Optimizing production performance of the Filling Lines of Euroma

BSc Industrial Engineering & Management

Bachelor thesis

General information:

Title: “Optimizing production performance of the filling lines of Euroma”
Publishing date: 23-09-2022
Intend: This report is intended for Euroma as an advice on optimizing the performance of its filling lines. The report was drafted as part of the bachelor assignment for the study Industrial Engineering & Management at the University of Twente.

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Management summary

This research is conducted at the company of Euroma on behalf of the production department. Euroma is a spice manufacturing company with facilities in Zwolle, Nijkerk, Schijndel and Wapenveld. The study is focused on the 709, 710, and 711 filling lines which are located in Zwolle, and reserved for co-manufacturing. The overall effectiveness of the filling lines is measured via OEE. Currently, the filling lines are underperforming, and overall OEE scores are low and prone to fluctuation. This study focusses on the performance category within OEE. The main research question is: *"How can Euroma improve the performance of the filling lines 709, 710, and 711?"*

The performance score is influenced by the occurrence of microstops, and incurred speed loss. Microstops are classified as production stops with a duration smaller than 3 minutes. Speed loss is incurred as a consequence of producing at a sub-optimal speed. The latter is influenced by the definition of this optimal speed. The optimal, or maximum, speed is based on the ideal cycle time of the products produced. This ideal cycle time ought to be seen as the "workload" of production. Currently, the speed based on this workload is set at 200 fills/min. This study points out that this is an overestimation of the capabilities of the filling lines. The newly determined technical maximum speeds of the filling lines 709, 710, and 711 are 180, 170, and 190 fills/min, respectively.

The average overall performance scores, adjusted for the re-evaluated workloads of the 709, 710, and 711 within the period of January 2021 – May 2022 amount to 70.76%, 67.72%, and 65.81%. A low score compared to the world-class score of 95%. Producing a single order on the 709, 710, and 711 takes an average of 15, 20, and 18 hours, respectively. 19%, 14%, and 16% of this time is lost on microstops and speed losses. When we consider the total time lost on microstops and speed losses within the period of January- May 2022, this amounts to nearly 1200 hours of wasted, valuable production time. Within Euroma, the setup time is examined more frequently. However, when the time lost within this category is examined over the same time period, this amounts to only 1150 hours. This makes that the time lost within the "ignored" performance category exceeds the amount of time lost as a consequence of the most examined loss: the changeovers between orders. The total "costs" of the performance loss within the first 5 months of 2022 amounts to over €143,000.

To decrease the amount of time lost on microstops and speed losses, we observed the filling lines. During this field study we identified common causes of microstops. Operators and team leaders were questioned to reveal the unobservable causes of speed losses. The findings within this field test were compared to, and supplemented with causes identified within the literature. Based on the results, we proposed nine solutions to increase the performance of the filling lines. Where possible, the quality of the proposed interventions was evaluated based on the effect on the occurrence of microstops, the effect on the experienced speed losses, costs, time to implementation, and additional benefits. Where a direct comparison to these criteria was not possible, the solutions were evaluated based on the objectives of this study which are: (1) to improve the performance of the filling lines, and (2) to enhance the observability, and communicability of this performance. The solutions deemed most appropriate are:

1. Replace the sensor of the 630 filling machine (709).
2. Place a guidance rail on the conveyor succeeding the cartoner machine (709, 710, &711).
3. Replace the closing mechanism of the cartoner (709).
4. Relocate/ adjust the sachets checkweigher (711).
5. Improve the operator training program.
6. "Visualize" the production speeds.

Recommendations
We recommend Euroma to readjust the workloads within the MES system that are used to calculate the speed losses incurred. These workloads should be based on the technical maximum speeds of 180, 170, and 190 fills/min for the 709, 710, and 711, respectively. This

corresponds to the production norms of 86400, 81600, and 91200 fills per shift of eight hours. By adjusting the workloads, the OEE scores of these lines are more aligned with reality. We also advise the company to persevere in its wish to steer on the OEE scores, as valuable information is contained within these scores and underlying registrations. In addition, it is beneficial for Euroma to implement (a subset of) the six solutions presented within this study. On top of that, the company benefits from carefully studying the recommendations, and additional findings presented in the report. Furthermore, we advocate on the potential benefits which monitoring and analyzing the performance more actively and/or frequently could bring. A good starting point would be to use this study as a guide and carry out a similar research, including the reevaluation of the workloads, focused on the filling lines that are not included within the scope of this study.

