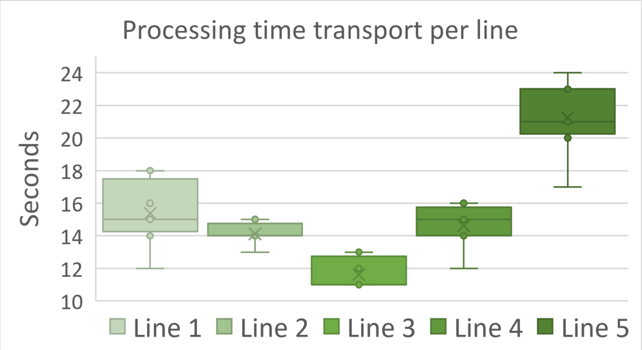


Figure 2.6: Transport seconds per line

The determined transport processing time for transport is 14 seconds to transport a keg within the wash and filling station. The transportation of a kegs takes place within the eight different heads of the wash and filling station. As explained in Section 2.2, two kegs arrive simultaneously at one filling line where the first keg is processed on head 1, 3, 5 and 7 and the second keg is processed on head 2, 4, 6 and 8. These two kegs are therefore processed together and the transport takes place between two heads. The results of the measurements show higher transport processing times (more than 14 seconds) for all lines except line 3, where the transport of a keg takes on average 7.5 seconds longer at line 5. This result directly influences speed loss for four of the five different lines for all different kegs and should be further investigated.

Root cause 2 and 3: Unused space buffer capacity (in front and after the wash and filling station)
In addition to the several manual measurements of the machines on the keg line, the researcher also performed Gemba walks where the second root cause is found. These Gemba walks are performed during various moments in order to see the differences and the equalities. The various moments refer to production in smooth moments, where everything takes place as planned, moments with operator shortage due to illness or breaks, but also at startup- and shutdown moments. Startups and shutdown moments are always in between the production of two different SKUs. When operators changed over all the machines, the buffer line (before the wash and filling station) is filled with empty kegs before the wash and filling station starts in order to ensure the wash and filling station has enough empty kegs to clean and fill. Gemba walks showed that some of these buffer spots are left empty even when the wash and filling station is not processing any kegs. An example is given in Figure 2.7 where the green kegs are spots filled with kegs on the buffer line and where the grey spots are left empty even though there is space for more kegs.

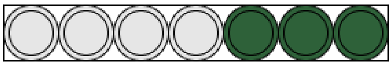


Figure 2.7: Buffer Example

The same accounts for spots after the wash and filling station when, such as when the palletizer experiences a malfunction. The buffer spots on the line are filled with kegs, since they cannot be processed by the palletizer, but also in this area, several spots are available for full kegs which are not used at moments of palletizer downtime. This relates to ten to twelve spots in front of the wash and filling station (in different places) and to ten spots (also in different places) after the wash and filling station. The researcher performed an analysis on the data from eight weeks of stable production between 16-7-2023 and 10-09-2023, where stoppages of the wash and filling station are caused by any of the machines on the keg line. We made a distinction between the machines before and after the wash and filling station and compared both the minutes of stoppages causing downtime of the wash and filling station. Comparing these numbers where the wash and filling station does not have any supply (caused by machine stoppages before the wash and filling station: rounded to 153 hours) and the wash and filling station cannot produce due to congestion (caused by machine stoppages after the wash and filling station: rounded to 132 hours), results in 15.7% more minutes of stoppages caused by machines before the wash and filling station.

Root cause 4: Downtime keg destacker
The third root cause of speed loss is the keg destacker. The keg destacker is one of the machines in the beginning of the keg line, where kegs are placed on the conveyor in order to be turned, cleaned, filled etc. Gemba walks during routine operations are conduced and revealed two predominant issues affecting the keg destacker: encoder error and disruptions caused by 19.5l kegs. These disruptions manifest only in the section between the keg destacker and the empty keg turner where no visual signal is provided along the keg line. Consequently, when an operator is solving issues on other machines or cleaning, they receive no immediate signal of a disruptive 19.5l keg, which stops the supply of kegs to the empty keg turner. Due to the presence of a buffer/queue of twelve kegs before the empty keg turner, the latter can continue processing for 1.5 minutes before an empty buffer occurs. After these 1.5 minutes the empty keg turner stops and empty kegs are blocked to enter the process causing an empty space surrounding the empty keg turner. At this moment, an operator notices something happened at the keg destacker and he can solve the problem. It therefore takes more than 1.5 minutes before the

operator realizes no new empty kegs enter the process and takes corrective action. The frequency of these occurrences (5 times per hour, which equals 40 times within one shift) requires the operators to remain stationed on the platform to mitigate disruptions. At moments where disruptions arise simultaneously on other machines on the line, operators do not have the opportunity to stay on the platform causing a longer delay (more than 1.5 minute) between occurrence and solving the disruptions.

Root cause 5: Speed empty keg turner
The empty keg turner is responsible for turning kegs in order to be filled upside down. This machine shows less than 10% overcapacity of the empty keg turner compared to the capacity of the wash and filling station when processing 50l kegs, which is the same for 30l and 19.5l kegs. The empty keg turner has a small overcapacity compared to the wash and filling station, causing a slow increasing buffer in comparison with the empty keg turner with an increased overcapacity. Therefore, it shows that the buffer between the empty keg turner and the wash and filling station should always be filled to catch small interruptions of the station in front of the wash and filling station. In addition, the capacity of the empty keg turner is lower for 50l Netherlands kegs in comparison with all other kegs, where the difference is around one second compared with 30l kegs and 19.5l kegs and more than half a second for 50l Peroni kegs which are of the same size.

2.5 Conclusion

The root causes which have the highest effect on the ME are:

1. Delay in transport within the wash and filling station (2.67% ME impact)
2. Unused buffer space in front the wash and filling station (1.03% ME impact)
3. Unused buffer space after the wash and filling station (1.01% ME impact)
4. Downtime of the keg destacker (due to 19.5l keg disruptions) (0.59% ME impact)
5. Speed empty keg turner (0.49% ME impact)

These root causes should be solved where the unused buffer spots should be divided, because the solution for increasing one buffer part will not have the same solution for another buffer part (for example, spots before the wash and filling station and spots after the wash and filling station). Changing the unused buffer spots into available buffer spots have different approaches and solutions, where each spot has different components to take into account, such as kegs pushed back on the main conveyor, safety protocols, capacity of conveyor chains, capacity of stoppers and the capacity of the machines before and after the buffer spots. The complexity of making implementation plans for these interventions to increase the ME of the keg line, is the combination of different interventions where each intervention has a complete different root cause and several methods have to be used in order to find interventions for solving the root causes.

First, we should link these root causes to speed loss within literature and find the factors which are responsible for speed loss. Next, we have to find literature about Lean techniques and elements to improve the performance of the keg line within Grolsch. In addition, there is an absence within Grolsch of a standardized method in order to detect speed loss issues in an (early) stage, a selecting method where to focus on and a standardized method in order to overcome the root causes. Therefore, we should find literature on how to develop these methods where issues can be detected in an automated production line, gather the issues and use a systematic approach to determine which issues should be tackled first. In order to solve the most important root causes on the keg line, a method needs to be developed which can be applied all these cases in order to find the interventions to solve these root causes. Methods in literature will be analyzed to select the most important steps and develop the methods. The literature study should also contain how to execute experiments, since experiments can be physical executed on the line due to the design of the keg line. This method is required, since test will be performed to analyse how different adjustments affect the problem and therefore the production.

3 Literature review

In this chapter we discuss the findings in literature, where we link speed loss factors to literature in Section 3.1. Section 3.2 elaborates on the principles within Lean for improved performance within manufacturing. Section 3.3 gives an overview of the methods to find the maturity level of a company towards Lean, where Section 3.3.1 explains the CIMM scan for discovering the maturity level of Grolsch. Section 3.4 shows the missing elements within Lean for an early detection of issues and which literature can be used to overcome this gap. Section 3.5 shows literature for criteria selection and ranking issues to develop implementation plans for. The method and tools for developing implementation plans to overcome the issues are explained in Section 3.6. The methods for determining the effect of the issues on the output of the line are explained in 3.7 and Section 3.8 shows the conclusion of this chapter.

3.1 Factors related to speed loss

Section 1.2 elaborated on the calculation scheme of FE and ME for a packaging line within Grolsch. This schematic of Grolsch is derived from the Overall Equipment Effectiveness (OEE) scheme for measuring manufacturing productivity as described by (He et al., 2018). Despite literature, Asahi and therefore Grolsch, calculate the ME and FE of a packaging line instead of the OEE. OEE is part of the Total Productive Maintenance (TPM) methodology (Nakajima, 1988). Through the optimization of equipment availability and performance, TPM seeks to increase overall productivity and quality. By regularly measuring OEE and making improvements, companies can reduce waste and increase productivity (Suryaprakash et al., 2021). According to Muchiri and Pintelon (2008) OEE categorizes reasons for poor performance and therefore provides the basis for setting improvement priorities and beginning of root cause analysis. They also mention it can point hidden capacity in a manufacturing process and lead to balanced flow. OEE identifies six big losses which should be identified and reduced. The six big losses are divided in three sections: downtime losses, speed losses, and quality losses. Speed losses are divided in two sections within breweries according to Pintelon et al. (2000):

- **Idling and minor stoppage losses** occur when production is interrupted by temporary malfunction or when a machine is idling.
- The discrepancy between the equipment's design speed and its actual operating speed is referred to as reduced **speed losses**. Within Grolsch, speed loss is determined as the difference between the actual operating speed and the rated speed (line rating) of the line.

TPM examined six efficiency losses, where speed loss gives significant opportunities to improve the efficiency in manufacturing operations according to Trattner et al. (2020). Nevertheless, Benjamin et al. (2015) states significant losses from lower operation speed are frequently ignored or undervalued and as one of the largest OEE losses, speed loss must be addressed immediately. Trattner et al. (2020) found fifteen different factors related to speed loss, organised them into ten categories and divided them into three dimensions: 1) technology factors, 2) human factors and 3) product factors, which is shown in Table 3.1 developed by Trattner et al. (2020). The top five root causes determined in Section 2.4 can be related to these factors identified in literature by Trattner et al. (2020) (Table 3.1):

- Delay in transport speed within the wash and filling station (**Equipment age**)
- Unused buffer space capacity in front of wash and filling station (**Queue capacity for work in progress**)
- Downtime keg destacker (**Production stops/material quality**)
- Unused buffer space capacity in front of wash and filling station (**Queue capacity for work in progress**)
- Speed empty keg turner (**Technological limitations**)

Each of these five causes belong to the dimension Technology according to Table 3.1, where Downtime keg destacker also belongs to the dimension Product. Therefore, solutions for these causes should be found within the technology of the keg line and in the material quality of the kegs.

Table 3.1: Dimensions and categories of speed loss contributors (Trattner et al., 2020)

Dimension	Category	Factors identified in the literature
Technology	Technology reliability	Machine Reliability Production stops Equipment wear Improper maintenance
	Technology limitations	Technological limitations Equipment age Queue capacity for work in progress
	Environmental limitations	Environmental limitations
Human	Operator inefficiency	Operator training Operator inefficiency
	Measurement error	Measurement error
	Planning issues	Production scheduling Ideal cycle time set too low Capacity utilisation
Product	Material availability	Material availability
	Material quality	Material quality Natural process variation Raw material mix
	Product variety	Product variety
	Product quality	Quality (finished goods)

Benjamin et al. (2015) also found issues in literature regarding speed loss in production, although significant, they are not sufficient in providing organizations detailed guidance on identifying the underlying factors that contribute to OEE losses like speed loss, lowering and even eliminating them. Although, Lean principles can be used to identify underlying factors of speed loss within a manufacturing environment.

3.2 Lean principles for improved performance

Lean elements, when effectively incorporated, can attain the optimal performance of the manufacturing system according to Sundar et al. (2014). Lean is originated in the automotive industry, but can also be applied in the industry of Fast Moving Consumer Goods (FMCG) (Aljunaidi and Ankrah, 2014). Aljunaidi and Ankrah (2014) suggest that the waste issues seen in the automotive industry are also found in the FMCG industry. This implies that Lean principles can be useful in both sectors. Several Lean elements are available within the literature listed by Sundar et al. (2014) as shown in the list below. Several Lean elements of this list are useful within this research and some are already incorporated or outside the scope of this research. For example, the keg line of Grolsch is already designed as an U-line manufacturing system. Also, within this research, we do not focus on scheduling or inventory levels. Therefore, we only elaborate short on some of the Lean elements which can be used in this research.

- Scheduling
- Employee perceptions
- Value stream mapping
- Takt time
- Bottleneck process
- Group technology
- Cellular manufacturing
- U-line manufacturing system
- Line balancing
- Flow Manufacturing
- Quick Changeover
- Small Lot size/Small Batch
- Inventory
- Pull System with One-piece Flow
- Kanban
- Production Levelling/ Heijunka
- Quality at source
- Continuous improvement (CI)/ Kaizen
- Standardized Work

The essence of Lean Manufacturing revolves around the philosophy of continuous improvement, where the **Voice Of Employees** (VOE) in form of thoughts and recommendations within problem solving activities is

important. Unfortunately, despite the importance, Lean practitioners have their focus on tool-based solutions, where the VOE and their participation is disregarded causing the sub-optimal performance or case failures of Lean initiatives according to Latif (2019).
Bottleneck process: the bottleneck in the manufacturing line is determined by the maximum cycle time in the line. A Value Stream Map (VSM) can be used to identify the bottleneck process by the takt time of the process steps. The gap between the demand and capacity is calculated after which a Lean executing project is started based on the gap. However, the bottleneck is not detected in one clear visualization, but this is present in the V-Graph. The V-Graph method does not belong to Lean principles and will therefore be explained in another section within this literature review.
One of the Lean elements is **continuous improvement**, which is described by Deming as "Improvement initiatives that increase successes and reduce failures". After achieving process stability, tools related to Continuous Improvement (CI) elements become essential for identifying root causes of inefficiencies and implementing effective countermeasures to overcome the causes.
Standardized work is a basic tool for continuous improvement suggested by Berger (1997). Work standardization is a set of analytical tools to generate a set of Standard Operating Procedures (SOPs). The objective of SOPs is to ensure consistency in implementation, minimize communication errors and comply with regulatory standards.

In conclusion, Standardized work and VOE are most applicable to 'Keg destacker' and the Bottleneck process to 'Delay in transport speed', 'Buffer capacity' and 'Speed empty keg turner'. In addition, we should also focus on standardized work in order to create optimal performances.

3.3 Maturity level before implementing Lean principles

If an organization wants to undergo a Lean or Six Sigma transformation, it is crucial to first assess the current maturity level of the organization. The appropriate method for continuous improvement strongly depends on the organization's current maturity level. Maturity models represent the ability of an organization for improving continuously within a particular discipline. There is a difference between one-dimensional linear presented maturity models and stage gate presented maturity models according to Lindemulder (2015). Models of one-dimensional linear stages are wildly accepted where the maturity is evaluated as an overall or average level opposite to the stage-gate representations where there are detailed layers for each maturity level besides the overall assessment (de Bruin and Rosemann, 2005). The Capability Maturity Model Integration (CMMI) is built on the framework where elevated stages are constructed upon lower levels of maturity which increases the capability of software processes according to Goldenson and Gibson (2003). CMMI is mostly adapted in software companies and is not suitable as a Business Process Management Maturity (BPMM) due to the difference in the basis of software and business processes according to Lindemulder (2015). Another method is described by Lindemulder (2015) which is the Business Process Maturity Model for the Object Management Group (BPMM-OMG) where attaining a maturity level requires the fulfillment of the process areas associated with that maturity level, along with the classification of the process. Where one-dimensional linear maturity models offer a straightforward way to compare maturities, they do not consistently offer organizations the guidance to improve the processes, particularly given the complexity of various organizational domains. For organizations with various organizational domains, it is more useful to apply the stage-gate process to distinguish maturity assessments within different domains. Grolsch does not consist of the complexity of various organizational domains, and therefore a one-dimensional linear maturity model can be used. Within this one-dimensional linear maturity model, the 'average' maturity level is taken into account instead of all details within each layer per maturity level within an assessment. Maturity models are used to support companies by the application of the best practice methods and techniques as well as the mindset for process improvement for the different maturity levels. If the maturity level of a company is assessed, one knows which elements should have the most attention in order to increase the maturity level of the company to reach the end goal of a future-proof process.

3.3.1 CIMM scan

The before mentioned methods do not contain the specific steps to take in order to increase the maturity level and are not specifically meant for manufacturing processes. These steps are however included in the Continuous Improvement Maturity Model (CIMM) of Theisens (2016). CIMM places a spotlight on processes, where the best practices from TPM, TQM, Six Sigma, Kaizen and Design for Six Sigma are included. Selecting the appropriate area for improvement depends on the organizations current maturity level. CIMM provides guidance to organizations in their journey toward greater maturity, distinguishing itself from other models by slightly modifying the maturity levels and by encompassing and structuring best practices, methods, techniques as well as the mindset, skill set and tool set for process improvement. Through CIMM assessment, one gains a precise understanding of the organizations position on the development of continuous improvement. The CIMM scan is an assessment based on a survey supplied by Symbol, where statements are displayed. The assessor gives a number on a scale from 1 to 5 to indicate the extent to which this statement is applied within the company. how this statement is applied within the company. The statements are based on five CIMM levels:

- CIMM 1 - Process improvement solid foundation
- CIMM 2 - Process improvement continuous improvement culture
- CIMM 3 - Process improvement stable and predictable processes
- CIMM 4 - Process improvement capable processes
- CIMM 5 - Process improvement future-proof processes

Each CIMM level (1-5) consist of three different subsections and five statements within each subsection, resulting in $5 \cdot 3 \cdot 5 = 45$ different statements. In addition, 25 statements are assessed with the theme 'Business Development' with the subsections Strategy, Leading, Openness, Learning and Agility. The latter is integrated within the organization and gives an interpretation on the development within the management towards Lean Six Sigma. The result of these 25 statements gives insight into the organizations culture. After the conducted assessment, scores for each subsection are added together, at a maximum of 25 for each subsection. The average scores are thereafter calculated, which gives an average score per CIMM level. With a percentage exceeding 75%, it is reasonable this element is sufficient present within the organization (Vollebregt, 2023).

In conclusion, applying the CIMM scan to Grolsch results in the maturity level of Grolsch. The results will pinpoint areas for improvement in order to increase Grolsch' maturity level effectively. It is important to know this maturity level, since one should not focus on one of the highest maturity levels when there is no solid foundation for process improvement. The CIMM scan therefore provides insight in the current situation and is the starting point for Lean improvement initiatives.

3.4 Missing elements within Lean for early detection

Once the starting point for Lean improvements is determined (where to focus on), the Lean principles for improved performance of Section 3.2 can be applied. These elements are commonly applied within manufacturing after the occurrence of a sign of waste or an issue has occurred. After the identification of the signs of wastes/issue or project ideas, a Project Idea Form is commonly used within the implementation of Lean to start a project to solve the observed waste. Besides, brainstorm sessions are also commonly applied within Lean in order to find causes or issues within a manufacturing environment. Brainstorming alone is not enough to identify relations for the possible root causes of a problem and therefore one should include a data analysis to verify the assumed relationships as announced by Garvin (1993). Substantiating assumptions with data ensures targeting the right elements and provides information on their comparative effectiveness. When causes are found, Lean projects are started to focus to eliminate the found wastes. Nevertheless, Lean projects start after the occurrence of an issue or sign of waste and does not focus on an early detection of issues before it becomes an issue.

Early detection

Early detection is a process of identifying and recognizing potential issues, challenges or abnormalities in various contexts, ranging from healthcare to manufacturing. Early detection is already commonly applied in the medical field where the primary components of early detection include screening and education to recognize symptoms and encouraging an early diagnosis according to Dillner (2019). Early detection is not commonly used within manufacturing in literature. However, with an early detection of issues, businesses are able to reduce the downtime of machines and improve the efficiency of production times (Aljunaidi and Ankrah, 2014). The literature consist of two approaches of problem detection: reactive and proactive problem management.

Problem detection

Reactive problem management is triggered after an incident occurs which need to undergo a root cause investigation. An incident could be a considerable incident or similar incidents which are noteworthy in its entirety. Within this approach, the root cause of the problem is investigated by analyzing the data and the system where after the problem is solved. The main drawback of reactive problem management is the defensive approach, which is similar to trying to prevent a problem after it has already occurred, rather than proactively addressing issues before they arise (Mathenge, 2019). However, according to Balakrishnan et al. (1995) within manufacturing there is mostly a reactive problem solving approach. Manufacturing needs to actively engage in competitive positioning, and organizations have to develop approaches to navigate through turbulence and uncertainty where a proactive strategy is needed (Lindberg, 1990). A proactive problem is guided by a perspective of ongoing improvement where it seeks to address the problem or issue before it has the opportunity to fully develop and therefore we should apply this to the manufacturing industry. The monitoring approach can detect errors within the system, which are not causing downtime of the system, but a decreased speed or indicate issues within diverse problem domains according to Mathenge (2019).

Context awareness

The detection of operation states within the manufacturing system is also known as context awareness in literature (de Calle Etxabe et al., 2021). Rosenberger and Gerhard (2018) describes context as any information that is used to distinguish an entity, the condition or the surrounding condition. This information becomes significant in the context of the interaction between an user and an application or machine. In this context, an entity can denote a person, location, material object or immaterial state, encompassing both the user and the application itself. Context awareness is also applied in Business Process Management issues (Rosemann and Recker, 2006), where it refers to the ability to understand and respond to specific circumstances, conditions and variables that influence a business process, like a manufacturing line.

Maintenance strategies for early detection

Since reactive problem management is the standard in manufacturing processes and within Lean, we examine additional principles documented in literature where proactive problem management is applied. We can learn from proactive problem approaches in literature in order to develop a method in Section 4.2 for an early detection of issues within manufacturing. Maintenance management strategies are an example where proactive problem approach is applied. Maintenance strategies within manufacturing are threefold: Corrective Maintenance (CM), Preventive Maintenance (PM) and Predictive Maintenance (PdM) (Motaghare et al., 2018), where preventive and predictive maintenance strategies are proactive and run-to-failure reactive. Ahmad et al. (2011) describes CM as the collection of actions to bring a component or machine back to a conditions where it can effectively fulfill its designated functions. Applying CM continuously over time, reduces the machine performance. Therefore, a different CM strategy can be applied which is known as PM. PM is applied through activities of preventive replacement and preventive repair before a failure occurs at equipment according to Ahmad et al. (2011). According to Usher et al. (1998) PM decreases the incidence of machine failures or the frequency of failures where it contributes to minimising production loss (by machine downtime), improving quality and an expanding productivity. PdM uses data analysis to detect abnormalities and potential equipment defects to conduct rapid repairs before the occurrence of failures according to Motaghare et al. (2018). The goal is to reduce the frequency of maintenance, prevent unplanned disruptions and unnecessary costs associated with PM. PdM therefore focuses on the actual condition of equipment instead of the average or expected life time. Therefore, the theory behind PdM can be used in order to keep track of data points and check if abnormalities arise in order to create a proactive approach of early issue detection, by utilizing control charts. Control Charts are based on the control limits of 3σ in order to detect out of control situations (Grant and Leavenworth, 1980).

V-Graph

We already mentioned the V-Graph method in Section 3.2, which is a method developed by Härte (1997) and not a component of Lean. This theory is explained within this section (Section 3.4), since a V-Graph gives an overview of the manufacturing line and can also detect issues in an early stage based on the machine capacity ratios within a manufacturing line. Härte (1997) developed the method of a V-Graph, which is a structured way to show the machines and eventually buffers of a manufacturing line in order to see the machine interaction on a higher level, which is also the goal of the V-Graph. The first step of the V-Graph analysis is indicating the core machine. Arena et al. (2019) defines the core machine as the one with the lowest theoretical production capacity. It is considered to be the most crucial machine in the line since any production time lost on this machine cannot be redressed causing a reduction in line efficiency. The required data in order to create the V-Graph is the order of the different machines on the line and the corresponding machine capacities. The machine capacity percentage is calculated as shown in Equation 2.

$$\text{Capacity Machine (\%)} = \frac{UPH_{machine}}{UPH_{Bottleneck}} \cdot 100\% \tag{2}$$

where,
$UPH_{machine}$: units per hour (capacity) produced by the machine in focus
$UPH_{bottleneck}$: units per hour (capacity) produced by the bottleneck machine

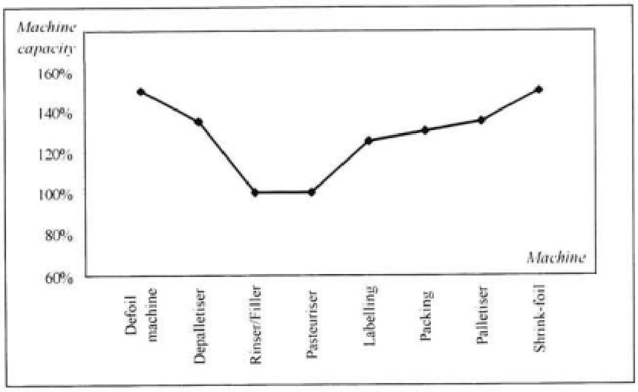


Figure 3.1: V-Graph according to Härte (1997)

Härte (1997) also made some remarks according to develop V-Graphs, where the most important one is: there should be a selection of machines to include in the V-Graph. Machines that are irrelevant are excluded from the graph, but also machines with an extreme high overcapacity which otherwise result in an unreasonable V-Graph.

Within this section about the missing elements within Lean for early detection, we can conclude that we should develop a method where we take into account a proactive problem detection approach. In this approach, we can use the theory behind predictive maintenance, where data analysis is used to detect abnormalities and find deviations in an early stage before the abnormalities become issues and affect the output of the keg line, by for example, control charts. In addition, the V-Graph method can also be used. How to organize this proactive problem detection approach to Lean will be discussed in Section 4.2.

3.5 Ranking methods and criteria selection for causes/issues

If KPIs are detected in an early stage and issues are identified which were an issue but never tackled, the subsequent method should be developed: a ranking method based on criteria to select the interventions to focus on. The outcome of this ranking method can be used as input for starting a Lean project. The prioritization of projects is an order scheme where projects are based on the benefit-cost ratio for that project. However, Vargas (2010) states a benefit-cost relationship does not only include financial criteria, but also a broader concept of benefits for executing the project and the related efforts. The principles of the Analytical Hierarchy Process (AHP) is most known in the prioritization and selection of projects. This method has some drawbacks for implementing within this research, since it relies on subjective judgements and pairwise comparisons, where the inconsistency in these judgements can lead to unreliable results. In addition, this method uses pairwise comparison which is hard for decision-makers to make accurate pairwise comparisons, especially when there are many criteria or alternatives. Nevertheless, the method consists of several suggestions for project selection criteria, which are financial (benefits of the project associated with costs and productivity), strategic (eco-friendly practices, improve reputation), risks (threads for executing the projects), urgency and stakeholder commitment (customers and organizational) and technical knowledge (technical knowledge to execute the project). Possible definitions for high benefits can also be the increase of production, less internal resistance or an increased working environment (Palcic and Lalic, 2009). There is no determined amount of criteria, but at least two criteria should be taken into consideration to make well-considered choices. After determining the criteria, the criteria should be scored to compare the projects and determine the overall rank in the end. It is common to use uneven numbers for the scores, since when a natural consensus cannot be reached, it raises the need to determine a middle point as the negotiated solution Saaty (1984). However, to overcome the subjectivity of the scores, the scores should be clearly defined in a quantitative manner. For example, the increase of production should not be defined as 'low', 'medium' and 'high', but as percentages such as 1%, 5% or 10% increase.

In conclusion, we should develop a ranking method which is easy to implement and can be implemented within the keg line, but also applied to other manufacturing lines. The ranking method should consist of more than two criteria where each criteria is scaled according to a number (minimum of 1 and a maximum of an uneven number), where each number represents a quantitative value per criteria.

3.6 Method and tools to solve root causes

The literature mentioned in the previous sections will be used in combination with the self developed methods to develop a method in Section 4.2 and 4.3 for an early detection of issues and the ranking and selection of interventions in order to develop implementation plans and overcome the causes. The most important root causes, as outcome from the developed method in 4.2 and 4.3, are already determined in Section 2.4 and we will develop interventions to overcome these root causes. The continuous improvement strategy of the keg line, applied in this research, will take part during continuous production where test can be performed on the physical keg line. It is therefore important to know what the issues are within these root causes and where they originate to make well-considered choices for improvements. Each of the root causes suffer from their own issues that have to be solved, but they can all be solved within the same structured approach which can be applied to all interventions.

Different approaches are available to continuously improve the process, which are the 3A method of Lean, 8D method for process improvement and SGA (Small Group Activity). The A3 Lean method visualizes the problem-solving steps on a single sheet to track project progress. The A3 method focuses on the communication and alignment between stakeholders of the project, where 8D emphasizes containment and correction of the problem. The disadvantage of the 8D method is the lack of tools for the last steps to measure the results and to standardize the implemented result to overcome the problem in the future. The disadvantages of these two methods do not occur in the SGA method, which is used in order to execute improvement interventions and have an increased focus on the last steps of measuring the results and standardize the implementation.

SGA is based on the PDCA-cycle (Plan, Do, Check and Act) of Edward Deming, which is especially used within continuous improvement (Miron et al., 2016). By applying SGA, the knowledge, experience and creativity of the employees of all levels within an organization are used in an effective way. The SGA approach uses the principle: improvements invented by employees are more likely to be accepted than improvements that are imposed from above (Łyjak and Ejsmont, 2016). In addition to earlier and more acceptance of the improvements, this group of employees takes ownership of the problem and the improvement. Bringing together employees from different departments guarantees a mix of knowledge and experience. The solutions invented by a team will be accepted earlier by the team members but also by the departments the employees represent. The eight steps in the improvement cycle are briefly explained in Appendix C based on Figure 3.2.