We conclude with a remark on the research performed. Within the course of conducting the research, the definition of a “workload” as identified by Euroma has changed. Initially, this workload ought to accommodate speed losses caused by product characteristics. The meaning, and implications of this shift are more thoroughly discussed in Section 6.3.1. As the change manifested at a later stage of the research, considerable time and effort had already been invested in investigating the relationship between product characteristics and achieved production speeds. We found that products with a maximum weight between 35-90 grams are produced at higher rates when compared to products which fall outside this range (this holds for the 709, and 711). We also found indications of the order size effecting the speed losses incurred. These are potentially interesting areas to further investigate, and we therefore recommend the company to do so.

Preface

Dear reader,

Before you lies my bachelor thesis of the program Industrial Engineering & Management, followed at the university of Twente. The research was conducted at the company of Euroma in the period of February 2022 – July 2022. During the course of conducting the research, there have been numerous people who have given their help and support. Within this preface I would like to take the liberty to say a special thanks to some of these people.

First of all, I want to thank the company, and employees of Euroma for providing the challenging assignment and being so welcomingly received. A special thanks goes out to my supervisor: Remco van Denderen, who has been supportive, understanding, and involved throughout the entire research. I will miss our weekly conversations during which we discussed the progress, but where there was always room for small talk. I would also like to thank Alfredo Spies, who has helped me to find my way around the technical systems, and whose door was always open when help was needed.

Secondly, I am grateful for the feedback which my university supervisors have provided. At the start of my research, I have had some good discussions and debates with my first supervisor, Leo van der Wegen. I am certain that without these discussion, and his sharp critique, the research would not have come out as it did. In addition, I would like to thank my second supervisor, Marco Schutten, for his eye for detail within the feedback which he provided.

Last but not least, I want to thank my family and friends for showing an interest in my work. This interest has kept me motivated and has been a quality boost for the overall research.

I hope that you enjoy reading this report.

Kind regards,

Thomas Nieuwenhuizen
July, 2022

Contents

Glossary

Term	Definition
ERP	"Enterprise resource planning". An ERP-system manages and integrates business processes through a single system.
Free weigh	A specific type of PLC used to determine whether a product adheres to the weight criteria imposed on the product.
Theoretical cycle time = Ideal Cycle Time	The amount of time it ideally takes to produce one unit of output, typically based on the NPC of the machine used.
Theoretical maximum speed	The theoretical maximum speed at which a machine can operate.
MES (Manufacturing Execution System)	Operating system that gathers data on production performance.
NPC (Nameplate capacity)	The maximum speed with which a machine can operate as this has been laid down in the specifications of the machine by its manufacturer.
OEE (Overall Equipment Effectiveness)	A metric that serves as an indicator of the percentage of production time that is truly productive.
OTIF (On Time In Full)	The percentage of orders that is delivered in full at the agreed upon delivery date.
PLC (Programmable Logic Controller)	Programmable controller that is used in writing the operating status of a machine to the MES system.
PowerBI	Data visualization and analysis tool.
Workload	The ideal amount of time it takes to produce one unit output.
Production norm	The number of products that ought to be produced on a line during an eight-hour shift when the availability and quality scores of that line are considered to be 100%.
Standard cycle time	The expected time it takes to produce one unit of output considering the typical losses including planned stops, unplanned stops, small stops, slow cycles, and defects.
Operating Time	The amount of time that a production line is available for production. It therefore excludes planned (maintenance), and unplanned (breakdowns) downtime from the total time period considered.
Processed amount	The total number of products produced during the runtime.
WMS (Warehouse Management System)	Inventory system used to keep track of inventory levels and needed materials in production.