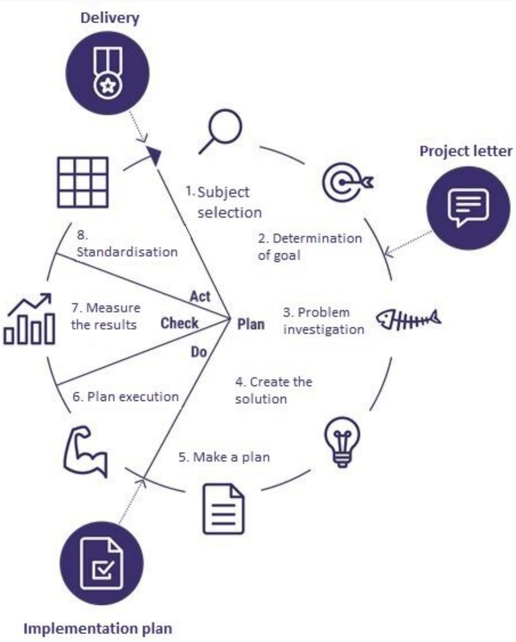


Figure 3.2: SGA improvement cycle (de Groot et al., 2005)

However, a drawback of the SGA method is the number of tools that can be applied across the various stages. In contrast, Lean Six Sigma consist of various tools, including the DMAIC tool. DMAIC represents the five phases: Define, Measure, Analyse, Improve and Control, which can be compared with the PDCA and SGA cycle. DMAIC refers to a data-driven improvement program to improve, optimize and stabilize business processes and products according to Theisens (2016). The DMAIC framework provides a targeted and systematic method to improve processes and solve issues within an organization. Existing literature showed several tools of Lean Six Sigma, but due to the high number of tools, we arranged them within the sections of DMAIC to create an overview. These tools are therefore arranged according to the DMAIC sections, which can also be used in certain phases of DMAIC. The overview is created based on the tools which are mostly used within the Lean Six Sigma project steps found in literature. It is important to note that the tools allocated to each DMAIC section are not confined solely to that phase, but can also be applied in other sections. For example, histograms can both be a tool used in both the Measuring and Analyzing phase.

In the pursuit of identifying and addressing the root causes of operational challenges and determine interventions, the SGA method will be applied in combination with Lean Six Sigma tools. Within each step of the SGA method, the tools of Figure 3.3 can be used. The selection of tools per SGA step is dependent on the outcome of the CIMM scan and therefore the tool selection per SGA step is made in Section 4.4. EVolutionary OPeration (EVOP) and Defects per Million Opportunities (DPMO) will both be described after Figure 3.3.

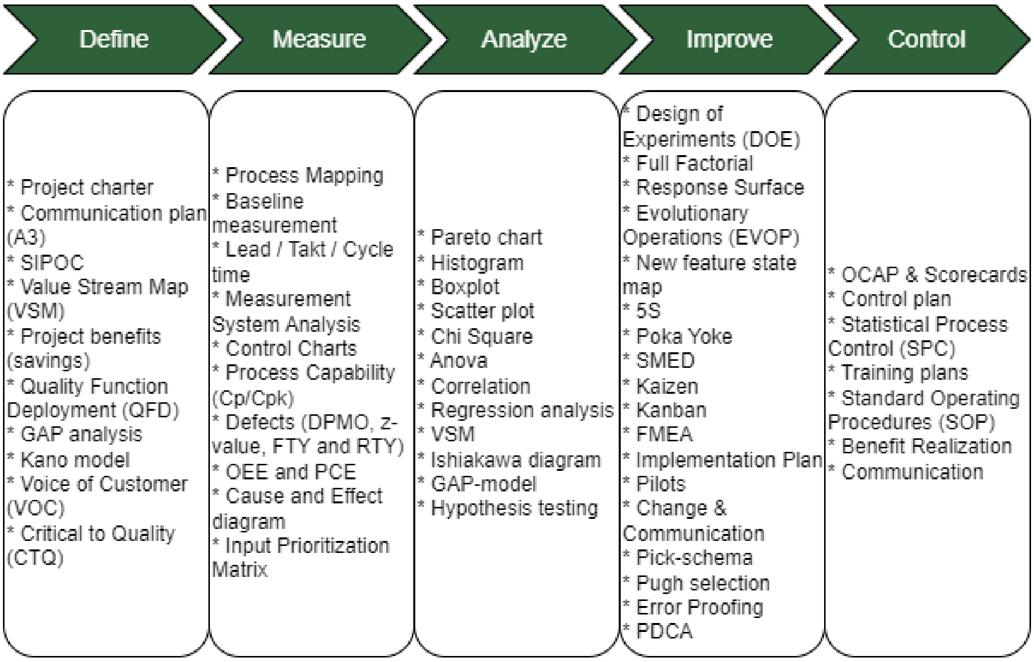


Figure 3.3: Lean Six Sigma tools

Evolutionary Operation Methodology

EVolutionary OPeration (EVOP) is a technique for process optimization and is selected since it allows immediate feedback and adaptation, leading to faster identification of optimal process settings and continuous improvement of the process. The main idea behind experimental interventions is to ensure they do not disrupt the operational process, when a process cannot supply reliable data in order to develop a simulation model to find optimal settings. EVOP consist of consecutive experiments with small changes compared to the conventional process settings. Due to small incremental process setting changes and closely monitoring the results, the settings are not substantial to result in non compliant products. Therefore, experiments can be performed during normal production without causing significant disruptions or deviations from the regular workflow according to Rutten et al. (2014). Normal production refers to the standard course of operational activities within a process, where no intentional experimental variations or changes are being introduced. This approach also allows for the collection of valuable data and optimizing insights without compromising the quality or efficiency of the ongoing production process (Østergaard et al., 2020). Simultaneously, the settings are large enough to facilitate an analytical examination of the process and define optimum process setting (Theisens, 2016). Upon identifying a significant factor (e.g. the speed of a machine or conveyor belt), the operating conditions are readjusted associated with the corresponding factor. Then, experiments are conducted again till no additional improvement or advantage is noticeable (e.g., no improvements in terms of product quality). Consequently, the conceptual framework of evolution is solidified. According to Hessing (2023) the application of EVOP is particularly suitable when an increased number of conditions influencing the product performance. It is applicable when the operations process involved two or three distinct process variables and the temporal evolution of the process results in variation in its performance. At last, EVOP facilitates a minimization of process calculations.

Defects Per Million Opportunities

In order to quantify the performance of a process, the metric Defects Per Million Opportunities (DPMO) is commonly used within Lean Six Sigma. DPMO is used in process improvement to quantify the performance of a process by measuring the number of defects per one million opportunities for defects. DPMO is most applicable to this research in contrast to traditional defect rates, since it normalizes defects against the total number of opportunities for defects to occur. Consequently, fair comparisons between different products or time periods can be established. DPMO is calculated by Equation 3.

$$DMPO = \frac{1{,}000{,}000 \cdot D}{U \cdot O} \tag{3}$$

where,
D: number of defects
U: number of units
O: number of opportunities

The higher the DPMO value, the lower the sigma level. The goal of DPMO is to reach a sigma value of 6 where 3.4 defects occur within one million opportunities. Despite Table 3.2, sigma values are commonly expressed in one digit. However, for an increased readability, we only show the sigma values from 0 until and including 6 in Table 3.2. From this table, we can conclude a small difference between $\sigma = 5$ and $\sigma = 6$ according to the defects per one million. However, the difference between $\sigma = 0$ and $\sigma = 1$ are larger in comparison with the difference between $\sigma = 5$ and $\sigma = 6$ according to DPMO and success rate.

Table 3.2: Defects Per Million Opportunities (DPMO), success rate and the corresponding sigma value

Defects per one million	**Success rate**	**Sigma value (σ)**
933000	7%	0
691000	31%	1
309000	69.1%	2
66800	93.32%	3
6210	99.38%	4
233	99.9767%	5
3.4	99.99966%	6

3.7 Effect of interventions on output

Incorporating the methods and tools described in the previous section, the effect of the interventions on the output of the line are of great interest for Grolsch. Both analytical calculations and simulation studies can be used for this purpose. Simulations studies are applied within various sections such as manufacturing, healthcare and services to experiment with state changes when a production process is complex and cannot be approximated analytical (Jahangirian et al., 2010). Simulation models are used nowadays due to the high availability and accessibility of production data. Therefore, machine failure data of each machine on the line should be available and reliable to use as input for a simulation model (Skoogh and Johansson, 2008). However, the failure data of each machine on the keg line is not available for Grolsch since several machines are under management of the supplier. Failure frequencies and duration are therefore not available for all machines. In addition, some machines with available data showed higher values for starving and blocking compared with the operating state and are therefore not reliable for validating a simulation model. Within simulation models, experiments can be executed, since most experiments have a significant influence on the process and are high in costs to change the current system. Even though, experiments can still be executed on the manufacturing line without disrupting the operational process. The literature consist of two methods which are commonly used in Lean to perform experiments. These methods are Design of Experiments (DOE) and EVOP. DOE is a structured method which may result in an interruption of the production process for executing experiments. Contrarily, EVOP aims to implement small incremental changes to process variables within a normal production flow and therefore minimizes negative effects on the output of the manufacturing line. These alterations of changes do not lead to the production of non-conforming products, but are significant to establish the optimal process ranges (Box, 1957). Therefore, EVOP is most applicable for Grolsch within this research without interrupting the production process.

In addition to experimenting, the overall effect on the output of the line of the interventions can be calculated analytical for the keg line. As explained earlier, the keg line is designed as a U-shape where products are processed one-by-one, preventing overtaking. Therefore, the process is designed in a One-Way bottle packaging line, more or less one-piece-flow where each products travels the same route. If the bottleneck (wash and filling station), experiences downtime, the downtime is assigned to one of the machines on the keg line including the reason for downtime. During this downtime, Proleit (automation software) displays a popup where an operator must assign the reason for downtime. Assigning a reason for downtime of the wash and filling station occurs at three levels: cause - reason - comment. Within the first two levels, several options are available, where the first level consist of a machine e.g. empty keg turner, keg destacker or palletizer. The second level consist of for example Mechanical, Electric, Combination etc. An example is Palletizer (cause), reason (Mechanical) and Robot 4 drops a keg (comment). This data of 'Stop Accountability' is reliable enough to perform analysis and conduct calculations, since each downtime of the wash and filling station is assigned. Even a downtime of less than a minute is assigned to a cause, reason and comment and therefore this data is trustworthy enough to use as input data.

The total downtime caused by a specific issue on the keg line can be added up and converted into an increased running time of the wash and filling station, when this issues is removed from occurring. This increased running time can be expressed in the number of kegs, minutes of up time running and therefore also in an increased ME of the line. However, the speed of the empty keg turner is not directly causing downtime of the wash and filling station. On the other hand, increasing the speed of the empty keg turner results in a faster buffer replenishment and therefore results in less downtime of the wash and filling station at a machine failure in front of the wash and filling station. As a result, the increased output of the line can be expressed in an increased production of number of kegs, minutes of up time running and therefore also in an increased ME. Due to the high data availability of downtime causes of the wash and filling station and the fact only one machine is responsible for downtime of the wash and filling station, the calculations are trustworthy.

In conclusion, executing experiments with small incremental changes will be applied within this research in order to measure the effects on the machine or part of the line. In addition, the influence of the interventions on the keg line are analytical calculated as an increased running time of the wash and filling station by removing the corresponding issue, which can be expressed in an increased ME.

3.8 Conclusion

Each of the top five root causes belong to the dimension Technology where Downtime keg destacker also belongs to the dimension Product. Therefore, solutions should be found for these causes within the technology of the keg line and in the material quality of the kegs. The VOE, bottleneck process, continuous improvement and standardized work are Lean elements which are useful to consider within this research. Standardized work and VOE are most applicable to Downtime keg destacker and the Bottleneck process to Delay in transport speed, Buffer capacity and Speed empty keg turner. The CIMM scan should be conducted in order to find the maturity level of Grolsch towards Lean to find the starting point for Lean improvement. Lean projects start at the moment an issue is a problem, and therefore we should develop a method for a proactive problem detection, where we can use the theory of predictive maintenance, where data analysis is used to detect abnormalities and find deviations in an early stage. We should also develop a ranking method which is easy to implement for Grolsch' Process Engineers and can be implemented within the keg line. The ranking method should consist of more than two criteria where each criteria is scaled according to a number (minimum of one and a maximum of an uneven number), where each number represents a quantitative value per criteria. The outcomes of this ranking results in the selection of issues to solve the causes. The SGA method is most applicable to Grolsch, where Lean Six Sigma tools can be used within each SGA step.

Within Chapter 4, we show the results of the conducted CIMM scan within Grolsch to show where we can improve. Next, we define the KPIs to measure in order to detect issues in an early stage, the criteria selection and ranking method. At last, we show the standardized method where the SGA method and Lean Six Sigma elements are combined in order to elaborate on the interventions to solve the top five root causes.

4 Standardized (early) detection, ranking/selection and solving Method

The results of the conducted CIMM scan on Grolsch are presented in Section 4.1. Section 4.2 outlines the developed method for (early) detection of causes and issues for speed loss with proactive approach. The developed method for criteria selection and ranking the causes and issues found by the method of Section 4.3 will be explained. Finally, Section 4.4 provides an explanation of the method for addressing the causes and issues identified as the highest priority in Section 4.3

4.1 Application of CIMM scan on Grolsch

According to Section 3.3, it is crucial for an organization to assess the maturity level of an organization before Lean or Six Sigma transformations. In Section 3.3.1 we determined the CIMM scan as the most suitable scan for Grolsch. Therefore, the CIMM scan of Symbol is conducted through an assessment with the Continuous Improvement Manager within Grolsch. As explained in Section 3.3.1, a total of 70 statements are displayed and the Continuous Improvement Manager gives a number on a scale from 1 to 5 how this statement is applied within Grolsch. 45 statements are based on the five different CIMM levels and relate to one of the corresponding elements within that level. The remaining 25 statements relate to the Organization development towards Lean.

The results of the conducted CIMM scan shows the average score for CIMM 1 to 5 at Grolsch of respectively 33%, 48%, 40%, 30% and 38% in Appendix D. With a percentage exceeding 75%, it is reasonable that this element is sufficiently present within the organization (Vollebregt, 2023). Therefore, we can conclude that none of the CIMM levels are sufficiently present within Grolsch and that we should focus on CIMM 1 (Process improvement solid foundation) in order to increase the maturity towards Lean within Grolsch, before improvements are made on the two highest CIMM levels. The focus on improvements to increase the maturity level are the parts with the lowest score within the five CIMM levels. There is a lack of standardized work within Grolsch (9 out of 25 points), where standards and procedures form the basis of the continuous improvement process. Procedures and standards are required to improve towards new, improved standards resulting in an increased output. Standardization is therefore the intermediate step in the process of continuous improvement and never the end of the line. Therefore, we should focus on a standardized method for an (early) detection of issues which will be applied on the keg line within Grolsch to detect issues in an early stage and decrease the time between occurring and solving.

In conclusion, there are many improvements possible in order to increase the maturity level of Grolsch, which can be increased by the application of the method developed by the researcher, which will be explained in the next section. The developed method can also be applied to other lines within Grolsch after the application on the keg line as a case study. In addition, after this research, the method can also be applied to other manufacturing companies which score below 75% on the first CIMM levels. Several additional conditions are in force in order to apply this method, which are an automated production line with several production steps, operators are available for issue solving during production and one person is available and responsible for applying this method continuously. This method can help to standardize procedures within detection, ranking/selection and solving issues. The method is defined in three steps as shown in Figure 4.1: (Early) Detection, Ranking/Selection and Solving explained in respectively Section 4.2, 4.3 and 4.4.

Figure 4.1: Method in threefold

4.2 Developed method for (early) detection of causes/issues with proactive approach

Lean projects start at the occurrence of an issue, while we want to develop a method where causes and issues are detected at an early stage, before they affect the output of the keg line. The early detection applies to deviations which do not directly influence the output of the line, but can affect the output of the line in the future. This method also reveals issues which became 'normal' during last years. Therefore, the timing of starting is different for the developed method compared with the timing for starting a Lean project. The principles for early detection can be subtracted from the theory behind predictive maintenance, where data analysis is used to detect abnormalities and find deviations in an early stage before the abnormalities become issues and affect the output of the keg line. Where predictive maintenance keeps track of KPIs: MTBF, MTTR, Availability, Reliability and Backlog, Six Sigma keeps track of for example the diameter of a wheel, the KPIs to track within Lean Manufacturing are somewhat different. Besides, a selection of important KPIs are essential, since too many KPIs can dilute the focus. Focusing on a selection of meaningful KPIs that directly align with objectives, the issues can be better identified and addressed resulting in a culture of continuous improvement. Important KPIs to measure within a manufacturing line according to Lean are cycle times, machine capacities and machine downtime according to Theisens (2016) and Aherne (2023). These KPIs are one of the three elements of the method for (early) detection of causes and issues with proactive approach we developed, since we also take into account the operator impact and also the visual signals of waste (both will also be explained in this section). This method is standardized in three flowcharts as shown in Figure 4.2 and will be explained within section 4.2.1, 4.2.2 and 4.2.3 respectively.

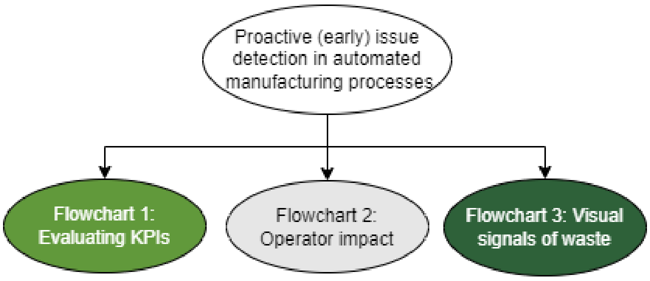


Figure 4.2: Proactive (early) issue detection method visualized: combination of three flowcharts

4.2.1 Evaluating KPIs

First, we provide an explanation of the KPIs (machine capacities, cycle time bottleneck and machine downtime), the measuring method and how to monitor hem. The KPIs can be tracked with the use of a statistical process control (SPC) tool, a Control Chart, to determine if a process is operating at an acceptable level. Next, we explain Flowchart 1 of Figure 4.3 we developed as a standardized method on how to evaluate these KPIs.

Machine capacities

In Section 3.2 about Lean principles for improvement performance, we described VSM as one of the methods to identify the process bottleneck using cycle times. However, the bottleneck is not detected in one clear overview even as the relation between the capacities of the machines on the whole manufacturing line. In order to visualize this, including the bottleneck machine, we will use a V-Graph. The basis of the V-Graph are the machine capacities of all machines on the keg line. Using this data, one can detect the difference between the capacities for different SKUs and the capacity between machines for processing a SKU. Each machine of the keg line should be measured manually, since the running capacity per machine is not reported within Grolsch. Each machine needs to be measured for at least 30 measurements per SKU in order to obtain statistical power of the study. For these measurements, the keg destacker, empty keg turner, exterior cleaner, wash and filling station, full keg turner, leak detection/weighing scale, cap placement, labeler and palletizer are taken into account. The leak detection and weighing scale are measured together, since these two processing steps are right

behind each other without space for waiting. All machines should be measured in the same way, except for the wash and filling station. Recordings of the wash and filling station interface needs to be made and analyzed afterwards to determine the processing times for the eight different heads at the five filling lines. This includes also the transport speed of the five filling lines where these two are measured separately and added together in the analysis. All other machines need to be measured by using a stopwatch to determine the processing time without delays, which equals the capacity of the machine. The machine capacity is calculated as the number of kegs processed per hour, where the machine capacity for one machine can be non-identical when processing different kegs (different in size or material).
V-Graphs show the difference in capacities between machines on the manufacturing line. The V-Graph is therefore useful to detect the differences within the machine capacities if one of the machines is improved. After the development of several V-Graphs, based on the different SKUs, we can identify deviations within a machine between different SKUs and also the capacity between machines. Therefore, we can use a V-Graph as a control chart in order to check the machines capacities towards the bottleneck. The machines in front of the bottleneck should be decreasing in capacity when the machine is closer to the bottleneck machine. After the bottleneck, machine capacities should increase as the machine is further away from the bottleneck.

Cycle time

The cycle time metric provides a way to measure the duration for completing a finished product, each component of the end product or the overall time for processing including delivery to the consumer. Therefore, cycle time can be used as a tool to analyze overall efficiency of a manufacturing line at macro level, while also pinpointing inefficiencies at a micro level. Manufacturers divide the KPI of cycle time in several layers, such as the time it takes to produce a part of the product or the time a products spends in a specific process step. The cycle times within the bottleneck process are therefore the most important one, since these cycle times determine the maximum output of the manufacturing line. Therefore, we should also include the division of the several process steps within the bottleneck machine, the wash and filling station, including the process steps for head 1 and 2 and the transport cycle time. The process steps for head 1 and 2 only need to be considered, since all other heads have a significant lower process time of at least five seconds (Figure B.1). Kegs on the other heads wait until heads 1 and 2 have finished before they are transported to the next head. The acceptable levels for these cycle times are determined based on the values determined by the supplier of the wash and filling station. In addition, we should also look at the difference between the set values for the different kegs (19.5l, 30l and 50l). Transport cycle times are part of the cycle time, but we should take them apart in order to find deviations within the transport times. Transport times should be measured over time, add to the control chart and take action if deviations occur. The transport cycle time are tested against the set cycle time of 14 seconds based on the information of the supplier, which can be seen as the maximum cycle time for transport.

Downtime of machines

Downtime of machines on a manufacturing line occur due to several reasons and some downtime is not a direct issue, except when they affect the process significantly. Within Grolsch, the stoppages for several machines which are occurring within ME are calculated as a percentage against the Paid Factory Hours in order to calculate the stoppages within ME against FE hours. In order not to deviate from this calculation, we will use this calculation to map the downtime per machine per week. However, in order to connect it to existing literature, we use the theory behind control charts. Control charts use average, Center Line (CL), an Upper Control Limit (UCL) and a Lower Control Limit (LCL). UCL and LCL represent the specified boundaries for deviations from the mean. The UCL is the highest value that a process is allowed to achieve without being considered out of control. Since each machine is different, the average, UCL and LCL are determined per machine based on the downtime as percentage towards FE hours. We need to incorporate machine downtime as a percentage, as otherwise, we cannot compare machine downtime fairly with each other. As an example, downtime of 10 minutes and 20 minutes may appear as a 50% difference. However, when considering the Paid Factory Hours (1000 and 2000 minutes respectively), the downtime for both cases results in 1%. The machine

downtime per machine towards FE should be added in a control chart, were we take into account the Center Line, UCL and LCL. This machine downtime is determined per week to rule out the deviation per day. More than two out of control situations can be a structural issue, where one out of control situation can be an outlier. A percentage above the UCL should be investigated when it occurs for one week and a separate research should be started if the percentage is above the UCL for more than two weeks. Machine downtime should be added to the control at the beginning of each week, since at the beginning of the week, all information is available within MicroStrategy (Business intelligence software using input from Proleit) over last week.
In conclusion, the defined KPIs to track within the keg line are:

- Machine capacities
- Bottleneck machine: cycle time and transport
- Machine downtime as a percentage of FE

Flowchart 1: Evaluating KPIs
We developed Flowchart 1 (Figure 4.3) in order to standardize the method for evaluating these KPIs, since each detection of KPI deviation should be added to the issue list (explained in Section 4.3) in order to keep track of the deviations and detect them in an early stage. The numbers at the end of the flowchart serve as a reference for the application of this method in Section 5.1. To apply this method properly, one should evaluate all three KPIs: machine capacities, cycle time bottleneck and downtime machines within the flowchart.
The periodic evaluation for each KPI is different. Machine downtime should be added weekly to the control chart in order to rule out the deviation per day. Evaluating KPI downtime machines can result in an out of control situation, where downtime of a machine is above the UCL. One out of control situation should be investigated immediately, but if two out of control situations (two weeks) are detected (Figure 4.3 (c)), the Process Engineer must add this machine with the corresponding issue to the issue list (Figure 4.3, 4.). Two weeks correspond to two (separate) weeks and not especially two consecutive weeks above the UCL. Two weeks are determined to rule out one out of control situation for a week which can corresponds to a specific issue (and should be investigated separately).

The KPIs for Machine Capacity and Cycle Time Bottleneck should be evaluated every two months. While the average project completion period within Grolsch spans four months, we must incorporate all changes on the line (intended and unintended). These KPIs remain relatively stable over time and therefore weekly measurements do not add value compared to bi-monthly updates. However, to identify any deviations in an early stage, these KPIs must be measured every two months and the Process Engineer must document these values in the corresponding control chart (either V-Graph, cycle time transport or cycle time process). Once the control charts are updated, the Process Engineer must analyze the new values and evaluate if the values are above, below or within the control limits. If deviations between measurements and the cycle times determined by the machine supplier (CL, UCL, LCL) are discovered (Figure 4.3 (b)) within the bottleneck machine, they should be added to the Issue list (Figure 4.3, 3.)).

When evaluating KPI Machine Capacities for the first time, there is absence of an available V-Graph and therefore the V-Graph principle should be checked with the measured machine capacities (Figure 4.3 (a)): Machines in front of the bottleneck should be decreasing in capacity when the machine is closer to the bottleneck machine. After the bottleneck, machine capacities should increase as the machine is further away from the bottleneck. These V-Graphs should be used as control charts for the different SKUs of the keg line. A V-Graph is out of control in two separate situations. First, a decreased machine capacity towards the previous measurement (two months ago) due to an increased cycle time of the corresponding machine. In contrast, a decrease in cycle time results in an increased machine capacity and is not an out of control situation. This is accomplished by improvements towards the decrease in cycle time by solving structural issues on this machine. However, this new machine capacity must be added to the new V-Graph to compare these values with the measurement in two months. All previous and current V-Graphs (with two months difference) should be plotted in the same graph (per SKU) to detect deviations. The second out of control situation is associated with a fail to adhere towards the V-Graph principle. This means for example a lower machine capacity for the first machine on the manufacturing line compared to the machine in front of the bottleneck. The same machine capacity of the machine before the bottleneck compared with the capacity of the bottleneck is also an out of control situation.

The CL, LCL and UCL must be calculated once before adding the first values to the control charts. Updating these values of CL, LCL and UCL should be done after significant improvement of the corresponding machine. Correct improvements ensure less machine failures and therefore CL, LCL and UCL decrease. However, these new values can only be calculated with a sample size of at least 30 measurements in order to obtain statistical power of the values. All discovered issues according to Flowchart 1 should be added to the Issue list. This is a list in Excel where deviations are described and where Grolsch can keep track off all keg line deviations. We made a format for the issue list, which is shown at the end of Section 4.3 in Figure 4.6.

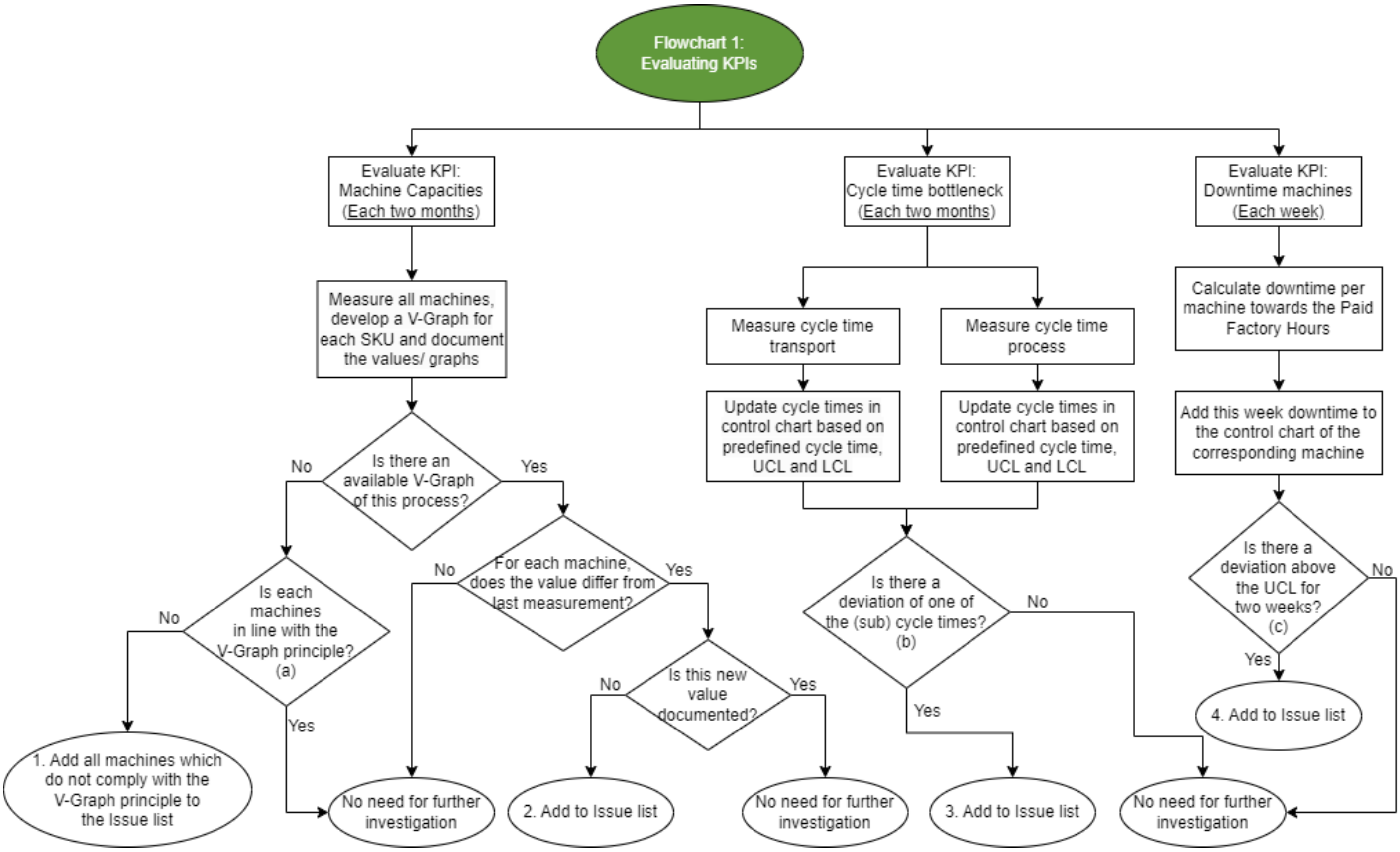


Figure 4.3: Flowchart for evaluating KPIs resulting in issues to add to issue list

4.2.2 Operator Impact

Monitoring KPIs in Control Charts or V-Graphs, as discussed in Section 4.2.1, provides a quantitative basis, but additional considerations are essential for identifying causes and issues. Section 3.2 emphasizes the importance of the VOE in issue solving activities, which is often overlooked before starting a Lean project. In addition, the VOE can be used to create optimal performances within Lean projects. We propose incorporating the VOE into this method to detect issues on the manufacturing line, which are not always captured by the results of data analysis. Grolsch faces challenges where some issues are deemed 'normal' and go unreported to project improvement teams, impacting both line output and the repetitive resolution by operators of the same issues. The experience of operators is crucial for identifying recurring issues, as they work closely with the process, solve daily issues and notice small deviations in small problem-solving frequencies. These issues can be detected based on Flowchart 2 of Figure 4.4 and the survey in Appendix E, where operators determine a top five of repetitive actions based on the keg line machines. An increased number of repetitive actions can detect issues in an early stage or even reveal issues which are considered normal over last years.

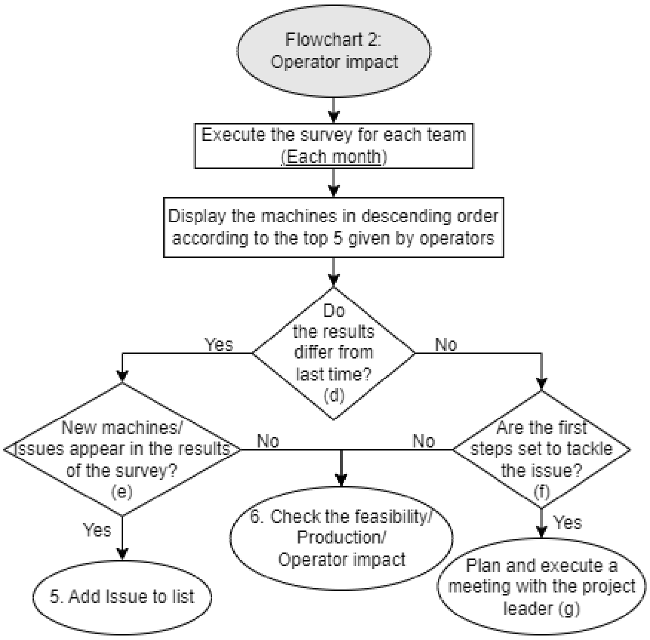


Figure 4.4: Flowchart for detecting (increased) operator impact and issues which are 'normal'

Within this flowchart, the survey of Appendix E should be given to each team on the keg line every month. It helps to determine the overall top five of operators towards the repetitions of solving issues on the keg line. One month is based on the 30 day cycle of operators (five shift schedule), where each operator worked three rounds of the ten day pattern. One ten day pattern corresponds to two morning shifts, two afternoon shifts, two night shifts and four days off. Within this 30 day cycle, each team worked each shift for at least six times. Using this flowchart for the first time results in the left side below question (d), since the lack of previous results. For example, if this flowchart is used again after one month and the results do not differ from last time, one should go to the right side at question (d). If the results are the same as last time (d) and no steps are taken in order to tackle the issue (f), one should check if the minutes associated with the corresponding tasks are increased, the feasibility is changed or the impact on production is increased or decreased since last measurement. If the result differ from last time (d) and no new machines appear on the list (e), a possible increase in operator actions can occur and therefore the operator impact should be checked. If the first steps are set to tackle the issue (f), the Process Engineer should plan and execute a meeting with the project leader (g), since the issue is not resolved. During this meeting, it is essential to brief the Process Engineer on the project execution schedule and he/she should give guidance to enhance the efficiency of the project progression.
In conclusion, the first execution of this flowchart will result in a top five added to the issue list (Figure 4.4, 5). All changes in this list at the second execution (after a month), must be added to the issue list (Figure 4.4, 5).

4.2.3 Visual signals of waste

The focus of Lean is to eliminate waste within a manufacturing line, where one of the pillars is to eliminate defects which do not meet quality requirements, resulting in wasted time and resources on repairs. Quality losses are covered by speed loss within Grolsch and therefore we should take these into account. Optimal usage of space within a manufacturing line is not a pillar of Lean, but unused conveyor capacity on a manufacturing line between machines can also be seen as a signal of waste. These visual signals of wastes can be identified by a Gemba walk by a Process Engineer (the one responsible for conducting the flowcharts) and afterwards, if possible, be checked by data analysis for the frequency of occurrence. These visual signals of waste can be discovered by Flowchart 3 of Figure 4.5. Two weeks (Figure 4.5 (h)) correspond to two (separate) weeks and not especially two consecutive weeks above the UCL. Two weeks are determined to rule out one out of control situation for a week which corresponds to a specific issue (and should be investigated separately). In order to apply this method properly, one should evaluate all three visual signals of waste: upstream buffers (in front of the bottleneck), downstream buffers (after the bottleneck) and all rejected products. Upstream and downstream buffer must be evaluated each two months based on the same principle as described in Section 4.2.1 (Flowchart 1: Evaluating KPIs) and rejected products must be evaluated each week. The acceptance level and UCL, are calculated per machine which rejects products, if these data are available. These acceptance levels are calculated using the average increased by L times the standard deviation σ, where L represents the dispersion of sigma lines from the control mean. The standard values are $\mu \pm L\sigma$, where $L = 3$ (Montgomery, 2019). The values for the acceptance levels are given and elaborated in Section 5.1. These values are percentages for a fair comparison between different kegs or failures. For example, we should always take into account the number of failures per keg type towards the total production per keg type and therefore percentages are most applicable.

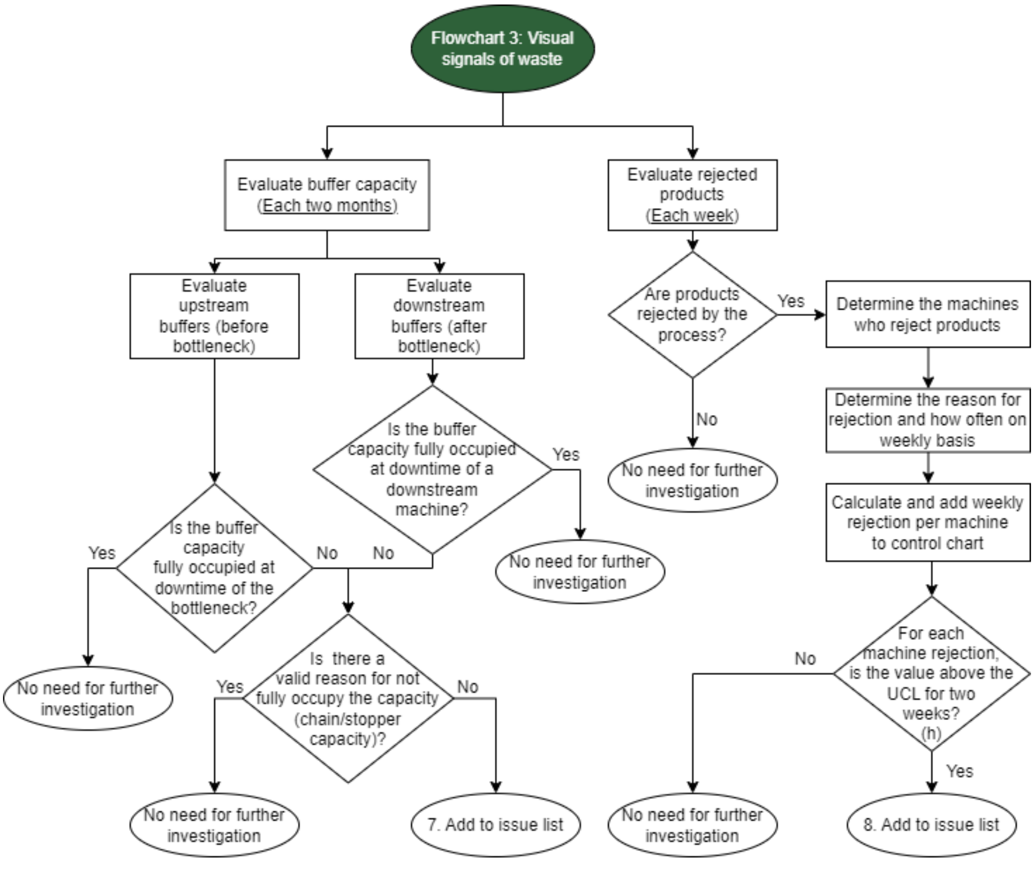


Figure 4.5: Flowchart for detect visual signals of waste resulting in issues to add to issue list

In conclusion, the defined KPIs to track within the keg line with their corresponding frequency are: 1) Machine capacities (each two months), 2) Bottleneck: cycle time and transport (each two months) and 3) Machine downtime as percentage of FE (each week). In addition, the operator impact (Flowchart 2) should be evaluated each month. Flowchart 3 consist of evaluating the buffer capacity and the rejected products which should be evaluated each two months and each week respectively. These flowcharts are used to standardize the execution.

In the pursuit of identifying root causes of speed loss and a lower ME of an automated production line, this section showed the developed method to uncover these issues in a structured approach. Using this approach, several issues which are not known within the organization or issues which are identified before they become an issue (early detection) and negatively effect the efficiency of the line in the future can be found. These issues should be added to the issue list (explained in Section 4.3) in order to keep track of all issues. Next, these issues must be prioritized where to focus on and will be explained in Section 4.3

4.3 Developed method for criteria selection and ranking causes/issues

After the causes and issues are found with the standardized method as described in Section 4.2, they have to be ranked in order to select the causes and issues to focus on for determining interventions for solving. We established three criteria before we rank them. Section 3.5 described we require at least two criteria and hence we determined three criteria: Feasibility, Increase Production and Impact Operator. Section 3.2 described Lean practices have their focus on tool-based solutions where the participation and VOE is disregarded. We therefore decided to take into account the VOE within the stage before a Lean project is started as the Impact Operator. We discuss these three criteria below and also an additional criteria especially for this Master Assignment (Focus for this research).

Column criteria: Feasibility

Root causes receive a ranking number between 1 and 5 for feasibility, where feasibility equals the time of implementation, with or without an investment. The description per ranking number is shown in Table 4.1, where the highest feasibility of 5 equals developing an intervention within two months without investment in order to overcome this root cause. Numbers 3, 4 and 5 do not contain information about investments, since if investments are needed within Grolsch, it takes time to make an application for investment, receive approval and receive materials from the supplier. This process takes on average more than four months and therefore there is no feasibility within four months with investment. These categories are determined to make a distinction between projects with comprehensive planning, executing and potential complexities and interventions with a short time frame. These categories are determined, based on the time and amount investments of previous interventions within Grolsch. Also, tackling a root cause by implementing an intervention which takes more than eight months will always accompany an investment. Within this ranking we do not take into account the amount of investment, since it may shift the focus toward financial considerations, which might not align with our current prioritization criteria. Number 3 equals a time of 4-8 months without investment, where an example is concerned with a quality issue. Conducting research on the root causes of this issue, determining an intervention and implementing this intervention can sometimes take time within 4-8 months where the developed interventions have to be distributed through several quality members in order to get approval. Therefore, we added number 3 of a time span within 4-8 months without investment.

Table 4.1: Feasibility

Ranking	Feasibility
1	More than 8 months with investment
2	Within 4-8 months with investment
3	Within 4-8 months without investment
4	Within 2-4 months without investment
5	Within 2 months without investment

Column criteria: Increase Production

Each cause has an influence on the production, where it is either a small or large impact. In order to quantify the impact on production, the production impact is calculated as the increased percentage of production time when the root cause is eliminated, which has a direct influence in an increased ME. The causes within the wash and filling station can be applied directly to the production output, because it is the bottleneck of the production line. Nevertheless, other causes are subjected to the place where they occur. Within Grolsch, if downtime of the bottleneck machine occurs, Proleit gives a popup where an operator has to assign the reason for downtime to one of the machines on the line or to Brewing, Warehouse, Materials Management etc. At selecting a machine to assign the downtime of the wash and filling station, an operator must insert a remark for the reason. Therefore, we have an overview of the causes caused by a machine failure with the corresponding reason. Within the remark section, we can see the different reasons for downtime of the wash and filling station towards the several machines on the line. The minutes of downtime caused by the specific root cause of that machine are added together for a specific period and added to the total production hours of the wash and filling station of the same period. The relative change between the total production hours plus the downtime for the root cause and the total production hours is calculated as the increased production when the root cause is eliminated. In conclusion, we use the Increase in Production percentage if the root cause is eliminated.

Column criteria: Impact Operator

Solving each root cause can be assigned to both an increase in production and duration of issue solving with or without investment. However, some causes have an effect on operators where other causes do not involve operator interventions. Causes with an impact on operators are described as an operator has to intervene in order to solve the issue and the issue cannot be solved without an operator intervention. The operator impact is divided in five numbers, where the higher the number, the more time and repetitions operators are lost on this issue (Table 4.2). It is based on the number of repetitions and the time an operator has to execute in order to solve the same issue within one shift (eight hours). The ranking of Table 4.2 is determined based on an incremental growth of 5% of the time spent to a specific issue within one shift (5% equals 24 minutes). The operator impact should be determined based on the developed satisfaction survey (Appendix E) in combination with manual counts per shifts. The manual counts can be conducted within several methods: a peat list, a video or photo camera, or visual observations. For all other root causes, operators do not have to intervene directly and therefore the root causes only affect the production.

Table 4.2: Impact Operator

Ranking	Impact Operator
1	[0-24) minutes
2	[24-48) minutes
3	[48-72) minutes
4	[72-96) minutes
5	$\geq$ 96 minutes

Include/Exclude: Focus for this research

Especially for this Master Assignment, we also determined a ranking Focus for this research. This arises from the implementation of the method outlined in this section (4.3) and Section 4.2, as applied in Section 5.1. It revealed some causes which are directly assigned to other employees to focus on in order to develop interventions for solving the causes. For some of these root causes, starts are already made to tackle them during the first months of this research. It is therefore not useful to interfere in these ongoing cases resulting in infeasible interventions for this research. As a result, either a zero or one is assigned to each root cause as shown in Table 4.3. A zero represents: we should not focus on this root cause and determine interventions for solving within this Master Assignment. A one represents: we can focus on this root cause to develop interventions for solving the root cause.

Table 4.3: Focus for this research

Ranking	Focus for this research
0	No
1	Yes

Column: Operational Improvement Potential

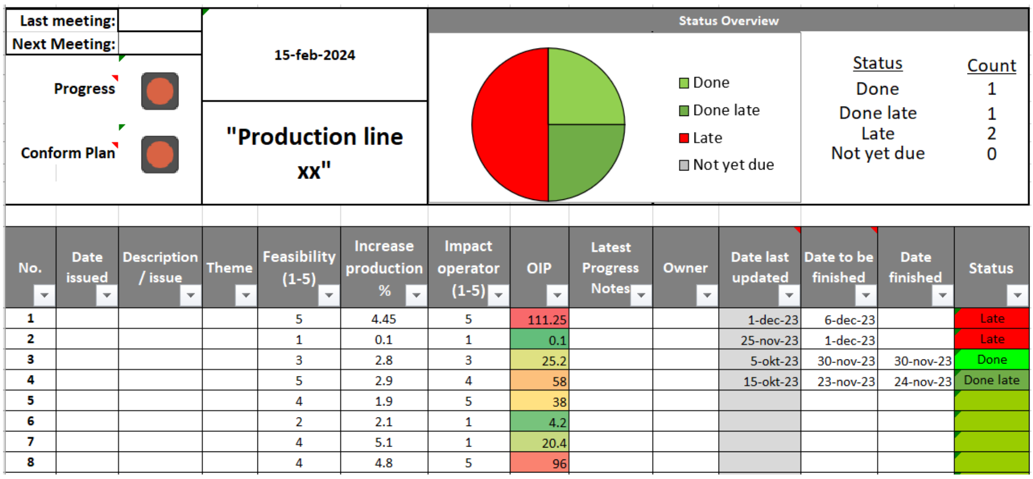
In order to determine the root causes to focus on and dive deeper into solving these issues, we should calculate the Operational Improvement Potential (OIP), which takes into account the ranking of Feasibility, Increase Production and Impact Operator. Especially for this research, we also added the criteria Focus for this research, which does not have to be applied again after this research. It is especially added to not interfere in ongoing root cause interventions. The OIP is calculated as follows:

$$OIP = FocusForThisResearch \cdot Feasibility \cdot IncreaseProduction \cdot ImpactOperator \tag{4}$$

Applying Equation 4 results in a ranking where causes without investment score higher compared to causes where an investment is needed to solve the cause. However, if a cause has a high impact on production (>5%), an investment is needed including a long time span (max eight months) in order to overcome this cause (hard to solve), this cause still receives a 10 ($5\% \cdot 2$), where a maximum of 25 ($5\% \cdot 5$) is possible at an increase of 5%. Therefore, causes which need an investment to overcome this cause and have a high impact on the increase of production are still in the upper part of the selection.

Format issue list including the criteria selection

The format for the issue list is developed and shown in Figure 4.6. Each issue should be ranked according to the determined criteria Feasibility (5th column), Increase Production (6th column) and Impact Operator (7th column) to create the value of OIP (8th column) in order to select the issues/causes where Grolsch should focus on. Notably, both criteria Feasibility and Impact Operator will be graded on a numerical scale ranging from 1 to 5 and Increase Production shows the increase in production as percentage. This format can be used within Grolsch in order to keep track of the detected issues on the keg line. In order to oversee the status of each issue in the list, a date for entering the issue on the list is added. In addition, to facilitate a comprehensive understanding of the ongoing process according to the issues, an illustrative representation detailing the categorization of issues into 'done', 'done late, 'late' and 'not yet due' is essential, which is the status of each issue in the last column. The pie chart shows the distribution of 'done' (light green), 'done late' (dark green), 'late' (red) and 'not yet due' (grey). Both the count status and the pie chart are updated automatically based on the last column of Figure 4.6.



Last meeting:
Next Meeting:
Progress ●
Conform Plan ●

15-feb-2024

"Production line xx"

Status Overview

Status	Count
Done	1
Done late	1
Late	2
Not yet due	0

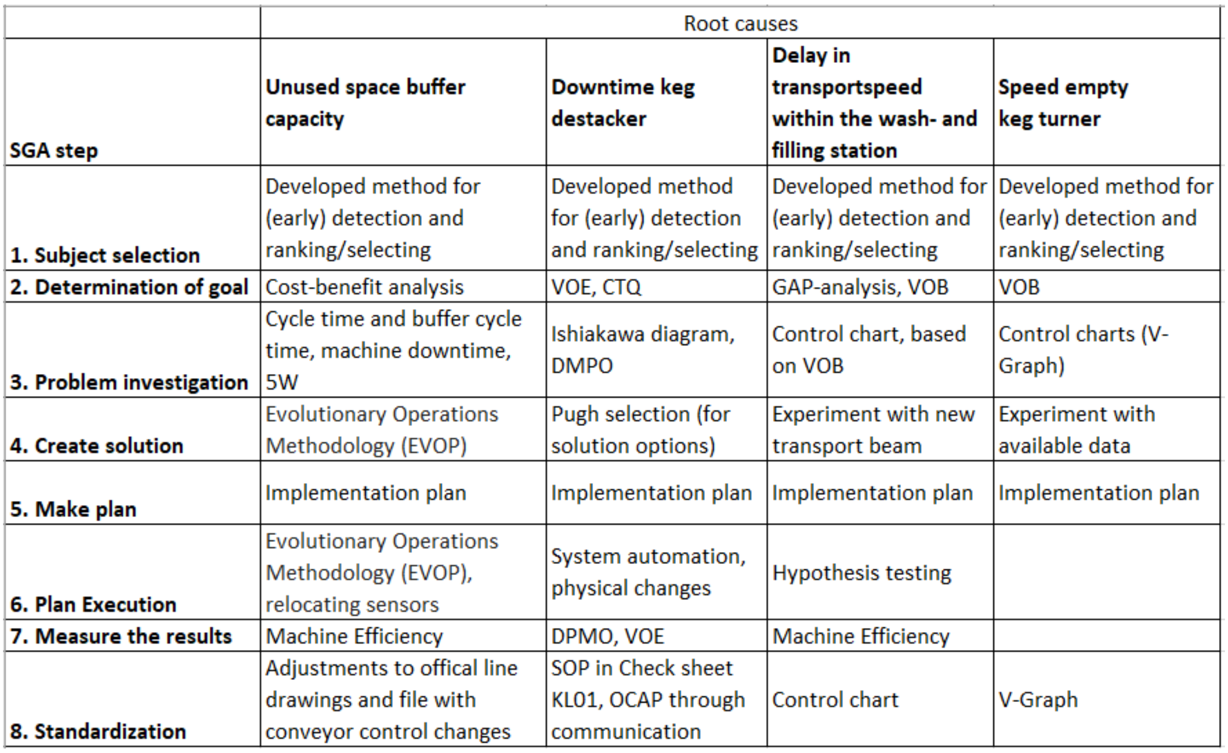
No.	Date issued	Description / issue	Theme	Feasibility (1-5)	Increase production %	Impact operator (1-5)	OIP	Latest Progress Notes	Owner	Date last updated	Date to be finished	Date finished	Status
1				5	4.45	5	111.25			1-dec-23	6-dec-23		Late
2				1	0.1	1	0.1			25-nov-23	1-dec-23		Late
3				3	2.8	3	25.2			5-okt-23	30-nov-23	30-nov-23	Done
4				5	2.9	4	58			15-okt-23	23-nov-23	24-nov-23	Done late
5				4	1.9	5	38						
6				2	2.1	1	4.2						
7				4	5.1	1	20.4						
8				4	4.8	5	96						

Figure 4.6: Issue list

Interventions should be developed for the issues/causes on the Issue list in order to deduct these issues or reduce the impact. The method for interventions to overcome these causes/issues will be explained in the following section.

4.4 Method for interventions to overcome causes/issues

Applying the methods for (early) detection of Section 4.2, the ranking and selection method of Section 4.3 results in the interventions where we should focus on to develop implementation plans for (Solving). We will apply a standardized method, where we combine the SGA method and Lean Six Sigma tools as explained in Section 3.6 (Methods and tools to solve root causes). The standardized approach for interventions in order to solve the root causes is shown in Figure 4.7. Each SGA step is explained in Appendix C and visualized in the first column of Figure 4.7. Each of the other four columns consist of a root cause, which is the outcome of Section 5.1 and 5.2 which we already explained shortly in Section 2.4. For each step, we determined the Lean Six Sigma tools which are most applicable according to the root cause and the SGA step. These tools will be used within the application of this standard method for interventions to overcome the causes and issues in Section 5.4-5.7. Except for the first step of SGA 'Subject Selection' we use our standardized method as explained in Section 4.2 and 4.3.



	Root causes			
SGA step	**Unused space buffer capacity**	**Downtime keg destacker**	**Delay in transportspeed within the wash- and filling station**	**Speed empty keg turner**
1. Subject selection	Developed method for (early) detection and ranking/selecting	Developed method for (early) detection and ranking/selecting	Developed method for (early) detection and ranking/selecting	Developed method for (early) detection and ranking/selecting
2. Determination of goal	Cost-benefit analysis	VOE, CTQ	GAP-analysis, VOB	VOB
3. Problem investigation	Cycle time and buffer cycle time, machine downtime, 5W	Ishiakawa diagram, DMPO	Control chart, based on VOB	Control charts (V-Graph)
4. Create solution	Evolutionary Operations Methodology (EVOP)	Pugh selection (for solution options)	Experiment with new transport beam	Experiment with available data
5. Make plan	Implementation plan	Implementation plan	Implementation plan	Implementation plan
6. Plan Execution	Evolutionary Operations Methodology (EVOP), relocating sensors	System automation, physical changes	Hypothesis testing	
7. Measure the results	Machine Efficiency	DPMO, VOE	Machine Efficiency	
8. Standardization	Adjustments to offical line drawings and file with conveyor control changes	SOP in Check sheet KL01, OCAP through communication	Control chart	V-Graph

Figure 4.7: Lean Six Sigma tools per SGA step per root cause

4.5 Conclusion

The emphasis of the method elaborated on in Section 4.2 lies on proactively identifying and eliminating potential inefficiencies before they have the opportunity to fully develop, thus reducing waste and optimizing processes in line with Lean principles. Simultaneously, with this method one can ensure rapid reactions to any unforeseen issues on an automated production line. Furthermore, the ranking and selection methodology outlined in Section 4.3 serves as a tool for identifying the most feasible causes for solving. Through continuous monitoring of the system (method of Section 4.2) and a well-defined issue solving protocol of Section 4.4, the organization maintains a dynamic responsiveness to retain a smoothly automated production line. This integrated approach not only minimizes downtime and waste, but also manage a culture of continuous improvement in a fast moving manufacturing environment. The developed methods in Section 4.2 and 4.3 will be applied in respectively Section 5.1 and 5.2. The standardized method of Section 4.4 will be applied in Section 5.4-5.7.

5 Process improvement case study

This chapter elaborates on the case study within Grolsch on the keg line, which is determined in three sections:
1) The application of the developed method for proactive (early) detection (Section 5.1)
2) The application of the developed method for ranking and selection (Section 5.2)
3) Solving the top five root causes (Section 5.4-5.7)

5.1 Case study: application of the method for (early) detection of causes and issues

This section consist of the application of the method for (early) detection of causes and issues as explained in Section 4.2 consisting of three different flowcharts. The visualization of the structure of this section is shown in Figure 5.1. Within this section, we show the issues found by the method as described in Section 4.2, but we will not dive deep into all issues to increase the readability.

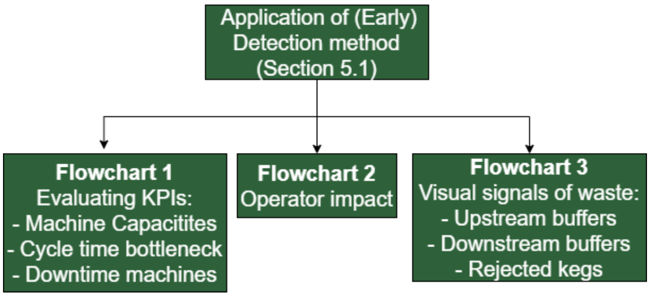


Figure 5.1: Application of (Early) detection

Evaluating KPIs: Machine Capacities
Within this section, we apply the Flowchart of Figure 4.3 on the keg line of Grolsch. Since the unavailability of a V-Graph of the keg line of Grolsch, we measured all machines on the keg line with at least 30 measurements per machine. As explained in Section 4.2.1, we measured the keg destacker, empty keg turner, exterior cleaner, wash and filling station, full keg turner, leak detection/weighing scale, cap placement, keg labeler and palletizer. The first step in the analysis, using the V-Graph method, is indicating the core machine. Arena et al. (2019) defines the core machine as the one with the lowest theoretical production capacity. Therefore, the capacity is calculated by the cycle time of the machine. It is considered to be the most crucial machine in the line since any production time lost on this machine cannot be redressed causing a reduction in line efficiency. The core machine of the keg line is the wash and filling station as already mentioned in Section 2.2. The required data to create the V-Graph is the sequence of the different machines on the line and the corresponding machine capacities. Each machine capacity is measured as described in Section 4.2.1.

With the use of the machine capacities and the capacity of the core machine (wash and filling station), V-Graphs are developed for the four most important SKUs and visualized in Figure 5.2. Within the V-Graph theory, the core machine capacity is set at 100% and with this value the other percentages are calculated (comparing all machine capacities with the core machine capacity). Therefore, the overcapacity per machine is calculated towards the capacity of the wash and filling station. It is important to note that the wash and filling station capacities for the several SKUs are nonidentical, which means that 20% overcapacity for a machine processing 50l kegs, is not equal to 20% overcapacity for a machine processing 19.5l kegs. If a machine has overcapacity for processing all SKUs, the overcapacity can be higher for 19.5l kegs, since the difference between this machine capacity and the wash and filling station capacity is higher, since 19.5l kegs have lower processing times in the wash and filling station. In addition, the labeler only processes kegs which are sold within the Netherlands and therefore this machine is not used for exported kegs, which are Grolsch Export and Peroni.