Chapter 1: Problem identification and approach

This chapter briefly introduces the company of Euroma (Section 1.1) before it addresses the context of the problem that the company is facing and the theoretical perspective of this study in relation to the problem (Section 1.2). Section 1.3 depicts the causes and effects of the problems that the company faces. In addition, it selects and explains the core problem on which this study is focused. The research questions and problem-solving approach are discussed in Section 1.4.

1.1 Introduction to Euroma

The venture began in 1899, when a man named Antonij ten Doesschate decided to found a company specialized in herbs, spices, and pharmaceutical articles. The company, then called "De Peperbus" was located at the heart of the city center of Zwolle and had a main focus of selling spices and canned herbs under the slogan: "pure kruiden, fijn gemalen". A future market leader was born.

The name "Euroma" was first introduced in 1966 and has changed only once ever since, when the company received its royal predicate. In 1991, Euroma developed the Prima Pura method. This is a unique method capable of disinfecting herbs and spices in a natural way by means of steam treatment. In the years thereafter, the company continued to grow. With the takeover of Intertaste in February 2018, Euroma did not only become the market leader in the Netherlands, but claimed a top position in the European market. Currently, the organization has four production sides which are located in Schijndel, Nijkerk, Wapenveld and Zwolle. The new production facility in Zwolle (*Figure 1*) became operational in 2019. The company produces a variety of products, ranging from dry products such as seasonings and herbs to ambient and fresh liquids. The annual turnover lies around 230 million euros, and the employee count exceeds 600 people. Euroma collaborates with large food companies as a co-manufacturer. In addition, the company has its own product lines which it sells in the Netherlands, Belgium, and online. Today, the company is partially in the hands of the Japanese "Marubeni Corporation". According to Euroma, this investment business might open up opportunities for international growth and is a first step in expanding business outside of Europe.

Figure 1: State of art production facility Zwolle

1.2 Problem context

In 2019, Euroma closed its production facilities in Utrecht and Puttershoek and opened its new production site in Zwolle. In addition, the production side in Wapenveld was substantially downsized with an expected total closure in the fourth quartile of 2022. By building the new production facility, Euroma wanted to centralize production. However, as building costs were higher than expected, the company was put under a lot of pressure by its investors to start delivering output. The machines priorly used in Utrecht, Wapenveld and Puttershoek were shipped to the new production side and the company started production as soon as possible. Up until the start of 2022, production has mainly been steered on an operational level. This means that a high amount of focus was put on getting and keeping lines running and little attention was given to the analysis of overall performance and the formulation of strategic goals. Currently, the company wants to steer on a higher level and start optimizing its production output. However, now that the focus is put on performance analysis and improvement, problems related to the performance of the filling lines come to light.

The filling lines form the end station of production. It is where the products that have been treated and mixed are “filled”. This means that the product is correctly dosed and packaged. At these lines, management is currently facing issues in delivering orders on time. When we take a look at the OTIF-scores (On Time In Full), we see an average score of around 90%. This means that, on average, the company is only able to deliver 90% of their orders at the agreed upon time, in the agreed upon quantity. When we consider that the average weekly output of the filling lines fluctuates around 600 orders, this means that around 60 orders do not get delivered correctly. This mainly translates in low customer satisfaction. However, as price negotiations with customers are held before production starts, any delays and extra labor costs fall under the company’s own risk. This means that not meeting production schedules is not only a cause for low customer satisfaction, but is also suppressing the profit of the organization. In addition, it withholds the company from selling to more or new customers, and there are even customers which have sent claims due to not being able to, on their turn, sell the products that were not delivered on time. The subject of this study are the filling lines which are reserved for co-manufacturing. These are the lines that fill and package products such as soup mixes, lasagna mixes and nasi mixes for large companies which then sell these products under their own brand name. The study addresses and analyzes the performance of the filling lines from a process-monitoring and improvement point of view. In doing so, the study is primarily focused on the analysis of numerical data. An important source of this information is found in the company’s MES system, which is explained in the next paragraph.

Euroma makes use of Infor-LN, a cloud-based ERP system that communicates with several warehousing and operating systems. One of these systems is the MES system. This “Manufacturing Execution System” gathers data on production performance, machine-status, and quality. In addition, it can be used to perform pareto analyses on losses, downtime, and breakdowns of machinery. More in-depth analysis can be performed by programs such as PowerBI, which can access the data that the MES system gathers via the central database on which the system saves its data. Furthermore, MES forms the link between the operators and machines to the WMS system (Warehouse Management System). This means that the system automatically calls for new production materials when a batch of production starts. It is therefore a vitally important system used in production itself as well as in the monitoring and analysis of the performance of production. At Euroma, this MES system is installed at all of their filling lines. These lines are equipped with Free weigh and other PLCs (Programmable Logic Controllers) which are installed at various points of each filling-line. The PLCs register information about the status of the filling line to the MES system. Because every line is equipped with its own PLCs, MES can be used to analyze the performance of every individual line. One of the most important measures for this performance is found in a line’s OEE.

OEE stands for “Overall Equipment Effectiveness” and is a metric that serves as an indicator of the percentage of production time that is truly productive. It is a well-known metric that is used throughout the production-industry and can be broken down into three parts: availability, performance, and quality. Each of these three categories is expressed as a percentage, where the overall OEE-score is merely the product of the three (See *Equation 1*). Availability captures the percentage of time a line has been available, performance the percentage of time it should have taken to produce the number of products that have been produced in comparison to the amount of time it has actually taken, and quality the percentage of produced products that adhere to the quality standards imposed on these products (Vorne Industries, sd). For a more detailed elaboration on OEE, see Section 2.1.

$$OEE = Availability * Performance * Quality$$

Equation 1: OEE calculation

The most well-known method of measuring OEE is the so-called Nakajima-method. This method calculates OEE based on the formula shown in *Equation 2*. For now, this method will be used to explain the concept of OEE. However, as there are several ways in which the OEE-measure can be expressed and implemented, this study will further investigate these methods and search for the precise definition of OEE as it is used by Euroma. This will be done before any analyses on OEE is performed.

$$OEE = \frac{OperatingTime}{LoadingTime} * \frac{TheoreticalCycleTime * ProcessedAmount}{OperatingTime} * \frac{ProcessedAmount - DefectAmount}{ProcessedAmount}$$

Equation 2: OEE Nakajima

For this study, the "performance" category within OEE is the most important one. The performance score is calculated by means of the "TheoreticalCycleTime", the "ProcessedAmount" and the "OperatingTime". The theoretical cycle time equals the time it ideally takes to produce one unit of output. It is therefore sometimes also referred to as the "Ideal cycle time". The processed amount captures the total amount of products that have been produced during the operating time, and the operating time is the amount of time that the production line has been available for production. It is calculated by subtracting the "unplanned downtime losses" from the "Loading Time", where the "Loading Time" is calculated by subtracting the "planned downtime losses" form the total amount of time available (see Equation 3, and *Equation 4* respectively). The loading time is the amount of time reserved for production. This means that it excludes planned downtime. Planned gaps in production time such as weekend shifts or shifts in which no orders are scheduled, and planned maintenance activities are therefore excluded. The unplanned downtime includes equipment failures, setups, resets, and other unplanned stops measured in time (Kechaou, Addouche, & Zolghadri, 2022).

$$OperatingTime = LoadingTime - Unplanned\ downtime$$

Equation 3: OperatingTime calculation

$$LoadingTime = TotalPossibleTime - Planneddowntime$$

Equation 4: LoadingTime calculation

By means of the theoretical, or "ideal" cycle time, which can be seen as a products workload, production norms can be calculated. A production norm captures the number of products that ought to be produced on a line during an eight-hour shift when the availability and quality scores of that line are considered to be 100%. If the ideal cycle time is expressed in minutes, these norms can be calculated by means of the calculation shown in *Equation 5*. Here, the equivalent of an eight-hour shift, that is 480 minutes, is divided by the ideal cycle time.

$$Production\ norm = \frac{480}{Ideal\ cycle\ time}$$

Equation 5: Production norm calculation

The study takes a process monitoring and improvement point of view. The choice to analyze and monitor the performance of the filling lines in the structured, numerical way that has been presented, was made to ensure the highest level of objectivity in identifying, analyzing, and capturing this performance.