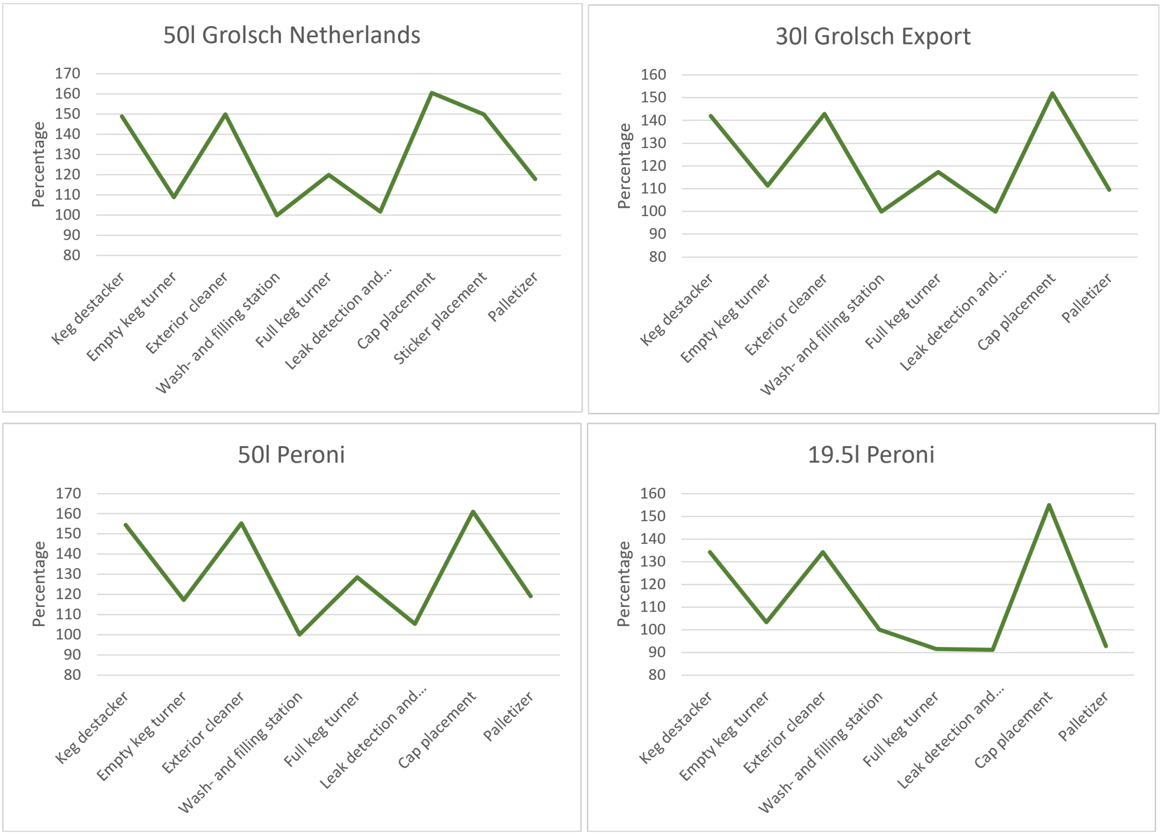


Figure 5.2: V-Graphs for 50l Grolsch Netherlands, 50l Peroni, 30l Grolsch Export and 19.5l Peroni

Five conclusions can be drawn from the V-graph:

- The shape of the V-Graph, which should look like a V. The machines in front of the core machine should be decreasing in capacity when the machine is closer to the core machine. At the other side, machine capacities should increase as the machine is further away from the core machine. The two machines immediately before and after the bottleneck machine, need to be set 10% faster in recovery speed than the bottleneck machine. Each machine before the bottleneck machine should run 10% faster in recovery speed than the upcoming machine.
- Figure 5.2 shows less than 10% overcapacity of the empty keg turner when processing 50l kegs, which is the same for 30l and 19.5l kegs. The empty keg turner has a small overcapacity compared to the wash and filling station, causing a slow increasing buffer in comparison with the empty keg turner with an increased overcapacity. Therefore, it shows the buffer between the empty keg turner and the wash and filling station should always be filled to catch small interruptions of the station in front of the wash and filling station.
- The capacity of the empty keg turner is lower for 50l Netherlands kegs in comparison with all other kegs, where the difference is around one second compared with 30l kegs and 19.5l kegs and more than half a second for 50l Peroni kegs which are of the same size.
- The full keg turner has a higher capacity according to the wash and filling station for all SKUs except for 19.5l kegs. As earlier explained, 19.5l kegs are processed in a dummy and when the keg is turned by the full keg turner, the dummy has to be transported from the place where the keg is picked up to the place it is placed by the robot by a conveyor. Therefore, it takes around a second more to turn a 19.5l keg.
- The leak detection capacity is lower compared to the previous processing step, the full keg turner, for each of the four different SKUs. It has the most impact on 19.5l kegs due to the fact processing times within the wash and filling station are lower for 19.5l kegs compared with 30l and 50l kegs.

Both the full keg turner and the leak detection should be improved as a result of the 19.5l Peroni V-Graph. Improving one of these machines does not improve the capacity in the V-Graph, since both machines are dependent of each other and therefore both machines should be improved together. Besides, the production of 19.5l kegs in the upcoming year will be 29% of the total keg production in number of kegs. This 29% is divided in 15% Weizen and 14% non Weizen beers. Due to the turbidity of Weizen, an additional cleaning time in the wash and filling station is required causing longer processing times of Weizen. This results in a lower capacity for the wash and filling station for Weizen (327 kegs per hour) resulting in a overcapacity for the full keg turner and leak detection (above 100% in the V-Graph) when producing Weizen. Therefore, the capacity of the leak detection has only an effect on 14% of the production for the upcoming year. We also detected a lower capacity for the leak detection for 30l kegs, since the processing times within the wash and filling station is lower for 30l compared with 50l kegs. The speed of this station is already increased last year and should be increased further to achieve a capacity surpassing the capacity of the wash and filling station. The buffer after the wash and filling station and before the full keg turner has a capacity high enough to compensate for this small capacity cap. The buffer capacity is only not enough when producing 30l kegs without an extra cleaning step, which equals 7% for the total production of kegs next year. Therefore, we conclude that 19.5l non Weizen suffer the most from the capacity of the full keg turner and the leak detection, which equals 14% of the production in the upcoming year and therefore we should first focus on the 50l kegs and the empty keg turner, since the production of next year consist of 58% 50l kegs. In addition to the production numbers and the low overcapacity of the empty keg turner, the core machine should be running as much as possible and therefore it is recommended to ensure the wash and filling station has an continuous supply of empty kegs. As a result of the V-Graph, one of the root causes of speed loss is the empty keg turner.
As a result of Flowchart 1 (Figure 4.3), we should add the machines which do not comply with the V-Graph principles to the issue list (Table 5.2) (number 1 in Flowchart 1 of Figure 4.3), which are the Leak detection/weighing scale for 19.5l and Speed empty keg turner.

Evaluating KPIs: Cycle time bottleneck
Within this section, we apply Flowchart 1 of Figure 4.3 on the keg line of Grolsch. We already checked the machine capacities within the previous section and therefore we turn right at the first question in Flowchart 1. In Section 4.2.1 we determined to measure the cycle time of the process steps and the transport cycle times separately and test these cycle times with the acceptable levels, which are determined by the supplier of the wash and filling station. For each SKU (in line with Figure 5.2), we measured the cycle times for each of the eight heads for all five lines. In order to analyse the wash and filling station for speed loss, several recordings are made of the wash and filling station panel where each processing step for the different heads are shown. This information is not digitally available and therefore the recordings are analysed to receive the processing times per step for the different SKUs. Figure B.1 in Appendix B already shows some small deviations, but improving heads 3 until and including 8 will not result in a decrease in speed loss at first, since head 3 until and including 8 will wait till the moment head 1 and 2 are finished in order to go to the next processing step. Therefore, we should first focus on head 1 and 2 and when these are improved, one can improve the subordinate steps (head 3 until and including 8).

Testing these measured cycle times against the cycle times of the supplier, did not reveal significant differences. However, within this analysis we discovered a ratio within the cycle times, which is not in line with the ratio between the capacity between the kegs. The cycle times for Deullage showed this deviating ratio of 2, 4 and 6 seconds for keg capacities respectively 19.5l, 30l and 50l even though the capacity of 30l is not double the capacity of 19.5l. In addition, we also found deviations of the times within Air Purge where the process times for this step are determined as 9, 9 and 8 seconds by the supplier. However, Air Purge takes less time within a smaller keg and therefore this deviations are not in ratio with the keg capacities. The same accounts for the Wash pulses according to kegs for Weizen beer. Kegs especially filled with Weizen need extra cleaning pulses, due to turbidness of Weizen resulting in extra cleaning pulses in order to fully clean the keg before filling. The

Wash pulses for 30l and 50l Weizen are determined as six, where one pulses has a cycle time of respectively 8 and 8.5 seconds. However, the Wash pulses for 19.5l kegs are determined at 7 with a cycle time of 8 seconds per pulse. For comparison, the Wash pulses for all other kegs are determined at 3 for all keg capacities. The Quality Manager could not give any explanation for the change in Wash pulses for 19.5l kegs and therefore we should find the reasons and ascertain if we can reduce the the cleaning step to 6 pulses.

In addition, we also measured the transport cycle time for each parallel line within the wash and filling station resulting in a total of 150 measurements. The results are shown in Figure 5.3 where each measurement is the average of three measurements per line. This results in a total of 30 measurements per line. Figure 5.3 shows the acceptance level of 14 seconds for transport as determined by the supplier. In addition, this figure shows the LCL and UCL of respectively 12.3 and 15.7 seconds which are calculated with the acceptance level of 14 decreased and increased by a factor of 3σ as determined by the machine supplier. The acceptance level of 14 seconds and the corresponding σ values are equal for each line as determined by the machine supplier. Within this visualization, we can see the deviations from 14 seconds for each line except for line 3, which is below each measurement towards the control limit of 14 seconds. Each transport cycle time above 14 seconds result in a direct speed loss and therefore directly decreases the keg line ME.

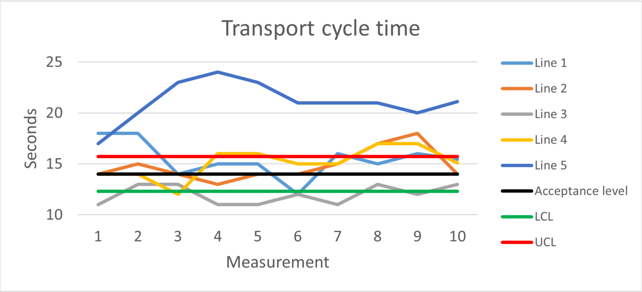


Figure 5.3: Transport cycle time per line, including acceptance level (14), UCL (15.7) and LCL (12.3)

In conclusion, we add the different cycle times within the wash and filling station for Deullage, Air Purge and Wash pulses Weizen to the issue list according to the flowchart of Figure 4.3 (3. Add to issue list). In addition, the cycle time of transport within the wash and filling station also deviates from the acceptance level of 14 seconds and should therefore be added to the issue list according to the flowchart of Figure 4.3 (3. Add to issue list).

Evaluating KPIs: Downtime machines

The downtime per machine according to FE, as described in Section 4.2.1 (Evaluating KPIs: downtime of machines), are calculated and visualized in a control chart including the calculated three levels of Control Limit, UCL and LCL. Since we are calculating the machine downtime as a percentage, the LCL commonly results in a negative value and therefore we determine the LCL at 0% and this value is therefore not visualized within the control charts. Each Control Limit and UCL is calculated per machine according to the control chart, where each measurement is the total downtime per week according to FE, by increasing the CL with 3σ of the data per machine of last half year. The visualizations are developed for each machine on the keg line including the corresponding CL and UCL. Each visualization including the CL and UCL is shown in Appendix H, except the visualizations of the machines which had an out of control situation for two times over the last half year (according to Flowchart 1 (Figure 4.3 (c)). This occurred at both the Palletizer and Capper as shown in Figure 5.4 and therefore we should add these machines to the issue list according to Flowchart 1 (Figure 4.3 (at number 4. Add to issue list)).

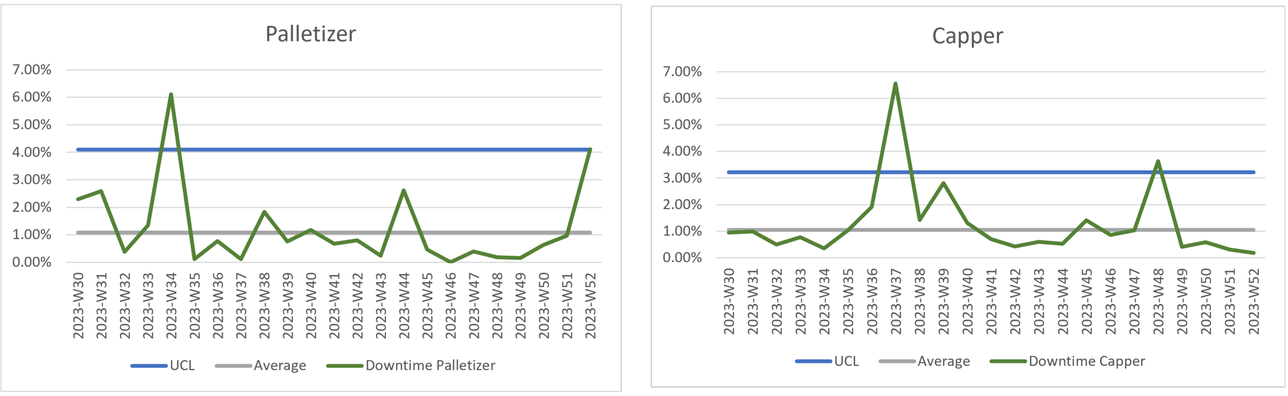


Figure 5.4: Downtime per week for Palletizer and Capper including CL and UCL

Operator impact

The survey of Appendix E is executed with the five teams of the keg line. It was the first time this survey was executed and therefore we stay at the left side of Flowchart 2 (Figure 4.4). Within this survey, each team made a top five for the (daily) issues on the keg line where the issues coexist with the repetitions of solving the same issues over and over without the appliance of interventions to overcome the problem in the future. The results of the five teams are combined and resulted in the following issues: Downtime keg destacker (due to 19.5l keg disruptions), Reaction time F10 procedure, Shortage of Dummies, Downtime keg destacker (due to encoder), Emergency stop empty keg turner, Empty keg turner and Downtime palletizer. Therefore, we should add all these seven causes to the issue list according to Flowchart 2 of Figure 4.4 (at number 5. Add issue to list).

This method revealed some issues on the keg line, which become ’normal’ to operators. One of these issues is the downtime of the keg destacker due to 19.5l keg disruptions, which is occurring since the time Grolsch started to produce 19.5l kegs (several years ago). In addition, the emergency stop empty keg turner was revealed within this method and communicated to the Reliability Project Engineer, who takes this cause into account within the Peroni Phase 2 project. Without this method, these causes where probably not detected and distributed to the right person in order to solve this cause.

Visual signals of waste

In order to apply Flowchart 3: Visual signals of waste, several Gemba walks are performed, where after data analysis are performed. The Gemba walks are performed during various moments in order to see the differences and the equalities. The various moments refer to production in smooth moments, where everything takes place as planned, moments with operator shortage due to illness or breaks, at downtime of machines, but also at startup- and shutdown moments (between the production of two different SKUs). In order to check the upstream buffers before the wash and filling machine, we detected an incomplete utilization of the buffer capacity without reasons. The chain capacity of the transport lines and the stopper capacity for preventing kegs from passing are not the reason for the unused buffer capacity and therefore, according to Flowchart 3 of Figure 4.5 (at number 7. Add to issue list), we should add the unused upstream buffer capacity to the issue list. In addition to upstream buffers, we should also evaluate the downstream buffers. The buffers between the downstream machines (after the wash and filling station) are also not fully occupied at downtime of downstream machines and therefore the wash and filling station has a decreased running time compared to an ideal situation where the buffer capacity after the wash and filling station is fully used. Therefore, according to Flowchart 3 of Figure 4.5 (at 7. Add to issue list), we should also add the unused buffer capacity between downstream machines to the issue list. We will diver deeper into these two visual signals of waste and also the background in Section 5.4.1.

At this moment, we already evaluated the buffer capacity and therefore we go to the right side of Flowchart 3 of Figure 4.5, where we check the rejected kegs on the keg line. Some machines reject kegs according to the critical values (determined parameters). If a keg fails to align with these parameters, it is rejected. Kegs are rejected at several machines, since it need to align with all these parameters. Kegs are rejected between the keg destacker and the empty keg turner when the keg is still above the weight of an empty keg. This implies a full keg and is therefore rejected at the beginning of the process. After the keg is emptied manually, the keg can still be added to the process. Since this rejection is not rooted in a defect in the process of the keg line, it is not considered as a complete waste. However, it takes additional time to empty the keg which has to be done manually by an operator. In addition, this machine is not working as expected, since it is sometimes too slow to reject the keg causing a constriction between the pusher and the frame of the machine. Therefore, we should still add this cause to the issue list.

In addition, the leak detection rejects kegs which fail to align with the determined parameters. The reason for a leak keg can have several reasons and should be investigated and therefore added to the issue list. The capper not only has a high downtime compared to other machines on the keg line as shown in Figure 5.4, it sometimes fails to place a cap on a keg. Where other machines are available to reject the keg, this function of the capper is not properly working. In order to check if a keg really contains a cap, an employee is deployed to check every keg for a cap. However, there is no availability of data for the number of rejected kegs at both the leak detection and capper. We should still add these both to the issue list, since there is a loss of money (costs for one employee for only evaluating each keg for a cap) at the capper and a loss of beer and speed loss at the leak detection. Each rejected keg at the leak detection is manually emptied (loss of beer), the keg cannot enter the process again and waste is created since it took several cycle times without a keg output of the line.

Within the wash and filling station, kegs are rejected when they do not align with the determined parameters, which are several parameters within each head. We analyzed all rejections within the filler and conclude the seal failures possesses the predominant proportion. The seal failures per week are shown in Figure 5.5 including the UCL of 2.7% which is based on a sample of stable failures resulting in an average of 1.8% increased by 3σ, where σ for seal failures equals 0.3%. Seal failures within the wash and filling station are within several week above an acceptable level of 2.7% and therefore we should also add Rejection in filler to the issue list.

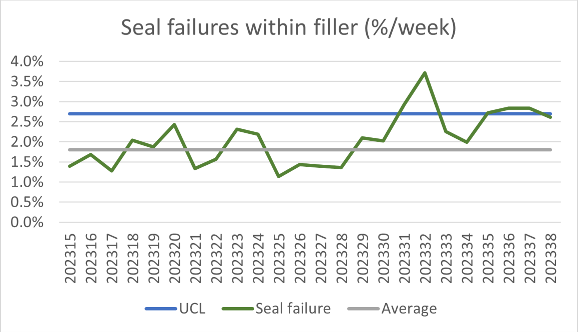


Figure 5.5: Seal failures within filler, UCL= 2.7%

At the weighing scale, kegs are rejected which are below the pivotal parameters, which are different for each keg type: 50l Peroni (61.2 kg), 50l Grolsch (61.5 kg), 30l Grolsch (38.5 kg) and 19.5l (30.56 kg). We analyzed the data of underfilling and tested the percentage underfilling for each keg type according to the acceptance level of 0.5%. The acceptance level is determined by the average, Control Limit of 0.18%, increased by 2σ, where σ equals 0.16%. This acceptance level equals the UCL for underfilling, where we deviate from 3σ, since underfilling results in two losses, both speed- and beer loss. Therefore, 95% of the kegs according to underfilling have to be within the Control Limits. The results are shown in Table 5.1 and we conclude only 50l Peroni is above the acceptance level of 0.5% and should therefore be added to the issue list.

Table 5.1: Underfilling

SKU	**Percentage underfilling**	**SKU**	**Percentage underfilling**
Fust 19.5ltr DKk_Pls	0.00%	Fust 19.5ltr Per_PNA	0.08%
Fust 19.5ltr Gro_Hbk	0.09%	Fust 30ltr Gro_Pls_E	0.08%
Fust 19.5ltr Gro_IPA	0.00%	Fust 30ltr Gro_Ra2.0	0.41%
Fust 19.5ltr Gro_Pls	0.01%	Fust 50ltr DKk_Pls B	0.34%
Fust 19.5ltr Gro_Wzn	0.12%	Fust 50ltr Gro_Pls_4	0.49%
Fust 19.5ltr Ond_Dis	0.02%	Fust 50ltr Gro_Pls_B	0.33%
Fust 19.5ltr Ond_Han	0.04%	Fust 50ltr Per_PNA B	0.51%

In conclusion, all issues found in this section are added to the issue list in Table 5.2 in Section 5.2. We will not repeat all issues, since they are all visualized in the the upcoming section. In Section 5.2, we will apply the method for ranking of Section 4.3 to all these issues. The application of this method will result in the list with issues in order to solve.

5.2 Case study: application of the method for ranking and selection

Each issue is listed in Table 5.2 and we arranged all issues based on the four categories, as described in Section 2.3: speed loss in front of wash and filling station, speed loss within wash and filling station, speed loss after wash and filling station and rejected kegs. As explained in Section 4.3 we use the criteria Feasibility, Increase Production, Impact Operator, and Focus for this research to determine the Operational Improvement Potential (OIP). For each cause, we calculated the Increase in Production as described in Section 4.3 and also the Operator Impact and determined the Feasibility according to the number of months for solving the root cause including or excluding an investment. We first explain the Focus for this research column, where after we show Table 5.2 and determine the causes to solve within Section 5.4-5.7.

Column: Focus for this research
After the list of the root causes which have an effect on the speed loss and ME of the keg line was developed by the researcher, we found some root causes which were already known within Grolsch. For some of these root causes, starts are already made to tackle them during the first months of this research. It is therefore not useful to interfere in these ongoing cases resulting in infeasible interventions for this research. For example, starts are already made for the speed loss caused by the leak detection and weighing scale for 19.5l and the rejection of the leak detection, but these interventions are delayed. These two root causes received a zero for Focus for this research in the third column of Table 5.2. The values for Feasibility, Increase Production and Impact Operator are not shown for the root causes with a zero for Focus for this research, since we will not focus on these root causes in this research as explained before. All other causes which received a zero for Focus for this research will be shortly explained.

Both causes Emergency stop and Downtime palletizer will be taken into account during the Peroni Phase 2 project (implementation in January 2024). The shortage of dummies was one of the causes found by the researcher, but the researcher did not had the knowledge starts to tackle this problem were already made. The cause Reaction time F10 procedure is related to the signal of the wash and filling station when there is a F10 procedure. There is a signal of the Andon system (it visually indicates the status of a machine: green, orange or red light) which is one of the key elements of Jidoka quality control. The wash and filling station gives a signal to the Andon, causing downtime of the line within the wash and filling station causing a F10 procedure. Adding an Andon per line within the wash and filling station instead of one Andon for the whole wash and filling station will result in a shorter reaction time. In the optimal scenario, an operator does not have to walk to the screen initially to observe which line triggers a F10 procedure, leading to a reduced reaction time. The rejection in the wash and filling station causes are divided and starts are already made by several employees of Grolsch, where interfere in these ongoing cases within this research is not meaningful. The problem investigation for 'Underfilling' is already started for 19.5l and 30l kegs, but for 50l kegs the optimal value of liters beer in a keg taking into account the minimum liters of beer for the customer and the minimum amount of beer loss for Grolsch should still be determined.

Column: Operational Improvement Potential (OIP)
In order to determine the root causes to focus on and dive deeper into solving these issues, the last column of Table 5.2 shows the OIP, which is calculated by Equation 4 as shown in Section 4.3. For increased readability (less decimals), we increased the OIP with a product of 100 in Table 5.2.

Table 5.2: Division speed loss according to Feasibility, Increase production and Impact Operator

	Cause	**Focus for this research**	**Feasibility**	**Increase production**	**Impact operator**	**OIP (·100)**
Rejected kegs	Rejection in filler	0				
	Underfilling	0				
	Rejection leak detection	0				
	Rejection cap placement	1	2	0.17%	1	0.33
Speed loss within wash and filling station	**1. Delay in transport speed**	**1**	**2**	**4.45%**		**8.90**
	Reaction time F10 procedure	0				
	Stoptime single filler lane	0				
	Processing times different filler steps (Wash pulses Weizen)	1	3	0.65%		1.95
	Processing times different filler steps (Air Purge)	1	3	0.53%		1.60
	Processing times different filler steps (Deullage)	1	3	0.80%		2.40
Speed loss in front of wash and filling station	4. Downtime keg destacker (due to encoder)	1	4	1.27%	1	5.07
	4. Downtime keg destacker (due to 19.5l disruption)	**1**	**4**	**0.98%**	**2**	**7.84**
	Shortage of Dummies	0				
	2. Unused space buffer capacity	**1**	**5**	**1.72%**		**8.58**
	Emergency stop empty keg turner causing stoppage of transportlines before filler	0				
	Full keg rejection not working as expected	1	3	0.25%	1	0.75
	5. Speed empty keg turner	**1**	**3**	**0.82%**		**2.45**
	Slow 'recovery speed' empty keg turner	1	4	0.08%		0.32
Speed loss after wash and filling station	Leak detection/weighing scale for 19.5l	0				
	3. Unused space buffer capacity	**1**	**5**	**1.68%**		**8.40**
	Investment extra buffer capacity	1	2	1.18%		2.37
	Downtime capper	1	1	0.67%		0.67
	Downtime palletizer	0				

Some of the causes in Table 5.2 have a higher effect on the ME compared with the decrease on speed loss to increase the ME. For the purpose of comparing the effects on the same level, i.e. ME, the effects per cause on ME is shown in Table 5.3. The ME per cause is calculated as the increase in production multiplied by the average ME of the keg line. This table only shows the causes which received a 1 in Table 5.2 for Focus for this research, since solving these causes are not interfering with ongoing interventions within Grolsch. In addition, changes for a whole machine are also outside the scope of this research and therefore not taken into account within Table 5.3. While an impact on ME of 0.67% may appear relatively modest, its monetary equivalents amounts €38,693 on a yearly basis.

Table 5.3: Cause effect on Machine Efficiency

Cause	**ME impact**	**Cause**	**ME impact**
Delay in transport speed	2.67%	Speed empty keg turner	0.49%
Unused space buffer capacity (in front of wash and filling station)	1.03%	Processing times different filler steps (Deullage)	0.48%
Unused space buffer capacity (after wash and filling station)	1.01%	Downtime capper	0.40%
Downtime keg destacker (due to encoder)	0.76%	Processing times different filler steps (Air Purge)	0.32%
Investment extra buffer capacity (after wash and filling station)	0.71%	Full keg rejection not working as expected	0.15%
Processing times different filler steps (Wash pulses Weizen)	0.65%	Rejection cap placement	0.10%
Downtime keg destacker (due to 19.5l keg disruption)	0.59%		

The encoder error (downtime keg destacker), at position four of Table 5.3, occurring at a frequency of 1.6 occurrences per machine hour of the keg destacker, leads to a downtime of 3.3 minutes per machine hour. Operators address this issue by a quick fix through the reset button. During the occurrence of the error and the subsequent rest button activation, the supply of kegs to the empty keg turner is temporarily paused. The encoder error is discovered during this research and while this problem is tackled by another employee, the focus of this research centers on the disruptions arising from the 19.5l kegs. This choice is made, since the 19.5l keg disruptions could be approached in a more academic way than the encoder error.

The ME impact of the investment for an extra buffer capacity after the wash and filling station is positioned at position five in Table 5.3, but there is no amount of investment available for the upcoming year and therefore we should not focus on a proposal for expanding the buffer capacity without possibilities for realization.
Starts were made to focus on the processing times for the steps within cleaning heads one and two within the wash and filling station (wash pulses Weizen, number six in Table 5.3). Nevertheless, we got feedback from the quality assurance specialist to not further investigate solutions to decrease the speed loss caused by this processing step. The feedback is based on the amount of complaints specific for 19.5l Grolsch Weizen. The number of complaints per month are on average three for the first ten months of 2023. Due to quality considerations, we cannot focus on this cause and the research should continue after the complaints of 19.5l Weizen are decreased to zero. Taking into account Table 5.2, Table 5.3 and the explanation given below Table 5.3, it results in the following top five root causes to focus on:

1. Delay in transport speed within the wash and filling station
2. Unused space buffer capacity in front of the wash and filling station
3. Unused space buffer capacity after wash and filling station
4. Downtime keg destacker
5. Speed empty keg turner

5.3 Case study: solving top five root causes

The root causes unused space buffer capacity **in front** of the wash and filling station and the unused space buffer capacity **after** the wash and filling station are compared within Section 5.4. Section 5.5 solves the 19.5l keg disruptions at the keg destacker and 5.6 elaborates on the root cause Delay in transport speed within wash and filling station. Section 5.7 elaborates on the Speed of the empty keg turner. At last, 5.8 shows the conclusions of Chapter 5. The structure for the upcoming four sections is visualized in Figure 5.6.

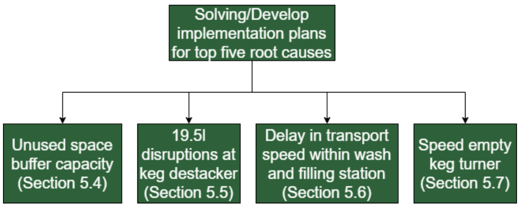


Figure 5.6: Structure Sections for solving root causes

5.4 Unused space buffer capacity

5.4.1 Background

In this section, we focus on the buffer capacity of the keg line. The kegs are transported one by one by a conveyor without passing each other, so the kegs are processed by a First In First Out (FIFO) principle. In Section 5.1 we already concluded the buffer spots are not fully occupied even though there is enough space. The buffer in front of the wash and filling station is used in case of a machine failure in front of the wash and filling station, for example the keg destacker. With enough kegs in the buffer, the bottleneck machine (wash and filling station) can process a while before the buffer is empty and the bottleneck machine stops running. Therefore, the buffer in front of the wash and filling station should always be filled. On the other hand, when downstream equipment fails (for example, the capper) the wash and filling station should be maintained in a running state as long as possible. This is only achievable with enough space between the machines after the wash and filling station. These spots should be left empty and should only be filled by the wash and filling station with kegs when a downstream machine fails.

The buffer spots enhances the throughput of the keg line by reducing the blocking and starving time of the bottleneck, the wash and filling station, resulting in an improved flow line efficiency according to Ameen et al. (2018). The data of 'Stop Accountability' from eight weeks stable production between 16-7-2023 and 10-09-2023 are retrieved from MicroStrategy, where we first filtered the data. Subsequently, Machine Hours and stoppage reasons related to the keg line, specifically those who arise from brewing-related issues (such as unavailability of beer), are excluded from the data set. In addition, all other stoppages caused by Planning, Maintenance, Cleaning and Sterilization, Conversion, Startup and Shutdown are filtered from the data set in order to save the stoppages which have an effect on the buffer usage. The residual data is analyzed revealing a significant journal entry of 01 KEG line, where the reason for stoppage is determined on a lower level (within the comments section). We found 69.8% of the stoppage minutes belong to machines in front of the wash and filling station, 24.5% to machines after the wash and filling station and 5.7% was due to technical issues which had an effect on all packaging lines of Grolsch. After the analysis, the stoppages are manual divided in stoppages with reasons before and after the wash and filling station. At last, the data is filtered where the duration of stoppages should be at least 40 seconds, as a shorter duration is deemed to lack consequential value for an increased buffer size.

This data set shows the stoppages of the wash and filling station caused by any of the machines on the keg line and the starvation and blocking caused by warehouse. Starving and blocking minutes of the wash and filling station caused by a lack of supply or a pick up lack by warehouse issues are included, since these stoppages also have an effect on the buffer size. A lack of pick up caused by the warehouse assert a claim to the available buffer spots in front of palletizer which stacks the kegs and transports them into the warehouse.

Within this stable production period of eight weeks, there was a total downtime of 152.99 hours (19.12 hours per week) of the wash and filling station caused by a machine failure before the wash and filling station resulting in a starvation of the wash and filling station. Within these eight weeks, taken into account the time between stoppages caused by different upstream machines (in front of the wash and filling station), which should be more than 40 minutes in order to make use of extra buffer spots. After a stoppage of the wash and filling station, with an empty buffer, it takes 40 minutes in order to fill the buffer to it maximum during a running wash and filling station. Therefore, we can only make use of extra buffer spots when the time between a fixed machine failure and a machine failure before the wash and filling station has a difference of more than 40 minutes. Within this time, the buffer has enough time to use the maximum capacity when the wash and filling station is in a running state. After these 40 minutes, the buffer is used till its maximum capacity (according to the system) and at this point we can increase the unused buffer spots into buffer spots. With the use of this restriction, it was possible to make use of the extra buffer spots in front of the wash and filling station for 346 times according to the data set. The number of extra kegs produced per day and week is dependent on the research how many buffer spots can be realized and therefore this value can be calculated after the number of extra buffer spots between upstream machines are determined.

Downtime of the wash and filling station caused by a downstream machine failure causing a blockage of the wash and filling station is also calculated. It must be noted downtime of the wash and filling station is caused by either a machine before or after the wash and filling station and not by a combination of both. Therefore, it is possible to apply almost the same method as applied for the buffer in front of the wash and filling station. Within the same period, the wash and filling station was not able to produce any full kegs due to congestion caused by downstream machine stoppages for 132.22 hours (16.52 hours per week). The time between a remedied congestion of the wash and filling station and empty buffer spots between the downstream machines takes 15 minutes and therefore we only take into account the times between a fixed machine failure and a machine failure of a downstream machine which are above 15 minutes. Within this time, the buffer spots between the downstream machines become empty and can be used for the next downstream machine failure. With the use of this restriction, it was possible to use the extra buffer spots for 414 times within eight weeks. Due to the fact these buffer spots are not used yet, the wash and filling station still had a congestion of 132.22 hours (16.52 hours per week). The number of extra kegs produced per day and week is dependent on the research how many buffer spots can be realized and therefore this value can be calculated after the number of extra buffer spots between the downstream machines are determined.

The improvement potential is based on the number of available spots, which then can be transformed into used buffer spots. In order to calculate the extra output and the decreased time for the wash and filling station to be either blocked or starved, we should first find the number of available spots, which then can be transformed into buffer spots that will be used in the future. Therefore, the current problem is divided in two:

- Spots on the buffer line in front of the wash and filling station (between upstream machines) are not filled with kegs even though there is enough place for more kegs.
- More spots are available after the wash and filling (between downstream machines) in order to fill with kegs when a downstream machine fails.

An overview is developed for the buffer spots on the keg line, where the green rectangles represent the number of spots used and the gray rectangles represent the spots where no kegs are positioned (Figure 5.7) when the wash and filling station is 'fully' occupied (even tough physical spots are unused). This overview is developed in two sessions, first to determine the used/unused spots in front of the wash and filling machine and second the spots after the wash and filling station. In the first session, the researcher counted the number of kegs in front of the wash and filling station at the moment the wash and filling station was not running. The keg destacker, empty keg turner and exterior cleaner were all running resulting in a padded buffer. In the second session, the palletizer is paused causing the wash and filling station to run till the moment the systems determines the buffer is 'full' precluding any further kegs from being positioned between the wash and filling station and the palletizer. These measurements are executed ten times for all different keg types (black and stainless steel for all different keg sizes), which corresponds to 30 measurements in front- and 30 measurements after the wash and filling station.

Figure 5.7: Used and unused buffer spots

Numbers are given to the different sections of the keg line, where the buffer capacity can be increased. Buffer number 1 is left empty, since the number of buffer spots filled within these places are different for 19.5l compared with 30l and 50l. 19.5l kegs are transported to the empty keg without a dummy where they receive their dummy and therefore more 19.5l kegs can be placed at buffer number 1 compared with 30l and 50l kegs (due to the smaller circumference). This part cannot be regulated separately for different SKUs and therefore we cannot increase this buffer for 19.5l kegs.

In order to determine which spots have the most influence on the running time of the wash and filling station, the researcher calculated the yield (Table 5.4). The yield is based on the extra number of kegs that can be processed in a time period of eight weeks stable production with an increased buffer. This increased buffer is dependent on the available spots that can be maximum used for a buffer which are currently not used (third column Table 5.4). In addition, we also take into account the distinction of downtime caused by a machine in front or after the wash and filling station. These minutes are available in the same filtered data set as explained in the beginning of this section (including the constraints of at least 40 minutes between failures before the wash and filling station, at least 15 minutes between failures after the wash and filling station and a duration of at least 40 seconds). The number of extra kegs that can be processed, taking into account the number of extra available spots (Table 5.4), is converted to the percentage of increased running time of the wash and filling station over the corresponding period. This percentage is then corrected by the average ME over that period. In order to determine the yield per year, this value is corrected by the FE and converted to a value in euros, which is based on the value of 1% FE increase (€X). The yield (Table 5.4) is based on the FE impact, since we can calculate the yield in euros per year, followed by subtracting the amount of investment. The yield is dependent on the place of the buffer (in front or after the wash and filling station) due to the minutes of downtime for the different machines.

Table 5.4: Buffer yield

Buffer number	**Description**	**Number of extra available spots**	**Yield per year (€)**
2	Between keg turner and exterior cleaner	6	49,500
3	Conveyor begin exterior cleaner	2	16,500
4	Conveyor end exterior cleaner	2	16,500
5	Conveyor between exterior cleaner and stopper		
6	Left corner after stopper	5	41,250
7	After wash and filling station	5	11,000
8	In front of capper	4	35,200
9	In front of sticker placement	3	12,210
10	In front of palletizer	4	16,280

Increasing the buffer spots of the keg line does not involve an investment, except for buffer number 7. This is due to the fact the spots of buffer number 7 cannot be increased without an investment of an extra conveyor. The increase of buffer spots can be achieved for all other buffer spots without investments and based on the cost-benefit analysis, we only focus on the increase buffer spots without investments. During the research for possible solutions per buffer, we experienced buffer 6 cannot be increased. A dry blower and datum labeler are positioned here, and discussions with maintenance engineers suggest repositioning them. They are unsuitable after the wash and filling station due to keg condensation from cold beer filling, which is more challenging to dry completely compared to empty kegs. Additionally, there are no other available locations to position them.

With this background information, we determined two **goals**:

- Increase the number of available buffer spots in front of the wash and filling station from 43 to 53 (Extra available spots of 6+2+2=10: buffer number 2, 3 and 4).
- Increase the number of available buffer spots after the filler from 26 to 37 (Extra available spots of 4+3+4=11: buffer number 8, 9 and 10).

5.4.2 Problem 1 investigation

We first focus on Buffer number 2, where we take into account buffer 3. Figure 5.8 shows a zoomed in version of Figure 5.7 with the corresponding motor and photocell numbers. Photocells are classified as sensors and will be referred to as sensors hereafter. The sensor numbers are shown, but do not affect the buffer size at this point. The green kegs correspond to filled spots and the grey kegs correspond to the available spots which are not filled by the system (currently not used). The figure also shows the motor numbers in black. Each conveyor is equipped with a single motor responsible for its operational state.

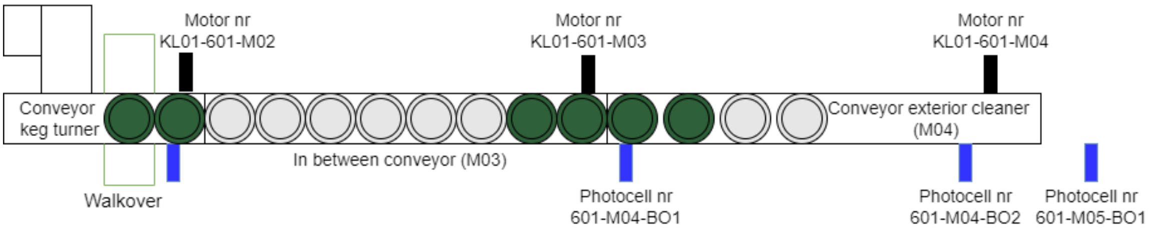


Figure 5.8: Buffer 2 used and unused spots

To investigate the factors contributing to the incomplete filling of conveyor M03 with kegs, we applied the 5W method on this problem, which is shown in Appendix G. The result of this analysis is: Conveyor M03 is in a running state with the following conditions: Section A (pallet area) is active, there is no malfunction within this area and conveyor M04 is running. If one of these conditions is not met, conveyor M03 stops running. If conveyor M04 (conveyor exterior cleaner) stops running, conveyor M03 immediately stops running causing the situation shown in Figure 5.8, where 75% of the conveyor is not filled with kegs. The problem therefore originates in the system where the coordination between the motors of the conveyors takes place. It means the predetermined conditions for motors M03 and M04 should be changed within the system in order to change the unused buffer spots into used buffer spots. The way in which the conditions should be changed and how they should be changed will be explained in Section 5.4.4 (Solution 1).

5.4.3 Problem 2 investigation

Buffer 8, 9 and 10 are combined and Figure 5.9 shows a visualization. In section 5.4.6 we divided the visualizations of Figure 5.9 in three parts. A complete visualization of all motor numbers, sensors (photocells) and stoppers are visualized in Appendix F, Figure F.2. This section of the line, from the weighing scale to the palletizer, consist of eighteen different sensors, all communicating with each other. The purpose of each sensor was not known and the researcher analyzed the drawings of the line from the moment of installment. Physical adjustments remained unaltered in the drawings and therefore the numbers on the line and the drawings did not correspond with each other. The researcher tested the influence of all these eighteen sensors in order to find the purpose of each sensor and which conditions must be met resulting in different communication signals between these sensors. The analysis resulted in the sensor names which have a direct influence on the number of used buffer spots. Figure 5.12 and 5.14 exclusively illustrates these sensors for an increased readability. The stoppers are visualized in red, which are used to hold the kegs to prevent two kegs are processed together. The stoppers enable kegs to pass through by a one by one and FIFO principle. The motor numbers are shown in black in order to visualize the conveyors (each conveyor is directed by one motor).

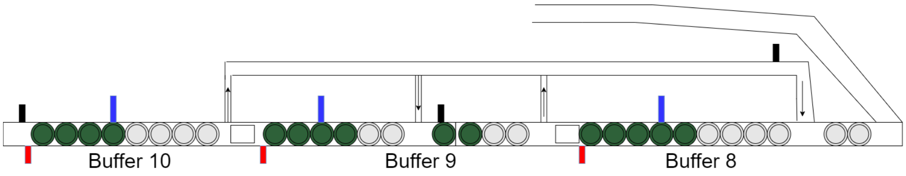


Figure 5.9: Buffer 8, 9 and 10 used and unused spots

Spots are left empty in between the wash and filling station and the palletizer when one of the machines has a malfunction, causing the wash and filling station cannot deliver any full kegs to the full keg turner, since the systems determines the conveyor belts are fully occupied. In order to find reasons for the conveyors are fully occupied according to the system even when they are physically not, the 5W analysis is also applied to this situation. The complete 5W analysis is shown in Appendix G, resulting in: the root cause of the problem originates in the locations of the following three sensors: 601-M11-B03, 601-M14-B07, 601-M14-B04 which are positioned before the capper, before the labeler and before the palletizer respectively.

5.4.4 Solution problem 1

In order to tackle the first problem, an EVOP is conducted, which is used to improve a process by methodically altering the factors that affect a particular set of factors' operating conditions according to Hessing (2023). An EVOP does not require extra resources or concessions since it only require small changes in the parameters of the researched process. Within these experiments of EVOP, the process enables the variation of the process and follows a straight forward pattern and therefore proof of the yield and physical characteristics of the result are obtained by repeating the procedure. Monitoring the physical product is important within creating a solution, since one factor need to be taken into account: kegs should not be forced into the exterior cleaner (i.e. they should be pulled by conveyor M04 and not pushed into the exterior cleaner by conveyor M03). We calculated the maximal settings for 'additional running time of M03' and it resulted in 30.8 seconds. 30.8 seconds correspond with three sets of two kegs leaving the empty keg turner based on lowest cycle time of 30l kegs at the empty keg turner. At downtime of the wash and filling station and a padded buffer, there is an extra space for six kegs on conveyor M03. 30.8 is therefore the maximum setting for 'additional running time of M03'.

With the use of EVOP, experiments of twenty minutes are run during continuous production in order to take the variation of the process into account. Continuous production is determined by: production within a day without machine failures above half an hour, but with the machine failures that are quite normal. Two variables are changed for six different experiments (each experiment is conducted five times). The two variables are: 1) the extra running time for M03 compared to the moment M04 stops running and 2) the waiting time for M03 to start running when M04 starts operating. 30 experiments are conducted within the production of 30l and 50l kegs and tested with 19.5l kegs with the optimal setting, resulting in 90 experiments. 19.5l are only tested within the optimal setting, since dummies guarantee the space between the kegs for a full exterior clean. The results of the experiments are shown in Figure 5.10, where the numerical indicators within circles represent the experiment number, while those with squares denote the number of kegs on conveyor M03. Green squares represents no issues, but the red squares represent the issue we already expected: kegs are pushed against each other and pushed into the exterior cleaner caused by the still running conveyor M03. The optimal value of these experiments is shown in the upright corner (eight kegs on conveyor M03 with a 30 seconds additional running time if M04 stops operating and a waiting time of 10+5 seconds for M03 to start running again if M04 starts operating again).

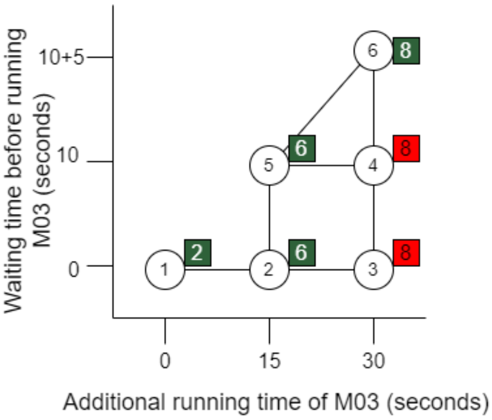


Figure 5.10: EVOP

With these results, an Input Rate Control is developed by the researcher, which is a control mechanism to regulate the input rate of products onto conveyor M03. The Input Rate Control guarantees the products are add onto conveyor M03 in a controlled manner to avoid overloading it and without pushing the kegs into the exterior cleaner. We added an Input Rate Control to the system with the use of two if-statements:
1. If M04 stops running, M03 is running for 30 more seconds thereby ensuring the continuous turning of kegs by the keg turner. The keg turner remains capable of supplying conveyor M03 with kegs.
2. If M04 starts running again, a) M03 waits 10 seconds before running and b) the keg turner waits 10+5 seconds before turning kegs.

These two settings within the developed Input Rate Control mechanism have an effect on two moments which happens constantly: 1) conveyor M04 stops running and 2) conveyor M04 starts running after a stop. Within these two settings, we can assure if M04 stops running (moment 1), M03 does not stop running (which was the case before this research). M03 is now running for 30 more seconds when M04 stops, resulting in a running state of the empty keg turner and supplies conveyor M03 with kegs for 30 more seconds. This mechanism therefore ensures a padded buffer of eight on conveyor M03, which was two before this research.
At moment 2, where conveyor M04 starts running after a stop, conveyor M03 waits 10 more seconds before it starts running. Within the experiments, this was the optimal amount of seconds to ensure conveyor M03 does not push kegs onto conveyor M04, but the kegs are now pulled by conveyor M04 into the exterior cleaner. It must be noted conveyor M04 has a lower speed compared with conveyor M03 in order to create space between two kegs. There must be space between the kegs on conveyor M04 (conveyor exterior cleaner), since otherwise kegs cannot be properly cleaned within the exterior cleaner. The extra 5 seconds (10+5) correspond to the extra waiting time for the keg turner in order to start running again, ensuring the kegs are not pushed against each other on conveyor M03.

5.4.5 Results

The Input Rate Control is already implemented in the system of the keg line within this research. This results in a padded buffer of eight kegs on conveyor M03 (Figure 5.11, which was an almost empty buffer of two before this research (Figure 5.8)). In the beginning of this paragraph (5.4.1 Background), we calculated this buffer could be utilized for 346 times within eight weeks of stable production. Stable production is described as: an average week of production without more than two days planned downtime, enough operators on the line and a continuous production of kegs. 346 times is the outcome of the calculations of the number of extra buffer spots that can be used, with the constraint of at least 40 minutes between solving a upstream machine failure and another upstream machine failure, where the disruption is at least 40 seconds. Therefore, 359.5 extra kegs per week can be processed by the wash and filling station when one of the upstream machine fails. This equals an increased production of 37.1 kegs per day, which results in a decreased downtime of the wash and filling station of 5.5%. Taking into account the number of extra kegs processed per week of 259.5 and the number of kegs processed within the previous mentioned eight weeks, the production is increased with 1.19%. Within terms of ME, the average ME is taken into account, wherefore the results of six extra buffer spots on conveyor M03 equals an increase of 0.71% ME on a yearly basis.

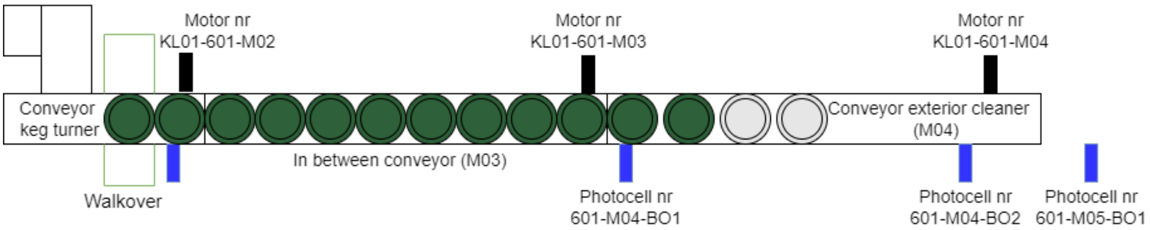


Figure 5.11: Improved used buffer spots Buffer 2

5.4.6 Solution problem 2

To tackle the second problem, sensors 601-M11-B03, 601-M14-B07, 601-M14-B04 should be relocated in order to fill the spots that are currently not used. Two risks have to be taken into account before determining the new sensor positions. The first one belongs to the rejection on and of the main keg line (as shown by the arrows in Figure 5.12, 5.13 and 5.14) and the second one belongs to safety which is explained at Buffer 10. There should be space reserved for a rejected keg by the capper and subsequently conveyed back to the area in front of the capper due to malfunctions (for example, an upside down cap). If this position is not left empty, there is no possibility to add a rejected keg on the main conveyor causing a constriction of kegs. This place is shown in Figure 5.12 with a star in a grey keg spot. Therefore, the new position of sensor 601-M11-B03 is determined empirical, taking into account these constraints and is shown on the right side of Figure 5.12. Replacing this sensor results in three extra buffer spots to be filled when a downstream machine has a failure.

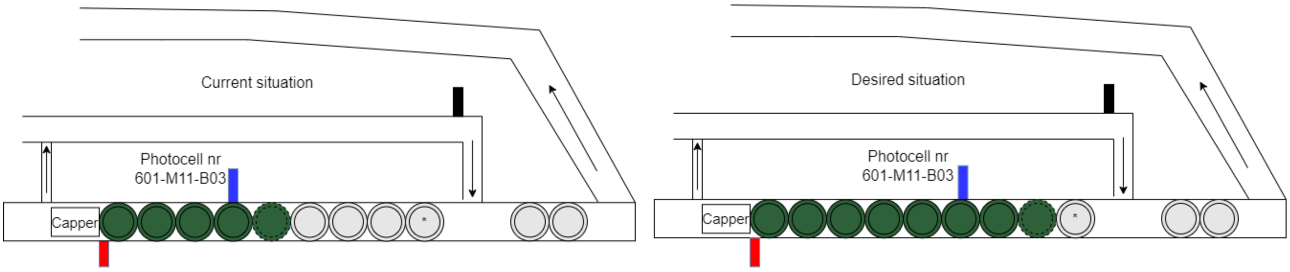


Figure 5.12: Current situation and desired situation Buffer 8

The first issue also occurs at buffer 9, where space should be reserved for kegs without a label and are rejected. These kegs re-enter the conveyor between the capper and labeler (Figure 5.13) and therefore no kegs should be placed in this position, resulting in a lost extra buffer spot. Repositioning sensor 601-M14-B07 results in two extra buffer spots before the labeler. Two grey spots after the capper cannot be realized, since there is a transition between two conveyors. If kegs are placed in these two positions, the two kegs before are pushed on the conveyor between the labeler where the position beneath the vertical conveyor is filled. Preventing this issue results in an open space where kegs without a label are allowed to re-enter the main conveyor in order to still get a label without causing a constriction of kegs.

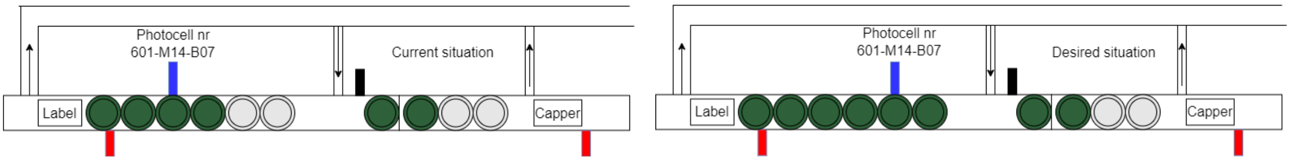


Figure 5.13: Current situation and desired situation Buffer 9

The second risk that necessitates consideration occurs at the end of the keg line, in front of the palletizer. As shown in Figure 5.14, a walkover facilitates operators to enter the keg line. These buffer spots remain unoccupied unless the palletizer experiences a malfunction, occurring 0.63 times per shift for on average 12.4 minutes. During these occurrences, operators are required to traverse the kegs, prompting concerns about safety. Consequently, guidelines are retrieved from the SHE (Safety, Health and Environment) specialist and are consulted through collaboration with the SHE specialist and the researcher. The existing situation and the desired situation are assessed against the SHE regulations. The outcome of this evaluation indicated an absence of SHE concerns to withhold these implementations. Replacement of sensor 601-M14-B04 results in four extra buffer spots which can be used in times of palletizer malfunctions.

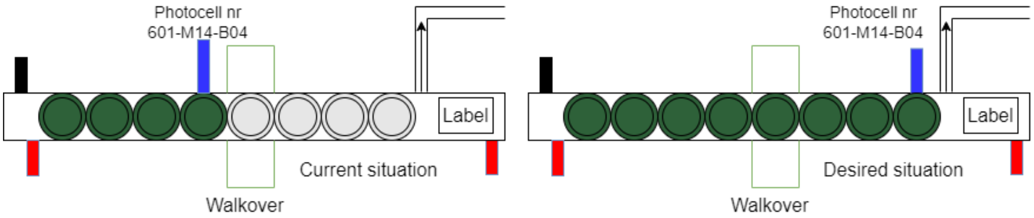


Figure 5.14: Current situation and desired situation Buffer 10

5.4.7 Results

Within the time of this research, the sensors are repositioned on 1 December 2023. The results are analyzed and a padded buffer of eight, eight and eight is realized in front of the downstream machines, respectively in front of the capper, labeler and palletizer. This buffer equaled fifteen in total in the beginning of this research. Therefore, we conclude an increase of available buffer spots which are used by the system of nine. Due to the fact either a downstream or an upstream machine causing the wash and filling station to stop, we can calculate the output separately from the output of the buffer between upstream machines.
In the beginning of this paragraph (5.4.1 Background), we calculated within eight weeks of stable production this buffer could be utilized for 414 times. Therefore, 465.8 extra kegs per week can be processed by the wash and filling station when one of the downstream machine fails. This equals an increased production of 66.5 kegs per day, resulting in a decreased downtime of the wash and filling station of 2.83%. Taking into account the number of extra kegs produced per week of 465.8 and the number of kegs produced within the previous mentioned eight weeks, the production is increased with 1.44%. Taking into account the average ME, the result of nine extra buffer spots between the downstream machines results in an increase of 0.86% ME on a yearly basis.

Standardization
The Input Rate Control is already established in the system program (PLC). The changes made are also explained in a document which is shared on Sharepoint (Increase Buffer Capacity), where everyone of Packaging has access to. The repositioned sensors, as determined in this research, are updated within the drawings by the Asset Care Specialist. In addition, the researcher shared the findings of this research of all sensors between downstream machines. With these findings, the Asset Care Specialist updated the drawings, which were never updated since installment. Therefore, the drawings are now up to date incorporating all sensor changes made during the last years.

In conclusion, the buffer capacity in front of the wash and filling station is increased by a total of six spots by implementing an Input Rate Control for the conveyor, resulting in 37.1 extra kegs processed per day. The buffer capacity after the wash and filling station is increased by a total of nine spots by relocating sensors, resulting in 66.5 extra kegs processed per day.

5.5 19.5l keg disruptions at keg destacker

5.5.1 Background

As explained in Section 2.4, operators are continuously positioned on the platform to resolve issues when processing 19.5l kegs. At moments of malfunctions of other machines, they leave the platform and the time between occurrence and solving the disruptions increases. As earlier explained, if operators are not positioned on the platform, it takes at least 1.5 minutes before the operator observes that no additional empty kegs enter the process. This 1.5 minute corresponds to the buffer before the empty keg turner of twelve kegs and the processing time of the empty keg turner (fifteen seconds per two kegs). After an operator realizes a lack of supply to the empty keg turner, it takes at least a minute before the issue at the keg destacker is remedied with the use of a pole. The complexity of this issue lies within the analyze phase of discovering root causes for two different issues which have similar and non similar causes. Solving one of these issues is not directly solving the other issue, since there are several dependencies.

Due to the lack of visual signals and the documentation of a disruption, a real time monitoring system is implemented by the researcher during this research which shows when the keg supply to the empty keg turner is disrupted. It is done through a camera, where operators were instructed to capture photographic documentation of the encountered disruptions at the keg destacker when processing 19.5l kegs. Visual or audible alarms could notify the operator immediately when a disruption occurs, but this will not solve the issue. It could reduce the time for issue detection, but operators still have to resolve the issue manually. We will focus on reducing the 19.5l keg disruptions, discover the root causes and address these root causes to minimize disruptions.

Figure 5.15 shows the visualization of the issue occurrences at the keg destacker. As shown, two issues occur at the keg destacker where number one is a lagging keg at the conveyor, while number two shows a constriction in between the iron frames. Both issues causing downtime of the keg destacker, since both sensors (at number 1 and 2) detect a keg where after the supply of kegs is interrupted. The consequence is a lack of supply to the empty keg turner. To solve these issues, operators are currently using a long pole in order to replace the kegs on the conveyor where kegs hopefully stay on the conveyor and not fall of the conveyor due to the manual interventions of operators. If kegs fall down the conveyor, operators have to open the security gate in order to remedy the fallen kegs, causing an emergency stop and subsequently the wash and filling station stops operating.

Figure 5.15: 19.5l keg disruptions

The Voice of the Business is to reduce the number of disruptions in order to increase the production output of the line. However, it is important to consider the complete VOE. This issue occurred during the introduction of processing 19.5l kegs at Grolsch several years ago, and was only known by operators. To gain insights in the VOE, a survey was systematically conducted across all five shifts of the keg line, as detailed in Appendix E. The survey targeted the most experienced operator of each shift, given their nuanced understanding of the operational challenges and their involvement in troubleshooting scenarios beyond the capacity of other operators. The survey was designed with two distinct sections, which are divided in the occurrence of issues during the production of 19.5l kegs and those arising during the production of 30l and 50l kegs. With the survey, a top five is developed according to the occurrence of issues on the keg line. Subsequently, respondents were required to assign a numerical grade ranging from 1 to 10 to indicate the level of irritation associated with the 19.5l keg disruptions of the keg destacker. Number one equals 'It is not a problem for me', number five 'Quite irritating' and ten equals 'I am completely done and it has a profound influence on my mood'. They also had the opportunity to write down their argumentation for the grade. The results of the survey showed the number one issue as the 19.5l kegs disruptions at the keg destacker. The argumentation of all operators are combined and resulted in: 'additional unnecessary manual actions which are not ergonomic safe'. The average grade of the 19.5l keg disruptions was an 8.8 out of 10.