1.3 Identifying the core problem

With low customer satisfaction and suppressed profits as a starting point, interviews were conducted to gain insight into these problems. Participants in these interview have been: the unit manager, the commercial consumer director, and the technical application manager. The unit manager is responsible for the status and performance of the filling lines, the commercial consumer director is the head of sales and therefore responsible for customer relations, and the technical application administrator has been involved in the implementation and setup of the MES system. In collaboration with the unit manager, who can be identified as the problem owner, the range of problems related to the low customer satisfaction and suppressed profits were analyzed. The cause-and-effect relations between these problems are mapped in the problem cluster depicted in *Figure 2*. The use of this tool is in line with the managerial problem-solving method (Heerkens & Van Winden, 2021).

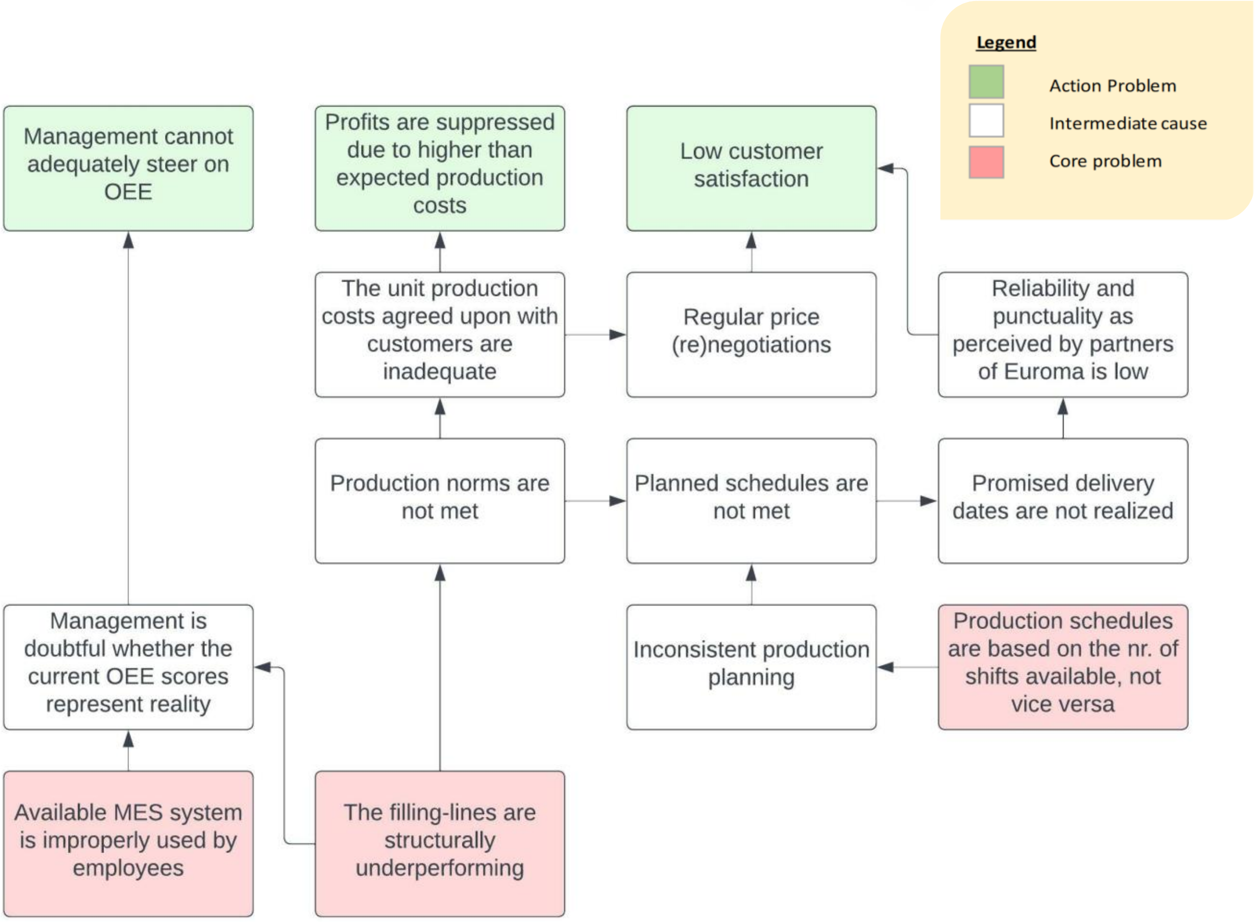


Figure 2: Problem cluster

It becomes apparent that customer satisfaction is low because of Euroma's struggle to deliver their customers' orders on time. In addition, profits are suppressed due to inadequate indications and agreements on unit production costs with these customers. Both of these problems can eventually be traced back to production norms not being met at the filling lines. This, in its turn, is caused by a structural underperformance of these lines.

This study will therefore address the following core problem:

"The filling lines are structurally underperforming"

As we can see, this is not the only core problem within the problem cluster. The next paragraph discusses why we should nevertheless select this problem over the other core problems.

There are two other problems which can be seen as core problems. The first relates to the correctness of the OEE measure. The structural underperformance of the filling lines is not the only reason for management to doubt the representativeness of the OEE scores. Another reason for this doubt is found in the improper use of the MES system by the line-operators. However, as this is a problem currently being addressed by the company, this will not fall under the scope of this study. The same holds for the identified problem of production schedules being based on the number of operators available instead of vice versa, as the company is currently hiring and training additional operators. As these core problems are therefore taken care of, we can address our attention to the performance of the filling lines.