With this survey, we conclude the 19.5l keg disruptions contributes the most to the operator irritation, which can lead to a decreased employee satisfaction. In order to translate the VOE to measurable units, the researcher developed a VOE-to-CTQ (Figure 5.16) where the VOE is developed in Critical to Qualities (the measurable units), CTQs. CTQs are an important input for the specification limits to calculate the sigma value of the process.

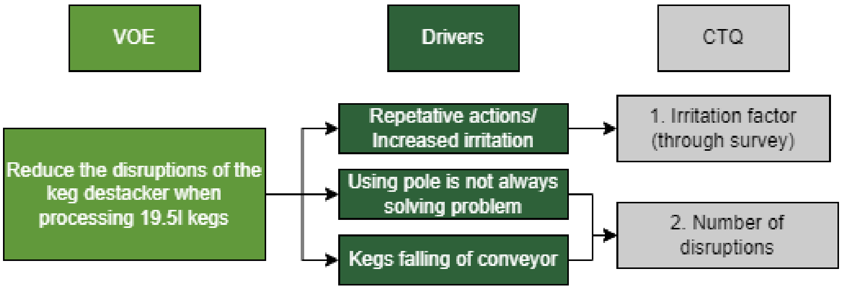


Figure 5.16: Voice of Employee (VOE) translated in Critical to Quality (CTQ)

Based on the VOE, the objective of this intervention is the prevention of disruptions at the keg destacker when processing 19.5l kegs where manual interventions of operators have to resolve the disruption.

5.5.2 Problem investigation

The photographic documentation of the encountered disruptions at the keg destacker when processing 19.5l kegs are analyzed and resulted in 21.7% disruptions towards the number of movements of the keg destacker. One movement equals supplying the conveyor with twenty kegs (four rows of five kegs) and therefore one out of five movements of the keg destacker caused a disruption. This analysis showed the disruptions take place for 20.3% at number one of Figure 5.15 and for 79.7% at number 2 of Figure 5.15. 61% of the disruptions occurred at the last row, while the other 39% occurred at one of the first three rows.

In order to quantify the performance of a process, the metric DPMO is commonly used. DMPO is used in process improvement to quantify the performance of a process by measuring the number of defects per one million opportunities for defects. In this case of the 19.5l keg disruptions, there are two opportunities for defects (number one and two in Figure 5.15). A sample is taken of $n = 60$ where 13 defects are measured resulting in a sigma value of $\sigma = 2.75$. This sigma value corresponds to a defect rate of approximately 108,333 defects per million opportunities, which falls short for the Sigma goal of $\sigma = 6$. The value of $\sigma = 2.75$ should be seen as an opportunity for continuous improvement, but the interpretation of this value should also be compared to the industry standards or similar processes. The process of the keg destacker with 19.5l kegs is compared to the process of 30l and 50l according to the disruptions at the keg destacker. Both the 30l and 50l kegs have zero disruptions at the two opportunities, resulting in a sigma value $\sigma = 6$ and therefore we conclude the sigma value of 2.75 should be moved in the direction of $\sigma = 6$, where 3.4 defects within a million opportunities are discovered.

To ascertain if disruptions are specific for a particular keg type, we examined which kegs experience obstructions. Grolsch is using two different type of 19.5l kegs, which are made of Stainless Steel (SS) or Black Plastic (both kegs are included in Figure 5.15). The results of Figure 5.17 shows 75% of the disruptions are caused by only black kegs (Black/Black and Black/Black/Black). Black/Black means a disruptions caused by two black kegs. Black/Black/Black means a disruption caused by three black kegs, as shown in Figure 5.15.

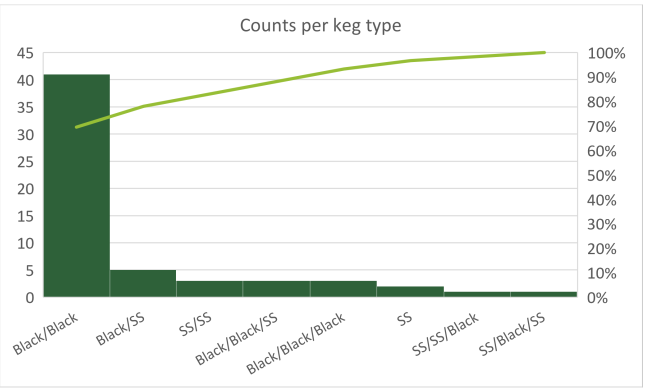


Figure 5.17: Disruptions per keg type: Stainless Steel (SS) and Premium (black) kegs

A potential solution could involve discontinuing the utilization of black kegs, but this lacks a long-term sustainable solution and therefore we should focus to prevent the disruptions. A comprehensive analysis is therefore conducted to identify the underlying root cause(s). To create an overview of the potential causes, brainstorm sessions are held with operators, daily technicians, Instrument Technician Packaging and the Packaging Performance Manager. Additionally, video documentation and manual observations are captured by the researcher in order to find the underlying issues. The results are visualized in an Ishikawa diagram of Figure 5.18 in order to find the potential causes of disruptions at the keg destacker when processing 19.5l kegs.

The causes of the issue are grouped in several categories, which can be 6M, 8P, 4S or 3M according to Latham (2023). 6M organizes information into six categories: Man, Machine, Material, Method, Environment (Mother Nature) and Measurement. 8P organizes information into eight categories: Procedures, Policies, Place, Product, People, Processes, Price and Promotion. 4S organizes information into the following four categories: Suppliers, Systems, Surroundings and Skills. 3M organizes the information into three categories, which are Man, Machine and Materials. 6M is an expansion of 3M and mostly used in manufacturing processes. 8P and 4S diagrams are mostly used in the service industry, which are not directly concerned with the production of physical goods. With a division in different categories, the tool makes it easy to examine potential causes resulting in a clear overview of causes per category. 6M is most suitable to apply in this research, since it takes into account all the different aspects of the production process reducing the probability of missing a root cause. Therefore, we use 6M, which organizes information into six categories: Man, Machine, Material, Method Environment (Mother Nature) and Measurement according to Luca (2015). 6M is divided in six categories which represent the skeleton of the Ishikawa diagram:

- Man: The workforce involved in the process.
- Machine: Includes the equipment, machinery, tools, and technology (automation) used in a process.
- Material: Raw materials, components or inputs used in a process.
- Method: Involves the procedures, workflows and processes used to perform a task or produce a product.
- Measurement: The accuracy, reliability and timeliness of data collection and analysis within a system influencing its overall performance.
- Environment: The physical and external factors that surround the process.

In order to produce useful input for the Ishikawa diagram, we applied the method 5Why where we continually ask ’why’ to achieve the sub-causes. This implies that the subcause not always belongs to the corresponding category.

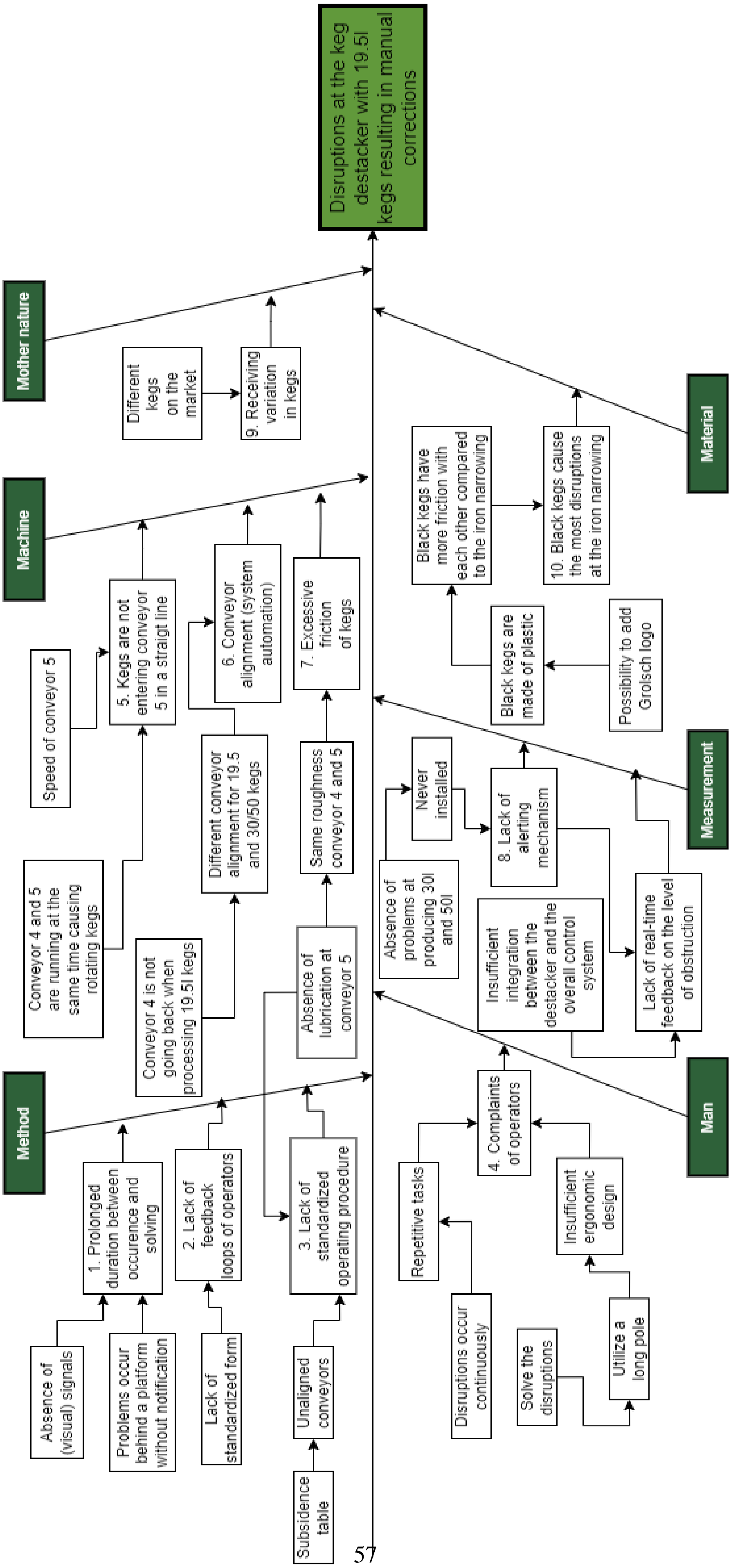


Figure 5.18: Ishikawa diagram - disruptions 19.5l kegs at keg destacker

Table 5.5 shows an overview of the relations between the causes of the Ishikawa diagram of Figure 5.18. This overview minimizes the disadvantage of an Ishikawa diagram, which is the uncertain correlation between causes and issues. This table gives an overview of the sub-causes which influence several other causes.

Table 5.5: Cause relationship

Subcause	Related causes
Conveyor control	5, 6
Conveyor lubrication	3, 7
Premium (black) kegs	9, 10
Constriction at iron frame	5, 6, 7, 9, 10

Subcauses

We will elaborate short on the current conveyor control, conveyor lubrication, Premium (black) kegs and the iron frame in order to create background knowledge for section 5.5.3 (Solution). A schematic is shown in Figure 5.19, which is linked to Figure 5.15. This schematic shows the three conveyors at the keg destacker and the direction of the conveyors indicated by the arrows.

The current **conveyor control** is determined as follows. After a stack of 20 kegs is placed on conveyor M04 and M05, M05 transports the first row to the empty keg turner by conveyor M02. If these five kegs are leaving conveyor M05, M05 keeps in an operating state and M04 transports the next five kegs onto conveyor M05 which are directly taken away by conveyor M05 while they are still positioned half on conveyor M04. In addition, conveyor M04 never operates backwards, resulting in a lack of space between the rows of kegs. If a kegs is lagging between conveyor M04 and M05, M04 stays in an operating state, which does not result in transferring the keg onto conveyor M05. At this point, an operator has to intervene to place the keg on conveyor M05 with the use of a pole. After this manual intervention, the sensor on M04 gives the signal of an empty conveyor to the keg destacker and a new stack of kegs is positioned on conveyor M04 and M05.

In the current situation, there is a fluctuation if the **conveyor lubrication** tap is open or not. The tap is closed and opened at no predetermined moments and therefore based on the intention of operators if they think it is necessary or not. Opening or closing this tap is not mentioned on the checklist for startup and shutdown and therefore there is no standard applied.

Within Section 5.5.2 Problem investigation, we showed 75% of the disruptions are caused by the **Premium (black) kegs**, due to the increased friction between the black kegs and the increased friction between the black kegs and the iron frame.

As shown in Figure 5.19, the deflection of green **iron frame** starts immediately after conveyor M04, causing constrictions of kegs when kegs are not transported in a straight line on conveyor M05.

According to Table 5.5 and the Ishikawa diagram of Figure 5.18, solutions are developed by the researcher we elaborate on in the next section.

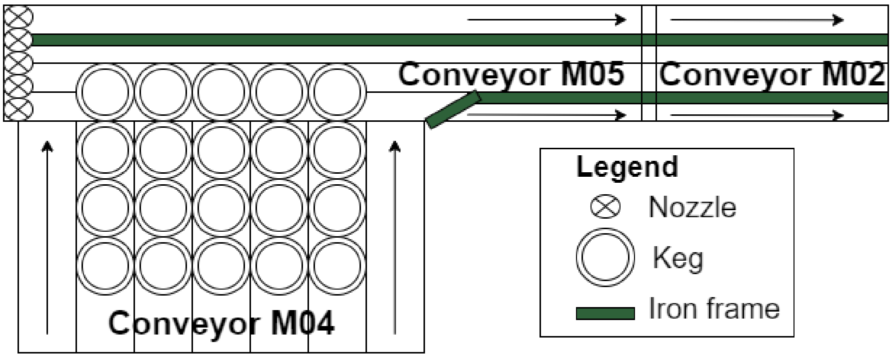


Figure 5.19: Schematic of conveyors and kegs at keg destacker where disruptions occur

5.5.3 Solution

All possible root causes are mapped and the relation between causes are also shown in Table 5.5. Solutions can now be invented in order to tackle the root causes. Several methods can be used, but we choose to use the Pugh concept selection invented by Stuart Pugh which is used to determine a structured and objective assessment, where the different strengths and weaknesses of each solution become visible (Karnjanasomwong and Thawesaengskulthai, 2015). This method determines the best alternative options, which value is more than the other alternatives based on the predefined criteria. Each alternative is individually evaluated based on the specified criteria using the scale range from -2 up to and including 2, where -2 is significantly inferior to the standard, -1 inferior to the standard, 0 equivalent to the standard, 1 is superior to the standard and 2 significantly superior to the standard. The baseline is determined as the current situation, and therefore receives a zero for each criteria. Four possible alternatives are determined by the researcher, which took a lot effort in order to find solutions, which prevent the lagging kegs and constrictions from occurring. These alternatives are determined in consultation with the daily technician, Instrument Technician Packaging and the Packaging Performance Manager in order to check the feasibility of the alternatives.

The alternatives according to the Pugh selection of Table 5.6 will be explained shortly and not in much detail to increase the readability and understanding.
A1: The application of conveyor lubrication to decrease the friction between conveyor M05 and the kegs.
A2: Convert the conveyor control (system automation) to guarantee kegs are placed in a straight line without interfering with the next row.
A3: The implementation of rolls to reduce the friction between the iron frame and the Premium (black) kegs.
A4: Curtail the iron frame in order to prevent constrictions at the beginning and utilize the increased speed of the next conveyor to create space between the kegs.

In addition to the determination of the alternatives, Alternatives 1 and 2 are physical tested by the researcher. Without changing anything about the process, the conveyor lubrication (A1) is added on conveyor M05. Adding conveyor lubrication on conveyor M05 decreases the friction between kegs and conveyor M05. Decreasing this friction results in an easier exchange of kegs between conveyor M04 (which has no conveyor lubrication) and conveyor M05, where kegs slide on conveyor M05 instead of creating friction between the kegs and conveyor M05. These tests are performed within a production of one shift, where the results are empirical determined by the researcher. The conclusion from this test resulted in a 1 for 'Dissolves all lagging kegs', since 10% more kegs did the transition from conveyor M04 to conveyor M05 compared with the situation without conveyor lubrication. However, kegs were still left behind on conveyor M04 which were not solved by the system automation and had to be resolved by the operators, using the long pole. Therefore, we performed two tests of both the production of two shifts, where we changed several settings within the conveyor control (A2) and during these settings, the results are analyzed by the causal-comparative approach, which is a methodology to identify the cause and effect relationship between dependent and independent variables. The researcher performed tests for the backward running time of conveyor M04, where we tested a time ranging from 0.5 until and including 2 seconds, where 0.5 and 1 second did not create enough space between the rows and kegs were still touching each other. 2 seconds created too much space which was not necessary and 1.5 seconds resulted in the optimal point, where there is enough space between the rows.

Table 5.6: Pugh selection. A1: Conveyor lubrication, A2: Conveyor control, A3: Implementation of rollers, A4: Curtail iron frame

Criteria	Baseline	A1	A2	A3	A4	Weighting
Costs	0	0	0	0	0	1
Efficiency improvement	0	0	1	1	2	2
Long term solution	0	1	2	1	2	1
Technology feasibility	0	2	2	2	2	1
Availability of resources	0	2	2	2	2	1
Dissolves all lagging kegs	0	1	2	0	0	2
Dissolves all constrictions	0	0	1	2	2	2
Unweighted	-	6	10	8	10	-
Weighted	-	7	14	11	14	-

Both alternatives A2: converting the conveyor control (system automation) and A4: curtail iron frame result in the highest weighted score according to the Pugh selection of Table 5.6. As none of the alternatives of Table 5.6 will solve both the issues completely, 1) Dissolve all lagging kegs and 2) Dissolve all constrictions, a solution will be developed by combining positive aspects from multiple options. According to the performed tests by the researcher with the conveyor lubrication and the conveyor control (system automation), the following solution is implemented:

Within the system automation:
1. If conveyor M04 is in an operating state, M05 is in a non-operating state which also applies the other way around. These conveyors are operating perpendicular. This ensures the two conveyors are not operating at the same time to prevent the rotation of kegs.
2. After the kegs are placed on the conveyor by the keg destacker, the first row of five kegs is transported by conveyor M05 to the empty keg turner. If these kegs leave conveyor M05, conveyor M04 start operating in order to convert the second row of kegs from conveyor M04 to conveyor M05. If this second row is positioned on conveyor M05, M04 runs 1.5 second backwards to create an empty space between the rows on conveyor M04 and M05. This results in enough space between the keg row on conveyor M04 and row of kegs on conveyor M05 where the two rows do not touch each other. With this implementation, kegs from the next row (on conveyor M04) are not pulled along with the first row.
3. If the sensor of conveyor M04 detects a keg between conveyor M04 and M05, conveyor M04 is operating for maximum eight seconds. If the counter is above eight seconds, M05 starts operating in order to transport the keg from conveyor M04 to M05 (conveyor lubrication is important at this point). This solution solves the issue mechanical without the intervention of an operator of a lagging keg at position 1 of Figure 5.15.

Within the keg line:
4. Even though two kegs are not arriving together at the same time at the iron frame anymore (with the implementation of the system automation), the black kegs still have friction among each other and are still rotating on their axes when arriving at the iron frame. Therefore, we decided to curtail the deflection of the iron frame, to the point of the transition of conveyor M05 and M02. If there is friction between two Premium (black) kegs or friction between a keg and the iron frame, there is no possibility for a constriction anymore, since we changed the speed of M05 to a much lower speed compared with M02. The new beginning of the iron narrowing is at the same point of the transition between conveyor M05 and M02. Therefore, if kegs have friction with each other or with the frame, they are pulled apart at the iron frame due to the difference in conveyor speed of M05 and M02 (and the later start of the iron narrowing).
5. In order to be 100% sure there are no constrictions at the iron frame, we added rollers on the point of deflection of the frame. If an Premium keg has friction with the frame, the rollers are rotating instead of the

kegs and will not causing a constriction.
6. Five nozzles are available at conveyor M05 (Figure 5.19) in order to apply conveyor lubrication resulting in less friction between kegs and conveyor M05 compared to the friction between kegs and conveyor M04. With less friction between the kegs and conveyor M05, kegs are taken away more easily by conveyor M05 compared to the situation without conveyor lubrication. The tap for conveyor lubrication should be always open, but a closed or open tap is operator dependent. Conveyor lubrication is crucial at this point and therefore should be a standard which is applied by all operators. In order to standardize this procedure, an action of opening the tap is added to the checklist for start up, which has to be followed by all operators.

5.5.4 Results

Both solutions within the system automation and physical changes within the keg line are implemented on 30 November 2023. With this solution, the two issues are solved where there is no lagging keg between M04 en M05 and constrictions are not occurring anymore. Within this implementation, each keg is transported to the empty keg turner even when one of the kegs is not transported with the kegs in the corresponding row. Therefore, this issue is solved within the system conveyor control and an intervention of an operator is unnecessary. Kegs of, for example, the third row are not transported together with the kegs of the second row, due to the created space between the two rows by the conveyor control of M04 (backward running time of 1.5 seconds). These both result in an absence of a harmonica effect of kegs before they arrive at the iron frame. The friction between the Premium (black) kegs cannot be changed, due to the lack of sustainable options and therefore we curtailed the iron frame and applied rollers to the iron frame. This combination prevents constriction at the iron frame and operators do not have to interfere anymore.

With this solution, we analyzed five disruptions within a sample of 524 movements of the keg destacker, where twenty kegs are positioned on the conveyor within one movement. These 524 movements took place (10,480 processed kegs) within 4.5 shifts, where five disruptions resulted in an average of 1.1 disruption per shift. Therefore, an operator only has to walk one time per shift to the keg destacker to solve the keg disruption. With the sample size of $n = 524$, five defects and still two opportunities for defects, the sigma value is increased from $\sigma = 2.75$ to $\sigma = 4.1$. The sigma value of $\sigma = 4.1$ corresponds to a defect rate of approximately 4660 defects per million opportunities, with a success rate of 99.53% per movement of the keg destacker without a disruption. The VOE was translated to two CTQs within Figure 5.16 and therefore the conducted survey as explained in Section 5.5.1 is conducted again. The results of this survey showed an average irritation grade of 1 out of 10. Therefore, the irritation of operators is significantly decreased from a grade of 8.8 to 1 where one represents 'no irritation' and ten 'hugh impact on my mood'.

The number of disruptions is significant decreased and the irritation factor of operators by the implementation of the solution as explained in Section 5.5.3. In addition, we also elaborate on the effect on the output of the keg line, where the downtime of the wash and filling station is caused by the disruptions at the keg destacker. Within ten days production, the total machine hours of the wash and filling station are analyzed and also the minutes downtime of the wash and filling station caused the disruptions at the keg destacker. After the implementation, the minutes of downtime of the wash and filling station caused by the disruptions at the keg destacker is decreased to zero. The downtime minutes are not occurring anymore caused by the disruptions at the keg destacker and therefore the running time of the wash and filling station is increased by 0.98%. Taking into account the average ME over the last year in order to calculate the increase of ME on a yearly basis, the ME on a yearly basis is increased by 0.59%. Resulting in a yield of €33,987 on a yearly basis.

Standardization
The objective of the last step is to standardize, where everyone works and continues to work according to the agreed standard. All fail safes are implemented within the conveyor control including the attached rollers and the curtailed iron frame. However, conveyor lubrication should always be applied on conveyor M05. In order

to keep the quality level high, conveyor lubrication should be checked during shifts. In order to standardize the check 'open conveyor lubrication tap', we determined, in consultation with the operators, the optimal point to check the tap is within the afternoon shift. Therefore, on January 4th, the check for 'open conveyor lubrication tap' within the section afternoon shift is added to Checklist Keg Line, which is the general checklist for all shifts on the keg line.

In conclusion, the 19.51 keg disruptions at the keg destacker were resolved through adjustments to conveyor control, adjusting the iron frame and ensuring constant lubrication in order to minimize the operator impact: decrease from 8.8 to 1 on a scale of 1 to 10. In addition the σ value increased from $\sigma = 2.75$ to $\sigma = 4.1$, where 4.1 corresponds with a success rate of 99.53% per movement of the keg destacker without a disruption.

5.6 Delay in transport speed within wash and filling station

5.6.1 Background

Two kegs arrive simultaneously at one of the five parallel lines within the wash and filling station. Within one of the lines, a keg is processed by either head 1, 3, 5 and 7 or head 2, 4, 6 and 8 i.e. kegs are passing through the wash and filling station in groups of two. Consequently, a keg always skips a head which is possible due to the fact head 1&2 have the same function. This applies also for the combination of head 3&4, head 5&6 and head 7&8. The interior of the kegs are cleaned at head one and two with compressed air, water and lye. Head three and four also have the purpose of interior cleaning, but then with acid, air and water. Head five and six guarantee keg sterilisation with steam before the kegs are filled with beer at head seven and eight. The transportation between the heads takes places on a transport beam, where kegs are shifted in the placeholders of the transport beam.

The wash and filling station is programmed in a way that the first keg is always transported first to line 5, then line 4 etc. As a result, the distribution of processed kegs for all five lines are not equal. To show this distribution, we retrieved the data from MicroStrategy of the processed kegs per line for seven weeks (Week 42 - 48 2023). Processed kegs is determined as the number of kegs processed at the corresponding line where a keg is either filled or rejected. The calculation is performed by dividing the number of processed kegs per line by the total number of processed kegs for the corresponding week. These calculations are performed for each week, after which an average is taken of the percentages processed per line. The distribution of processed kegs is given in Table 5.7, which shows the number of processed kegs at line 5 is 2.5% more compared with the processed kegs of line 1. It is important to take this distribution into account for upcoming calculations based on the speed loss and ME.

Table 5.7: Keg distribution per line within wash and filling station week 42- 48 2023

Line	Processed kegs
1	18.9%
2	19.7%
3	19.3%
4	20.7%
5	21.4%

Within the beginning of this research, the researcher measured all separate processing steps which also included the transport processing times within the wash and filling station for all parallel lines. In addition, these measurements are expanded to a total of 150 measurements, 30 per line, and can be used for further analysis. The results of these measurements are visualized together in Figure 5.3 and the average cycle time per line is shown in Table 5.8.

Table 5.8: Process time transport per line

Line	**Average**
Line 1	15.5 seconds
Line 2	14.8 seconds
Line 3	12 seconds
Line 4	15.2 seconds
Line 5	21.2 seconds

Figure 5.3 of Section 5.1 shows higher transport process time for all lines according to the acceptance level of 14 seconds, except for Line 3, which has an average of 12 seconds. Line 1 is 1.5 seconds above the acceptance level, Line 2 0.8 seconds, Line 4 1.2 seconds and Line 5 7.2 seconds. In addition to the higher process times of transport for four out of five lines, there is also a variation between the average processing time of transport between the five lines including a variation within one single lane as shown in Figure 5.3 and Table 5.8.

With this background information, we determined the **goal**: Decrease the transport processing times within the wash and filling station to at most the **acceptance level** of 14 seconds.

5.6.2 Problem investigation

Within Grolsch, it was known line 5 was under performing due to the noise during transport. If line 5 transports kegs from one head to another, the noise of friction between the transport line and the machine is clearly heard within the production hall of the keg line. However, it was not known the average transport time was equal to 21.2 seconds per keg. The detection of these average transport times of 21.2 seconds resulted in immediate action being taken by the mechanical team. It is important to note adjustments are made according to the silencers of line 5 between the measurements shown in Figure 5.3 compared with the measurements of Figure 5.20 and therefore the transport times are decreased. However, adjustment of the silencers were a temporary solution and could only be applied to line 5, since adjusting all silencers would result in an excessive pressure that the wash and filling station cannot withstand.

In this research, we also detected a deviation within line 1, 2 and 4 in an early stage. After this early detection of an increased transport process time of line 2 of 0.8 seconds above the processing time determined by the supplier, several weeks after this detection, the same noise as heard at transporting kegs within line 5 was heard at line 2. Therefore, we detected the deviation in an early stage. Each of the transport lines were implemented 20 years ago and due to the wear and tear of the transport line (without proper maintenance) within these years, the transport lines are bent and not functioning properly anymore.

First, we only focus on the transport within line 5, since we are able to perform tests within the new situation. Another 36 measurements are performed for the transport within line 5, which are visualized through an I-MR Chart of Figure 5.20. An Individual Moving Range (I-MR) chart is used when continuous data is not gathered in subgroups, where a single observation at a time is measured. The Process Average ($\bar{X}$) and Average Moving Range ($\bar{MR}$) are calculated using Equation 5 and 6, where x_i is the value at point i (measurement i) and k represents the number of subgroups.

$$\bar{X} = \frac{\sum_{i=1}^{k} x_i}{k} \tag{5}$$

$$\bar{MR} = \frac{\sum_{i=1}^{k} |x_i - x_{i-1}|}{k-1} \tag{6}$$

The I-MR chart illustrates the temporal variation in a process, showing the average, LCL and UCL. Figure 5.20 shows an average of 15.7 seconds with a moving range of 1.2. The moving range is still within the control limits of 3σ, however a moving range of 1.2 indicates an increased variability between consecutive observations. Within this problem investigation, we not only discovered transport processing times above 14 seconds, but also a high variability between consecutive observations and therefore we should decrease both.

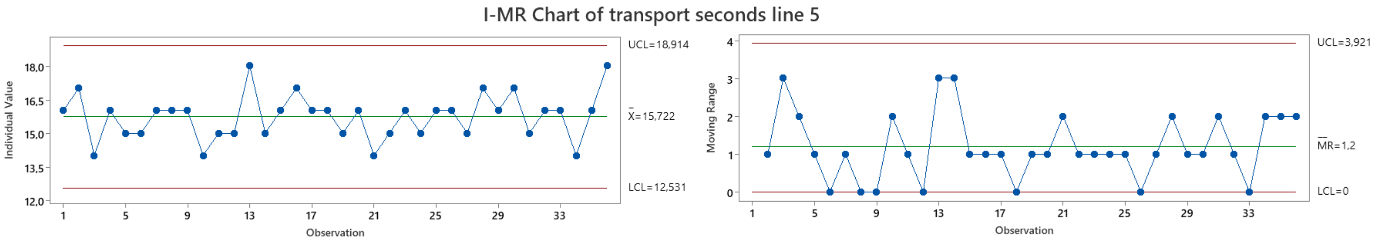


Figure 5.20: I-MR chart seconds old. Average = 15.7 seconds, MR = 1.2 seconds

5.6.3 Solution

Due to high processing time of keg transportation within the wash and filling station, the transport beam is replaced during this research in combination with the air cylinders, dampers and rollers within the transport beam of line 5. These components are crucial for the transportation of kegs within the wash and filling station. In addition, the design and the attachments are redesigned to decrease the tolerance space of the kegs on the transport beam. Before applying this to all transport lines, we first test if the processing time can be reduced to 14 seconds. After replacing the transport beam, 32 measurements are executed in order to determine the new I-MR chart as shown in Figure 5.21. The I-MR chart shows transport processing times between 12 and 13 with a process average of 12.3 seconds, which is significant lower than the average of 15.7 seconds. In addition, Figure 5.21 shows a MR of 0.387 resulting in a significant lower MR compared to the average MR of the processing transportation times before replacement (Figure 5.20).

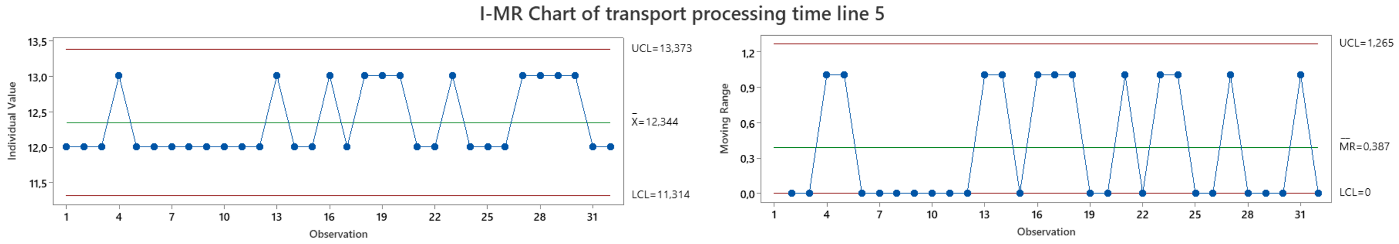


Figure 5.21: I-MR chart seconds new. Average = 12.3 seconds, MR = 0.387 seconds

Seal failures

In addition to variation of transport processing times within the wash and filling station within a single lane, we also analyzed the failures within the wash and filling station. One of the failures which are possible for occurring at all heads are seal failures. Seal failures are failures where the keg seal is not positioned perfect on one of the heads within the wash and filling station. Seal failures at head one and two are mostly affected by the alignment of the kegs on the transport beam. We analyzed the seal failures before and after the transport beam replacement. The results of this analysis are shown in Appendix I. In order to determine if the values truly differ, eight hypothesis tests are conducted. For each head, we tested the number of failures towards the number of processed kegs before and after the replacement of the transport beam. We chose the 2-Sample % Defective hypothesis test, since we want to test two samples with the percentage defective seal failures towards the number of processed kegs. The hypothesis tests are executed in Minitab for each head and resulted in a p-value below 0.10 (0.08) for head two, indicating a 90% confidence that seal failures decreased after replacing the transport beam. However, the p-values for heads 1, 3, 4, 5, 7 and 8 were above 0.10 and therefore we cannot state with 90% confidence these seal failures differ between before and after the beam replacement. We conclude seal failures at head two are decreased from 23% to 11% by the replacement of the new transport beam and the seal failures within the other heads are not significantly decreased but also not deteriorated.

5.6.4 Results

The results from Figure 5.21 showed a decrease from 15.7 to 12.3 seconds for transporting kegs to the next head within the wash and filling station with a replacement of the transport beam including the air cylinders, dampers and rollers within the transport beam of line 5. With these results, we concluded that a replacement of the transport beam the acceptance level of at a maximum of 14 seconds can be reached including a smaller moving range between the transport times. In addition, even 12.3 seconds can be reached when replacing the transport beam. In order to reach the new control limit of 12.3 seconds for line 1, 2 and 4, these transport beams should also be replaced. The transport times within line 3 are already at the control limit of 12 and therefore do not have to be replaced necessarily. Even though, seal failures at head two were the highest compared with the seal failures of all other heads, which are with a confidence of 90% decreased significant. In addition, there was no significant increase and difference with a confidence of 90% for seal failures at the other heads.

In order to determine the effect of the decreased transport times within the wash and filling station, we determined the loss in minutes as shown in Table 5.9. These minutes are based on the number of kegs processed within eight week production. The distribution of kegs per line as shown in Table 5.7 are taken into account, resulting in a total of 8230 minutes lost due to the lower transport speed of the control limit of 12.3 seconds.

The average processing time of a keg is 83 seconds taking into account the speed of 19.5l, 30l and 50l kegs respectively 78.2, 80.2 and 87.2 seconds (taking into account the reduced transport times) and the distribution of kegs as shown in Table 2.1. Therefore, the increased production within the wash and filling station is increased with 2.9%. Taking into account the average ME, a ME increase of 1.73% is reached by decreasing the transport speed for line 1, 2, 4 and 5 to 12.3 seconds. The decrease in transport has a direct influence on the speed loss of 1.2% towards the FE, where the average speed loss is 10% towards the FE resulting in a reduction on speed loss of 12% for decreasing the transport speed within line 1, 2, 4 and 5 to 12.3 seconds.

Table 5.9: Loss in minutes per line

	Seconds lost per keg	**Percentage kegs produced**	**Number of kegs**	**Loss in minutes**
Line 1	3.2	0.1889	33026.3	1761.4
Line 2	2.5	0.1976	34559.8	1440.0
Line 3	0	0.1930	33743.6	0.0
Line 4	2.9	0.2069	36183.9	1748.9
Line 5	3.4	0.2137	37366.4	2117.4

The increased ME can be expressed in euros taking into account the average FE, where a value is linked to a 1% FE increase. The yield per year is therefore €100,026 for decreasing the transport times within the wash and filling station to the control limit of 12.3 seconds. Even though transport beam 3 is within the control limits, Grolsch could decide to replace transport beam 3 together with the others. In order to standardize all transport beams within the wash and filling station, it is advised to also replace transport beam 3. As a result, we show the payback period for replacing four (1, 2, 4 and 5) and five transport beams. To determine the payback period, we take into account the costs for replacing one transport beam, which consist of four parts as shown the first column of Table 5.10. The yield for four and five lines are equal, since replacing transport beam 3 does not increase the yield in transport time. As a result, the investment is paid back within seven months if Grolsch decides to replace all five transport beams.

In conclusion, replacing transport beam 5 results in a decrease in seal failures from 23% to 11% towards the total processed kegs at head two. The seal failures within the other heads are not significantly decreased, but also not deteriorated. This results in a reduced speed loss, since all kegs which are not rejected at head 2 can still be processed on head 4, 6 and at last filled with beer at head 8. Replacing transport beam 5 showed a reduction in transport times within the wash and filling station to an average of 12.3 seconds. Replacing all other transport beams costs Grolsch in total €58,440, with a payback period of seven months. With this investment, the ME is increased by 1.73% where a speed loss reduction of 12% is realized.

Table 5.10: Costs and yield for replacing one, four and five transport lines

	Replacement one line	**Replacement four lines**	**Replacement five lines**
Transport beams	€ 5,379	€ 24,669	€ 31,099
Air cylinders and accessories (dampers)	€ 3,125	€ 14,331	€ 18,066
Rollers within transport beam	€ 1,144	€ 5,248	€ 6,616
Bearing bushes and rod ends	€ 460	€ 2,110	€ 2,660
Total costs	**€ 10,107**	**€ 46,357**	**€ 58,440**
Total yield		€ 100,026	€ 100,026
Payback period (months)		5.6	7.0

Implementation
Due to the promising results of replacing transport beam 5, Grolsch already decided to replace all other transport beams within the revision of January since several other elements of the wash and filling station are also replaced within this revision.

Changes in V-Graph by increasing transport times within wash and filling station
Decreasing the transport processing times to 12.3 seconds results in an increased capacity of the wash and filling station of 458, 447 and 411 kegs per hour for respectively 19.5l, 30l and 50l kegs. The capacity increase has the highest effect on the V-Graph towards the overcapacity of the empty keg turner, since the overcapacity of this machine is decreased from 3% to 1%, 7% to 5%, 17% to 10% and 9% to 6% for respectively 19.5l, 30l, 50l Peroni and 50l Grolsch (explained in Section 5.7). The distinction is made between 50l Peroni and 50l Grolsch, due to the difference in processing times of these two different kegs (Stainless Steel and Premium (black) respectively) at the empty keg turner. Grolsch already decided to replace all other transport beams based on this research and therefore we should take into account the increased capacity of the wash and filling station within the next section.

5.7 Speed empty keg turner

5.7.1 Background

V-Graphs are developed for the primary SKUs of 19.5l Peroni, 30l Grolsch, 50l Peroni and 50l Grolsch as shown and explained in section 5.1. All machines on the keg line are visualized in combination with the machine capacity towards the machine capacity of the bottleneck machine, the wash and filling station. The objective of the V-Graph analysis, besides bottleneck detection, is to guarantee a continuous flow of kegs in front of the wash and filling station at a rate surpassing the capacity of the wash and filling station. In addition, the speed of the machines in front of the wash and filling station are responsible for a buffer padding. As a result, with the overcapacity of the machine in front of the wash and filling station, one can improve the uninterrupted flow of goods along the keg line (Härte, 1997). After a machine has had a failure and (a part of) the accumulation is used, then the overcapacity of the machine is used to restore the system back to the situation before the failure (Härte, 1997). One of the machines in front of the wash and filling station which should have an overcapacity towards the wash and filling station is the empty keg turner. This machine guarantees the turning of kegs into a position where the fitting of the keg is at the bottom in order to be filled at the wash and filling station. Three out of four V-Graphs showed less than 10% overcapacity of the empty keg turner. The three SKUs with an overcapacity of below 10% are 50l Grolsch, 30l Grolsch and 19.5l Peroni. Besides, 50l Peroni has an overcapacity of 17% as shown in Table 5.11.

Table 5.11: Capacity empty keg turner for four SKUs at the beginning of this research

	Kegs/hour		
	Wash and filling station	**Empty keg turner**	**Overcapacity towards wash and filling station**
19.5l Peroni	447	462	103.4%
30l Grolsch	436	468	107.3%
50l Peroni	386	453	117.4%
50l Grolsch	400	436	109.0%

Within this Master Assignment, we already implemented the increased usable buffer capacity in front of the wash and filling station and the increase in transport speed within the wash and filling station. It is important to note transport beams 1, 2, 3 and 4 within the wash and filling station will be replaced at the end of this research and therefore we must take into account the decreased cycle time affecting the capacity of the wash and filling station. Otherwise, the calculations and results of this section will be impractical. The results of both Section 5.5 and 5.7 affect the overcapacity of the empty keg turner as shown in Table 5.12, where 50l Peroni still has an overcapacity above 10% of the empty keg turner. However, as a logical result, the overcapacity of both 19.5l, 30l and 50l Grolsch decreased further (comparing the overcapacity of Table 5.11 and 5.12). Therefore, it is even more important to increase the capacity of the empty keg turner.

Table 5.12: Capacity empty keg turner for four SKUs in the new situation

	Kegs/hour		
	Wash and filling station	**Empty keg turner**	**Overcapacity towards wash and filling station**
19.5l Peroni	458	462	100.9%
30l Grolsch	447	468	104.8%
50l Peroni	411	453	110.2%
50l Grolsch	411	436	106.1%

In addition to the overcapacity of the empty keg turner towards the wash and filling station, we found a difference in cycle time between a 50l Peroni keg (Stainless Steel) and 50l Grolsch keg (Premium black). Stainless Steel kegs are primarily used for Peroni and all other 50l beers are filled in Premium black kegs. These differences are found during the 30 measurements of each SKU processed at the empty keg turner. The cycle time of 50l Peroni at the empty keg turner equals 15.9 seconds, while 50l Grolsch equals 16.5 seconds resulting in a difference of 0.6 seconds. These cycle times directly affect the capacity of the empty keg turner as shown in Table 5.12: 453 kegs per hour for 50l Peroni and 436 kegs per hour for 50l Grolsch resulting in a difference of 17 kegs per hour for the same sized keg.

According to Härte (1997) the objective is to guarantee a supply of materials to the bottleneck machine at a rate surpassing its capacity, thereby improving the uninterrupted flow of goods along the packaging line. A decreased cycle time and therefore an increased capacity of the empty keg turner results in an quicker buffer padding (explained in Section 5.7.4) resulting in an increased running time of the wash and filling station after the occurrence of a failure.

Therefore, the **objective** is to decrease the cycle time of the empty keg turner as high as possible (considering technical characteristics) resulting in at least an overcapacity of 10% towards the wash and filling station.

5.7.2 Problem investigation

To investigate the root cause for less than 10% overcapacity of the empty keg turner in the beginning of this research and the cycle time difference between 50l Premium (black) keg and 50l Stainless Steel keg, we conducted two separate 5W analysis. The complete 5W analysis is shown in Appendix G and in this section (Problem investigation) we primarily conclude on the results of this analysis. The root cause originates in the programming code of the empty keg turner. The programming code is written in various codes (six small codes) instead of one code causing rough movements instead of smooth movements. Therefore, there is a lack of smooth movement of the empty keg turner causing a low overcapacity towards the wash and filling station.

5.7.3 Solution

Creating an overcapacity of at least 10% for the empty keg turner towards the wash and filling station can be achieved by decreasing the cycle time of the empty keg turner for each keg type. As stated earlier, we include the increased capacity of the wash and filling station achieved by decreasing the processing time of transport. As shown in Table 5.12, the cycle time of 19.5l, 30l and 50l Grolsch should be improved and 50l Peroni already has an overcapacity (10.2%) in the new situation with an increased capacity of the wash and filling station. In order to create an overcapacity of 10% for each of the keg types the capacity for 19.5l, 30l and 50l Grolsch should be respectively 507, 493 and 453 as shown in Table 5.13. Therefore, the cycle time reduction in order to create an overcapacity of 10% is respectively 1.4, 0.8 and 0.6 seconds as shown in Table 5.14.

Table 5.13: Capacity empty keg turner for four SKUs for an overcapacity of 10%

	Number of kegs add to buffer per minute		
	Wash and filling station	**Empty keg turner (new)**	**Overcapacity towards wash and filling station**
19.5l Peroni	458	507	110.7%
30l Grolsch	447	493	110.4%
50l Peroni	411	453	110.2%
50l Grolsch	411	453	110.2%

Table 5.14: Reduction in cycle time to create 10% overcapacity

	Current cycle time	**New cycle time**	**Reduction in cycle time**
19.5l Peroni	15.6	14.2	1.4
30l Grolsch	15.4	14.6	0.8
50l Peroni	15.9	15.9	0
50l Grolsch	16.5	15.9	0.6

In addition to creating 10% overcapacity of the empty keg turner, Grolsch additionally seeks to gain insight into the increased output of the line for decreasing the cycle time for each SKU with one or two seconds. In consultation with the owner of the programming code (external company) we concluded a decrease of one or two seconds are feasible. Therefore, section 5.7.4 shows both the results of an increased overcapacity of the empty keg turner toward the wash and filling station of 10% and the results for a decrease in cycle time of one and two seconds.

5.7.4 Results

Taking into account the implementations of Section 5.4 (increased buffer capacity) and 5.6 (decreased cycle time wash and filling station) and the current capacity of the empty keg turner, we conducted comprehensive calculations for an increased speed of the empty keg turner in order to create 10% overcapacity of the empty keg turner. First, we explain the principle of an overcapacity of the empty keg turner with an example and afterwards we explain the calculations for 10% overcapacity. The calculations for a decrease of one and two seconds are not explained separately, since they are performed in the same way as the calculations for 10% overcapacity.

Figure 5.22 shows the minutes on the x-as where we begin at the fist minute after a resolved failure of one of the machines in front of the empty keg turner causing an empty buffer. A maximum of 60 kegs in buffer are shown on the y-as, since this is the maximum buffer size between the empty keg turner and the wash and filling station. At 40 minutes, a failure occurs with a duration of four minutes causing an empty buffer with the capacity of 436 of the empty keg turner (c=436). However, decreasing the cycle time of one second resulting in a capacity of 465 does not result in an empty buffer (c=465) at the 44th minute. In addition, an increased capacity of the empty keg turner guarantees a faster buffer padding: 0.4 kegs per minute added to buffer compared with 0.9 kegs added to buffer for a capacity of respectively 436 and 465 kegs/hour. Within this example of Figure 5.22 with two failures at 40 minutes and 91 minutes, an extra production of 100.4 kegs are realized by increasing the capacity of the empty keg turner from 436 to 465 kegs per hour.

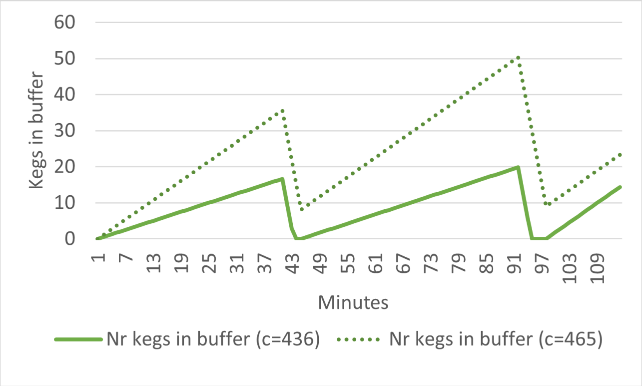


Figure 5.22: Example buffer padding with number of kegs in buffer per minute

To integrate this into the keg line, we utilized data from MicroStrategy associated with machine failures in front of the wash and filling station. The number of kegs added to the buffer between two consecutive failures are based on the input and output: capacity empty keg turner and capacity wash and filling station. The number of kegs added to the buffer are calculated by the difference of input and output buffer per minute and shown in Table 5.15.

Table 5.15: Number of kegs added to buffer per minute in four situations

	Number of kegs add to buffer per minute			
	New situation	10% over speed	Cycle time decrease by one second	Cycle time decrease by two seconds
19.5l Peroni	0.88	1.40	2.01	1.63
30l Grolsch	0.35	0.89	1.51	0.78
50l Peroni	0.70	1.20	1.78	0.70
50l Grolsch	0.42	0.89	1.43	0.70

The calculations are separated by the four SKUs in order to filter on the machine failures at processing the corresponding kegs. This data is extracted from MicroStrategy 'Stop Accountability' for week 29 - 36 2023. We calculated the difference in time between the beginning of a failure and the end of the previous failure. We computed several scenarios with this data where we changed the parameter of cycle time for the empty keg turner resulting in the number of kegs add to buffer per minute as shown in Table 5.15. In addition, we take into account the total buffer space of 60. For each time between two consecutive failures, we determined the total number of kegs added to the buffer by utilizing equation 7.

$$f(W_i, Y, T, B) = \begin{cases} W_i \times Y_i & \text{if } W_i \leq T, W_i \times Y_i \leq B, W_i \times Y_i \neq 0 \\ B & \text{if } W_i \leq T, W_i \times Y_i > B \\ \text{else} & 0 \end{cases} \quad (7)$$

where,
W_i: difference between the beginning of the failure and the end of the previous failure
Y: represents the number of kegs added to buffer per minute for specific SKU (based on the capacity of wash and filling station and empty keg turner) as shown in Table 5.15
T: time for a full buffer dependent on SKU, capacity empty keg turner and wash and filling station
B: total buffer space

Applying Equation 7 results in the total number of kegs added to the buffer for several machine failures in front of the wash and filling station for four situations: new situation, 10% overcapacity, cycle time decrease by one second and cycle time decrease by two seconds (as shown in Table 5.15). In addition to the machine failures of 'Stop Accountability', we also extracted the machine hours for the same period separated by the four SKUs. The difference between the number of kegs added to the buffer for the new situation and one of the three other situations are transformed to the number of extra machine hours based on the capacity of the wash and filling station for the specific SKU. This results in an increase of production (machine hours of the wash and filling station) as shown in Table 5.16. It is important to note we took into account the new capacity of the wash and filling station except for 19.5l Peroni. For 19.5l Peroni we calculated the increase in production and ME based on the capacity of the full keg turner since the capacity of both the full keg turner and the leak detection are below the capacity of the wash and filling station as shown in Figure 5.2.

Table 5.16: Increase in ME for for four SKUs for 10 % overcapacity, cycle time decreased by one second and cycle time decreased by two seconds for empty keg turner

	10% over-capacity	**Cycle time - 1 sec**	**Cycle time - 2 sec**
19.5l Peroni	0.35%	0.27%	0.45%
30l Grolsch	1.04%	1.29%	2.16%
50l Peroni	0.00%	0.61%	1.01%
50l Grolsch	0.33%	0.48%	0.78%

The total increase in production and ME is dependent on the production hours of the four different SKUs and therefore we take into account the weighted parameters based on the distribution between these four SKUs. This results, as shown in Table 5.17, in a total increase in ME of 0.37% at increasing the empty keg turner overcapacity to 10% towards the wash and filling station. Decreasing the cycle time with one and two seconds results in respectively a ME increase of 0.52% and 0.86% as shown in 5.17.

Table 5.17: Increase ME based on the increased cycle time empty keg turner

	10% over speed	**Cycle time - 1 sec**	**Cycle time - 2 sec**
19.5l Peroni	0.15%	0.06%	0.09%
30l Grolsch	0.05%	0.03%	0.05%
50l Peroni	0.00%	0.31%	0.51%
50l Grolsch	0.17%	0.13%	0.20%
Total Increase ME	0.37%	0.52%	0.86%

In conclusion, the empty keg turner cycle time requires no improvements according to 50l Peroni in order to create an overcapacity of 10%. However, the cycle time of 19.5l Peroni, 30l Grolsch and 50l Grolsch should be reduced with respectively 1.4, 0.8 and 0.6 seconds in order to create an overcapacity of 10%. The output of the line equals a ME increase of 0.37%. In addition, decreasing the cycle time for each SKU with 1 seconds to 14.6 (Peroni 19.5l), 14.4 (30l Grolsch), 14.9 (50l Peroni) and 15.5 (50l Grolsch) seconds results in an ME increase of 0.52%. The maximum cycle time decrease of two seconds results in a cycle time of respectively 13.6, 13.4, 13.9 and 14.5 resulting in a 0.86% ME increase.

5.8 Conclusion

This chapter showed the case study on the keg line of Grolsch, where we solved the top five root causes. We increased the buffer capacity in front of the wash and filling station with six by developing an Input Rate Control for the conveyor in front of the exterior cleaner. Nine extra buffer spots are created after the wash and filling station by relocating three sensors. With these increased buffer spots, 103.5 extra kegs per day can be processed. In addition, we solved the 19.5l keg disruptions occurring at the destacker by changing three sections within the conveyor control, ensuring constant conveyor lubrication, the application of rollers on the iron frame and a curtailment of the iron frame. It solved the disruptions and decreased the operator impact from a 8.8 to 1 on a scale of one to ten. It also increases the σ level from $\sigma = 2.75$ to $\sigma = 4.1$ resulting in a success rate of the keg destacker to 99.53% per movement without a disruption. Replacing a transport beam within the wash and filling station resulted in a decrease of transport processing time from 15.7 to 12.3 seconds. With these promising results, replacing all transport beams results in a payback period of seven months resulting in a reduction in speed loss of 12%. At last, ensuring a 10% overcapacity of the empty keg turner results in a total ME increase of 0.37%. In addition, comparing a decrease of one second cycle time and two seconds result in a higher ME increase from 0.52% to 0.86%.

6 Conclusions and Recommendations

In Section 6.1 we conclude on the main research question: *"What are the root causes for speed loss on the keg line, how could these issues have been revealed earlier to mitigate the impact and which implementation plans should be defined in order to decrease the speed loss on the keg line of Grolsch in order to increase the keg line ME?"*. In Section 6.2 we suggest recommendations to Grolsch based on this research. At last, in Section 6.3 we reflect on this research and discuss the limitations of this research.

6.1 Conclusions

Control charts based on control limits for machine downtime and cycle time bottleneck revealed deviations in an early stage. In addition, evaluating both buffer capacities and rejected products revealed wastes on the keg line: unused buffer capacity and rejected products at several machines. Determining control limits for rejected kegs resulted in keg rejections above the upper control limits for both seal failures and underfilled kegs.

V-Graphs are commonly used to analyze machine interaction on a higher level within a manufacturing line. In this research, we demonstrated V-Graphs can also be used as control charts to detect deviations in an early stage, which affect the keg line. Deviations in machine capacities are therefore detected between different SKUs. In addition, deviations between machine capacities on the line for a specific SKU are detected. Out of control situations are associated with a fail to adhere towards the V-Graph (a machine capacity in front of the bottleneck equivalent to or below the upcoming machine in the sequence) and an increase in cycle time of a machine in comparison to the previous V-Graph measurement.

Lean improvements incorporate the VOE at a relatively advanced stage of a Lean improvement, while we incorporated the VOE before the start of a (Lean) improvement, which revealed issues which were 'normal' within Grolsch. This accounted for the 19.5l keg disruptions at the keg destacker.

Periodic evaluating KPIs, Operator Impact and Visual signals of waste with the developed standardized method in this research (Flowchart 1, 2 and 3) reveals issues in an early stage and reduce the interval between identification and solving. The method for ranking and selection demonstrated the sequence of solving the issues. This method incorporates the time period for problem investigation and solving, investments, increase in production and operator impact.

The case study of the first two methods showed a top five root causes which have the highest effect on ME and should be resolved first. These root causes are: unused space buffer capacity in front and after wash and filling station, 19.5l keg disruptions at the keg destacker, delay in transport speed within wash and filling station and the speed of the empty keg turner. The case study of solving the top five root causes showed an effective combination of SGA and Lean Six Sigma techniques. SGA ensured the step wise structure, while Lean Six Sigma tools are used within each SGA step resulting in a comprehensive analysis. Except for the first step of the SGA method (subject selection), we used our standardized method for (early) detection and ranking/selection. The results of the case study of solving the top five root causes are:

1. The buffer capacity in front of the wash and filling station is increased by a total of six spots by implementing an Input Rate Control for the conveyor, resulting in 37.1 extra kegs processed per day.
2. The buffer capacity after the wash and filling station is increased by a total of nine spots by relocating sensors, resulting in 66.5 extra kegs processed per day.
3. 19.5l keg disruptions at the keg destacker were resolved through adjustments to conveyor control, adjusting the iron frame and ensuring constant lubrication in order to minimize the operator impact: a decrease from 8.8 to 1 on a scale of 1 to 10. It resulted in a success rate of the keg destacker of 99.53% per movement without a disruption.

4. Replacing a transport beam within wash and filling station reduced transport time, with potential benefits in terms of a seven-month payback period and a 12% reduction in speed loss at replacing all five beams.
5. Maintaining a 10% overcapacity of the empty keg turner contributed to a 0.37% increase in ME. Additionally, a comparison suggests a higher ME increase (0.86%) for a two second reduction in cycle time compared to one second (0.52%).

The summary of these results are shown in Table 6.1 towards ME increase (%), yield per year and investment. For the increased speed of the empty keg turner, we took into account the yield for an overcapacity of 10% for the empty keg turner. A ME increase is already realized within this research of 3.89% and an additional 0.37% ME increase for upcoming year can be realized by decreasing the cycle time of the empty keg turner of 1.4, 0.8 and 0.6 seconds for respectively 19.5l, 30l and 50l Grolsch Premium Black kegs.

Table 6.1: Results five case studies towards ME increase (%), yield per year and investment

	Increase ME (%)	**Yield per year**	**Investment**
Increased buffer in front of wash and filling station	0.71	€ 41,003	€ 0
Increased buffer after wash and filling station	0.86	€ 49,665	€ 0
Eliminate 19.5l keg disruptions	0.59	€ 33,987	€ 0
Replacing transport beams	1.73	€ 100,026	€ 58,441
Increase speed empty keg turner	0.37	€ 21,550	€ 5,500
Total	**4.26**	**€ 246,231**	**€ 63,941**

6.2 Recommendations

Keg line implementation

In this Master Thesis, we introduced the standardized procedures outlined in Section 4.2 and 4.3 for the first time at Grolsch' keg line. To optimize this application, we recommend implementing this methodology periodically. Each two months for V-Graph, cycle time bottleneck and buffer capacity. Each month for operator impact and weekly the rejected products and downtime machines.

In this research, we developed several control charts and updated them manually. To decrease the tasks, these KPIs should be updated automatically in MicroStrategy in one dashboard for the keg line. This dashboard should be printed and discussed within the weekly Packaging meeting in order to discuss all deviations and decrease the time between detecting and solving.