In measuring the performance of the filling lines, Euroma makes use of OEE. To put the current "underperformance" of these lines into perspective, we take a look at the overall OEE score (being the product of the availability, performance, and quality score). This score is very low and versatile. An 85% score is considered world class, and a 60% score is not uncommon for manufacturers for whom there is significant room for improvement (Vorne Industries, sd), but Euroma only scores between the 25-50% range. The company would like to improve this score by identifying the biggest losses incurred. The main research question of this study is therefore the following:

"How can Euroma improve the performance of its filling lines?"

As the consequences of the current ill performance of the filling lines are so extensive, the company is currently setting up a project team to improve this performance. However, this improvement project is fully focused on the availability category of OEE, and is mainly concerned with identifying the most frequent occurring equipment failures. This study will focus on the "performance-category" of OEE. It therefore has a completely different, and own focus area. When we look at the performance-scores of 2021, the average score lies around 65%. In comparison, the world-class score in the performance-category is set at 95%. Euroma has over 20 filling lines in operation. Including all of them in this study is not possible given the time frame. In consultation with the company, it has therefore been decided to scope the study on three filling lines: the 709, 710 and 711. These lines are among the most important for the company in terms of their output and handle orders from a single customer.

The terms "production norm", and "workload" are central terms within this study. The concept of a production norm is already explained in Section 1.2. A workload captures the time it ideally takes to produce one unit of output. It is therefore equal to, and interchangeable with "ideal cycle time". As the use of both terms is common practice within Euroma, this study uses the terms interchangeably. Within the next paragraphs, we elaborate on the different production norms used throughout the different departments of the company and link these discrepancies to the difficulties in analyzing the current performance of the filling lines. By doing so, a crucial intermediate step needed to analyze the performance of the filling lines is unveiled.