Detected issues by the application the method of Section 4.2 and 4.3 should be added to the issue list incorporating a calculation for the OIP. To guarantee a continuous application, we propose one of the three Process Engineers to be responsible for the keg line, with responsibilities for executing the standardized (early) detection method based on the predetermined criteria. In addition, this Process Engineer should also be responsible for maintaining the issue list as well as executing the interventions.

Currently, during the processing of 19.5l kegs without an additional cleaning step, the buffer between the wash and filling station, along with the full keg turner, effectively compensates for the difference in capacity. However, decreasing the cycle time of the full keg turner with one second results in the same capacity of the wash and filling station. Decreasing the cycle time of 1.7 seconds results in a 10% overcapacity of the full keg turner towards the wash and filling station. This can be realized to change the conveyor speed at 19.5l keg production in addition to adjusting the movements of the robot.

At the end of the time frame of this research, the system automation at the keg destacker is renewed and therefore it is important to verify if all changes made in this research, and already implemented, are translated in its entirety. The Instrument Technician Packaging is aware of these alterations, also accessible on Grolsch' Sharepoint within the section 'SGA 19.5l keg disruptions'.

Since each proposed solution to overcome the root causes are implemented within the time frame of this research, we only elaborate on the implementation of the increased speed for the empty keg turner. We suggest to implement at least a 10% overcapacity of the empty keg turner and a maximum cycle time reduction of two seconds. Therefore, MCA has to reprogram the code into one code instead of six small codes, test it during PPO (Planned Periodic Maintenance (*Dutch: Gepland Preventief Onderhoud*)) and implement the new code.

In order to increase Grolsch' keg line ME further, all other found issues within this research should be solved. The sequence of importance is already decided within this research and should be followed: processing times different filler steps (Deullage), downtime capper, processing times different filler steps (Air Purge), full keg rejection and rejection cap placement.

Implementation of the developed method on other Packaging lines within Grolsch
This research demonstrates increased ME and greater engagement of keg line employees through the suggested standardized method for (early) detection with proactive approach including the ranking and selection method. In addition, this standardized method is developed in such a way that it can be applied to other manufacturing lines within Grolsch. We recommend to apply this method to all other manufacturing lines within Grolsch, starting with Line 2 since it is under performing. Each line should be overseen by a Process Engineer who is responsible for executing the developed methods and keeping track of issues. Keeping track of the issues as well as the OIP for each issue can be calculated within the Excel Issue list as shown in Figure 4.6. The Process Engineer should be responsible for issue implementation and execution.

6.3 Limitations/Reflection

Existing limitations within this research have influenced the results, which are elaborated on in this section. In the selection method, some causes with a research/implementation time span of four months and a high Increase in Production (4%) will be selected earlier compared to an issue which join an investment and takes around six months with a higher Increase in Production (6%). However, the combination of several causes with a lower time span and without an investment can have the same increased effect on the output of the line compared to a cause with an investment. Nevertheless, with this method and the issue list all causes will be solved eventually.

In this research, we found several causes which affect the keg line ME significantly. One of those causes is the different processing times within the wash and filling station towards the wash pulses Weizen of 19.5l kegs. However, since the average complaints of three per month, we were not supposed to decrease the wash pulses and therefore an increase of 0.65% ME could not be realized within this research. In addition, several root causes were found during this research, but starts were already made by employees and therefore we were not supposed to interfere in these ongoing projects. However, using the issue list and have a responsible Process Engineer, these ongoing projects can be tracked for the keg line.

In this last section of this Master Thesis we will reflect on this research. Areas for improvement of this research are the data collection of the 19.5l keg disruptions. If we had data over a longer time period, a complete production year instead of two months, the calculations would have been more precise.
The primarily contributions of this research is a developed standardized method available for application on each packaging line within Grolsch and other manufacturing lines. Interdisciplinary approaches are incorporated within this research to address the complex issues and revealed solutions from various disciplines, which were all considered. An additional strength of this research lies in the upcoming application of the proposed method on Line 2 in April 2024.

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Appendices

A Machine figures

Figure A.1: Machine park keg line

B Wash and filling station analysis

In order to analyse the wash and filling station for speed loss, several recordings are made of the wash and filling station panel where each processing step for the different heads are shown. This information is not digitally available and therefore the recordings are analysed to receive the processing times per step for the different SKUs. Figure B.1 already shows some small deviations, but improving heads 3 until and including 8 will not result in a decrease in speed loss at first, because head 3 until and including 8 will wait till the moment head 1 and 2 are finished in order to go to the next processing step. Therefore, we first should focus on head 1 and 2 and when these are improved, we can improve the subordinate steps (head 3 until and including 8). Some measured times within head 1 and 2 differ from the seconds set within the wash and filling station, which are Air Purge and Deullage as shown in the second column of Table 5.2 for speed loss within the wash and filling station.

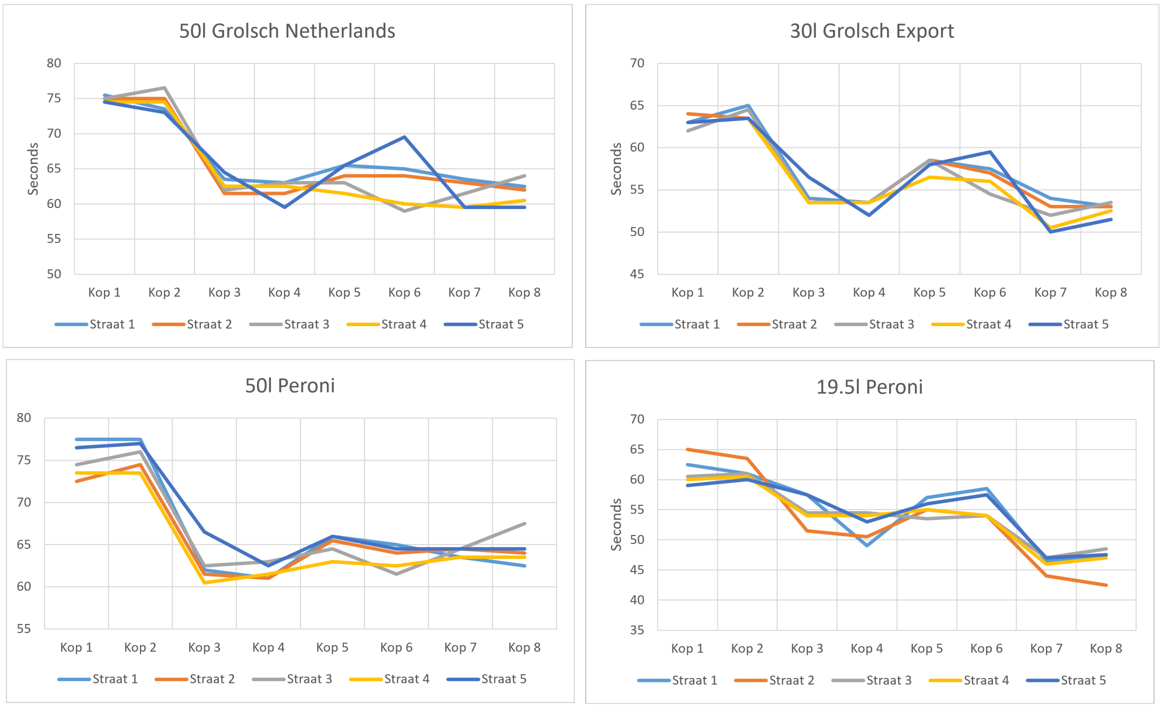


Figure B.1: Seconds per line and head

C SGA

1. Select a subject
   The first step is to select the subject, where the symptoms of the problem are described. The subject is linked to the departmental or organizational objectives. Within this research about speed loss, the different subjects are chosen based on the most important root causes of speed loss as explained in Chapter 2.
2. Set a target/goal
   The objective should be determined by the team manager or the team where the objective should be measured in the same units as the problem. Valuable, well-formulated objectives meet the SMART criteria (Specific, Measurable, Acceptable, Realistic and Time Based).
3. Problem investigation
   The goal of the problem investigation is to find the root cause of the problem, where three questions are important: 1) How is the process performing/behaving?, 2) What is going wrong? (Who experiences the problem, Where and when is the problem occurring?, What is the occurring frequency? What prevents us from doing it right the first time?) and 3) Why is the process failing?
   Tools that can be used in analyzing the process are brainstorm sessions, Pareto diagram, 5W2H (5Why's, 2How), Fishbone diagram, Flowchart, Registration card, and charts. The result of the problem investigation is the definition of the problem where the problem is quantified.
4. Invent solutions
   The next step is to invent solutions in order to remove the root causes which should be in line with the determined criteria. The criteria is based on the ROI (Return On Investment) or maximal budget, the quality of the finished product or service stays the same or improves, work safety must be guaranteed and the interventions need to be executable.
5. Develop a plan
   The implementation plan consist of the steps how the solutions will be implemented. These steps are visualized in a Gannt-Chart where the individual steps are clearly described possibly including a schematic of the desired situation. The implementation plan gives a 'Go' to implement the plan.
6. Execute the solutions
   This stage is a bridge between theoretical activities in solving problems and implementing to the actual operation according to Łyjak and Ejsmont (2016). It requires planning, update the completed tasks in the planning, training if needed and communications to the operation and involved operators.
7. Measure the results
   The results can be measured by either digital monitoring or visual monitoring which is solution dependent. When the measured results are insufficient, analyse step six, executing the implementation plan. If the correct actions are performed in the right way, start analyzing step five, invent solutions etc.
8. Standardise
   The objective of the last step is to standardize, the safest and most effective approach to reach and keep a certain quality level, and ensuring that everyone works and continues to work according to the agreed standard. The best way of standardise is to introduce a failsafe: there is one possible way to execute the job. When a failsafe is not possible, visual control tools are introduced (warn of deviations). Visual tools can also be used, which are One-Point-Lessons or visual information, for example work instructions.

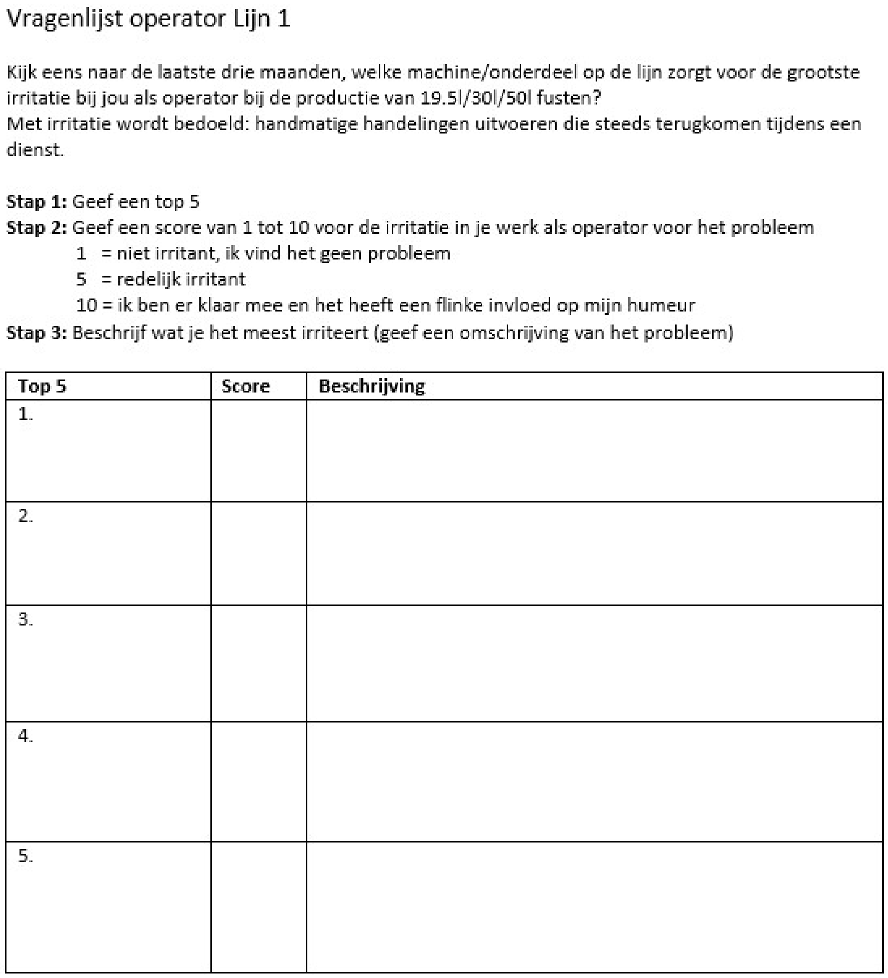
D CIMM scan

- **CIMM 1** - Process improvement solid foundation (33%)
  Quality management (15)
  Standardized work (9)
  Professional work environment (11)
- **CIMM 2** - Process improvement continuous improvement culture (48%)
  Work in Progress & Visual workplace (16)
  Short-cycle improvement (14)
  Kaizen events and ’Go to Gemba’ (14)
- **CIMM 3** - Process improvement stable and predictable processes (40%)
  Risk management and First Time Right (13)
  Eliminate waste (11)
  Lean Management (15)
- **CIMM 4** - Process improvement capable processes (30%)
  Lean Six Sigma organisation structure (11)
  Reduction of variation (8)
  Big data analysis (14)
- **CIMM 5** - Process improvement future-proof processes (38%)
  Product Lifecycle Management (PLM) (14)
  Design for Excellence (14)
  Smart industry (10)

Organization development (50%):

- Clear direction and focus (Strategy) (17)
- Quality of Management (Leading) (15)
- Transparency and action orientation (Openness) (17)
- Learning organization (Learning) (15)
- Agile and flexible organization (Agility) (12)

E Survey



Vragenlijst operator Lijn 1

Kijk eens naar de laatste drie maanden, welke machine/onderdeel op de lijn zorgt voor de grootste irritatie bij jou als operator bij de productie van 19.5l/30l/50l fusten?
Met irritatie wordt bedoeld: handmatige handelingen uitvoeren die steeds terugkomen tijdens een dienst.

Stap 1: Geef een top 5
Stap 2: Geef een score van 1 tot 10 voor de irritatie in je werk als operator voor het probleem
1 = niet irritant, ik vind het geen probleem
5 = redelijk irritant
10 = ik ben er klaar mee en het heeft een flinke invloed op mijn humeur
Stap 3: Beschrijf wat je het meest irriteert (geef een omschrijving van het probleem)

Top 5	**Score**	**Beschrijving**
1.		
2.		
3.		
4.		
5.		

Figure E.1: Survey

F In depth visualizations buffers

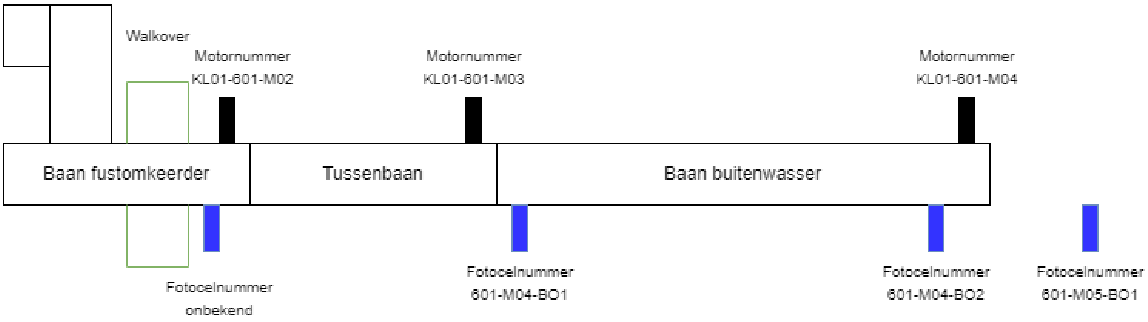


Figure F.1: Overview Buffer 2 and 3 including motor, sensors and stopper numbers

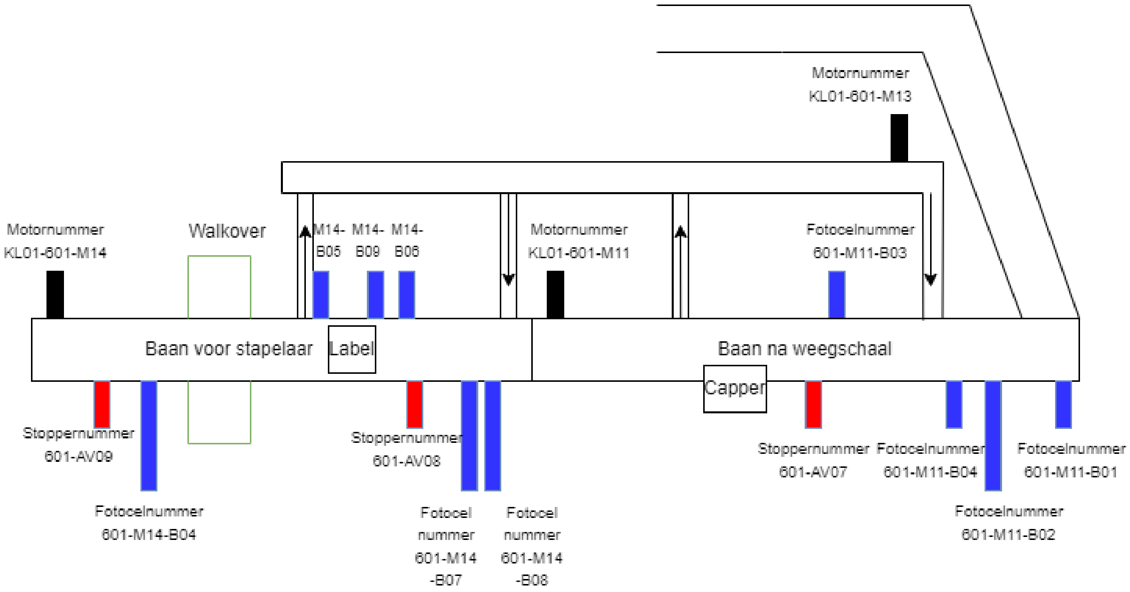


Figure F.2: Overview Buffer 8, 9 and 10 including motor, photocell and stopper numbers

G 5W analysis

5WHY Buffer 2

Conveyor B03 is not completely filled with kegs.

- 1W: Why is conveyor B03 not filled with kegs? If conveyor B03 stops running, the supply of kegs stops.
- 2W: What is the reason for conveyor B03 to stop running? Three reasons could occur: Section A is not active (the area between the keg destacker and the wash and filling station), there is a malfunction message or conveyor B04 is not running.
- 3W: In normal production, Section A is active and there is no malfunction message resulting in a stop of B03, but B04 can stop running causing in B03 stop running.
- 4W: Why stops conveyor B03 running when conveyor B04 stops running? Because it is predetermined in the system.
- 5W: How is it predetermined in the system? If B04 stops running, B03 immediately stops running.

The problem therefore originates in the system where the coordination between the conveyors takes place.

5WHY Buffer 8, 9 and 10

- 1W: What is the reason for the wash and filling station to stop supplying full kegs? Because there are no spots available to place these kegs.
- 2W: Why are there no spots available? Because one of the machines after the wash and filling station has a breakdown.
- 3W: Why if a machine has a breakdown, we still see available spots to place kegs? Because the sensors give a signal of an ’full’ conveyor.
- 4W: Why is the sensor giving a signal of a ’full’ conveyor? Because the sensors are placed close to the next machine.
- 5W: Why are the sensors placed close to the next machine in the process? These locations are predetermined in the past.

The problem therefore originates in the locations of the sensors.

5WHY Empty keg turner capacity

- 1W: Why is there a low overcapacity for the empty keg turner towards the wash and filling station? Since a high cycle time of the empty keg turner.
- 2W: Why is there a high cycle time of the empty keg turner? Lack of a smooth movement of the empty keg turner.
- 3W: Why is there a lack of smooth movement? The robot is programmed with various programming codes instead of one code.
- 4W: Why is the robot programmed with various codes? The code is written by a student of the supplier.
- 5W: Why is the code never adapted to one programming code? The machine is implemented and never optimized since no one measured this machine since.

The problem therefore originates in the programming code.

5WHY Empty keg turner difference between 50l Premium (Black) and Stainless Steel kegs

- 1W: Why is there a low overcapacity for the empty keg turner towards the wash and filling station? Since a high cycle time of the empty keg turner.

- 2W: Why is there a high cycle time of the empty keg turner? Lack of a smooth movement of the empty keg turner.
- 3W: Why is there a lack of smooth movement? The robot is programmed with various programming codes instead of one code.
- 4W: Why is the robot programmed with various codes? The code is written by a student of the supplier.
- 5W: Why is the code never adapted to one programming code? The machine is implemented and never optimized since no one measured this machine since.

The problem therefore originates in the programming code.

H Downtime machines

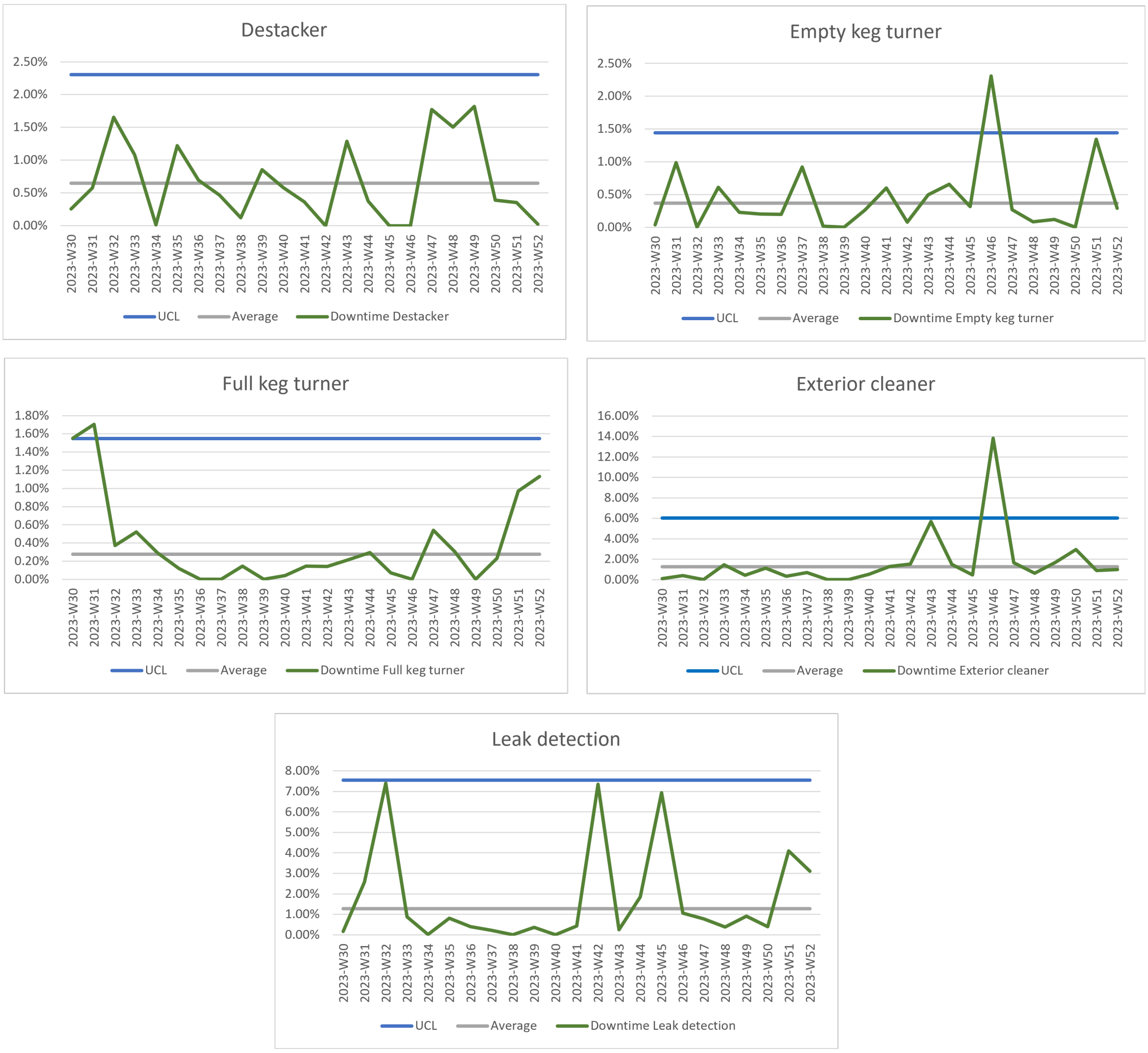


Figure H.1: Downtime machines per week including average and UCL

Table H.1: Average, σ, and UCL per machine

Machine	**Average**	σ	**UCL**
Exterior cleaner	1.26%	1.58%	6.01%
Capper	1.06%	0.72%	3.22%
Destacker	0.65%	0.55%	2.30%
Empty keg turner	0.37%	0.36%	1.44%
Leak detection	1.28%	2.09%	7.55%
Palletizer	1.08%	1.01%	4.09%
Full keg turner	0.28%	0.42%	1.55%

I Seal failures

In addition to variation of transport processing times within the wash and filling station within a single lane, we also analyzed the failures within the wash and filling station. Kegs are not filled with beer at head seven and eight when kegs did not pass a critical value at either one of the previous heads. Several failures can occur, where some of the failures are specific for a combination of heads. For example, the failure 'slow beer fills' only occurs at head seven and eight, since the other heads do not fill kegs with beer. One of the failures which are possible for occurring at all heads are seal failures. Seal failures are failures where the keg seal is not positioned perfect on one of the heads within the wash and filling station. Without a perfect alignment of the keg and the heads, the critical value is not achieved and therefore a failure occurs. Seal failures at head one and two are mostly affected by the alignment of the kegs on the transport beam. These failures are available in MicroStrategy since half October and therefore the data of four weeks before the replacement and five weeks after the replacement are analyzed, resulting in a number of seal failures for head one until and including eight per day compared with the number of processed kegs for that day. The average percentage of seal failures per head per week are shown in Figure I.1 and the values are shown in Table I.1.

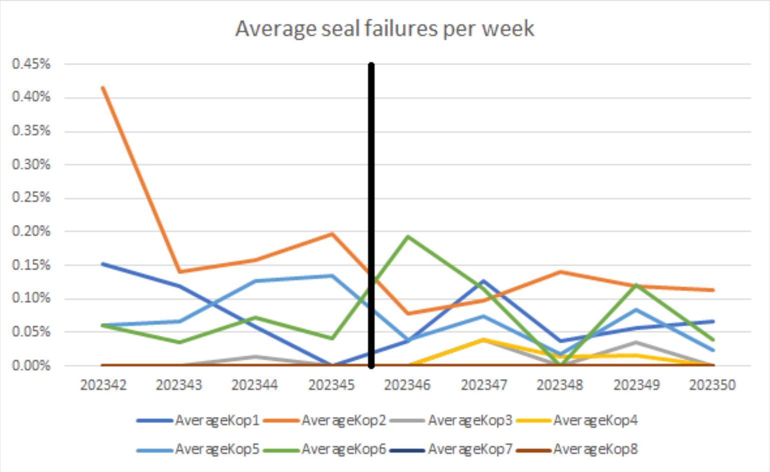


Figure I.1: Seal failures average per week. Black line shows the replacement of the transport beam

At the end of week 45, the transport beam is replaced and Table I.1 shows a decrease within head 2 and 5 when comparing the percentage seal failures from week 42 until and including 45 and after week 45. Nevertheless, in order to determine if the values truly differ, hypothesis tests are conducted. For each head, we tested the number of failures towards the number of processed kegs before and after the replacement of the transport beam. We chose the 2-Sample % Defective hypothesis test, since we want to test two samples with the % defective seal failures towards the number of processed kegs. The hypothesis tests are executed in Minitab for each head where the number of seal failures towards the total processed kegs before the replacement are tested against the number of seal failures towards the total processed kegs after the replacement. The results of the hypothesis tests showed only a significant difference in the percentage defective of the seal failures for head two. The results of the hypothesis test where we tested if the percentage seal failures before the replacement is greater than the seal failures after the replacement, resulted in a P-value of 0.08. Since the P-value of the hypothesis test is lower than p=0.10, we can state with 90% confidence the seal failures of head two are decreased after the replacement of the transport beam. For the comparison of the seal failures before and after the transport beam replacement, we cannot state with 90% confidence the seal failures differ for all other heads (1, 3, 4, 5, 6, 7 and 8), since all p-value had a value above 0.10 as a result of the hypothesis tests. Therefore, we can conclude the seal failures at head two are decreased from 23% to 11% by the replacement of the new transport beam and the seal failures within the other heads are not significantly decreased but also not deteriorated.

Table I.1: Percentage seal failures towards the processed head 1-8

Week	Head 1	Head 2	Head 3	Head 4	Head 5	Head 6	Head 7	Head 8
42	0.15%	0.42%	0.00%	0.00%	0.06%	0.06%	0.00%	0.00%
43	0.12%	0.14%	0.00%	0.00%	0.07%	0.04%	0.00%	0.00%
44	0.06%	0.16%	0.01%	0.00%	0.13%	0.07%	0.00%	0.00%
45	0.00%	0.20%	0.00%	0.00%	0.13%	0.04%	0.00%	0.00%
46	0.04%	0.08%	0.00%	0.00%	0.04%	0.07%	0.00%	0.00%
47	0.13%	0.10%	0.04%	0.04%	0.07%	0.06%	0.00%	0.00%
48	0.04%	0.14%	0.00%	0.01%	0.02%	0.00%	0.00%	0.00%
49	0.06%	0.12%	0.03%	0.02%	0.08%	0.06%	0.00%	0.00%
50	0.13%	0.11%	0.00%	0.00%	0.02%	0.04%	0.00%	0.00%