Normally, the performance of a filling line can be analyzed by comparing actual output to the production norm. However, currently there is an issue when we consider the way in which these norms are defined. The definition of a production norm is non-uniform between different departments of the company. The sales department makes use of entirely different norms in their correspondence with customers, and in the process of cost allocation when compared to the norms that the planning department uses in its production planning. As long as these norms are not equal, adequate agreements on prices and delivery dates cannot be made with customers. Especially when the norms used by the planning department are lower than that of the sales department, delivering on the agreed upon date is difficult. These discrepancies cause a lot of miscommunications between departments. When we consider the formula used to compute production norms (*Equation 5*), we can see that a production norm is dependent on the "Ideal cycle time" (workload). As this is the only variable in the equation, any discrepancies in the ideal cycle time used directly translate into different production norms. To provide insight into the scale of the discrepancies, interviews have been conducted to identify the ideal cycle times used throughout the different departments. Participants in these interviews have been the

business controller as representative of the finance department, the commercial consumer director as representative of the sales department, and the technical application manager and unit manager as participants knowledgeable of production and planning.
Table 1 summarizes the findings.

Filling-line	Ideal cycle time (minutes) Finance/sales	Ideal cycle time (minutes) Production	Ideal cycle time (minutes) Planning
709	0.0081	0.005	0.0120
710	0.0088	0.005	0.0137
711	0.0077	0.005	0.0120

Table 1: Department specific ideal cycle times

The poor, non-uniform understanding of the workload of the products produced is the main cause of the ill-defined production norms. In the ideal situation, the production norms should be based on the ideal cycle time as specified within the OEE calculation. This is the ideal cycle time as defined by the production department. However, the ideal cycle time used within the calculation of this performance-score is currently not used in determining production norms. How come? The ideal cycle time as defined within the OEE score, and used by the production department, has been determined based on the NPC (Nameplate capacity) of the filling lines. This is the maximum speed with which a machine can operate as has been laid down in the specifications of the machine by its manufacturer. Management is doubtful whether this is a correct measure as this time is based on an ideal performance from when the machines were purchased, over 30 years ago. As a consequence, production norms are currently determined by past experience rather than on the NPC's ideal cycle time. By doing so, production norms have been lowered to match past performance levels. However, as has been indicated in the problem cluster (*Figure 2*), even these lowest, adjusted norms used by the planning department are currently hardly ever met. By altering the production norms based on current or recent performance, the norms have lost their meaning. They are no longer the target to which performance can be compared, but rather a tool that can be used by the planning department to schedule production. A consequence of the discrepancy between the production norms that are currently used and the production norms that follows from the "Ideal cycle time" as embedded in the OEE, is found in the evaluation of performance. The evaluation on the current performance of a line differs based on the reference used. When the output is compared to the adjusted production norms used by the planning or finance department, this gives an entirely different indication of performance when compared to the OEE performance-score. As there is doubt as to how realistic the "performance-score" within the OEE is, the overall OEE score is questioned, which is one of the main reasons that the score has not been used in steering and improving the production output.

But why is it that the company wants to be able to steer on OEE, and what is withholding them from doing so? Euroma wants to have an adequate measure of how well their lines are performing so that any deficiencies are discovered on time and (future) performance can be improved based on data. As the OEE score is the most important measure of performance, management wants to be able to adequately steer on this measure. However, this remains impossible as long as the company is unsure whether this score represents reality. If this were no longer the case, the score could not only be used to analyze the performance of the lines, but serve as a base upon which to realistically schedule production. With the production norms currently in use being ill-defined, and the ideal cycle times upon which the performance-category within OEE basis its norms being questioned, there is no adequate measure to compare current performance with. We therefore cannot identify whether the production norms based on the ideal cycle time as defined in the OEE are overestimating the ability of the filling line or whether the filling line is not delivering up to par as long as the ideal cycle times are not adequately determined. The company needs to gain insight into what a realistic performance is and what target performance to compare to. Only then can the performance of the filling lines be analyzed. Prior to analyzing, we will therefore have to determine new, adequate production workloads. Once these have been determined, we will be able to analyze the performance of the filling lines by means of the performance-scores within the OEE, and identify the biggest losses incurred. Only then will we be able to answer the main research question and propose ways in which Euroma can improve the performance of its filling lines.

Overall, the goal of this study is to give the company advise on how the performance of the filling lines can be improved. As we have seen, there are some steps that have to be taken in order to be able to give reliable advice. First, we need to adequately determine the production workload. This means that the ideal cycle times currently used within the calculation of OEE will have to be re-examined and adjusted where needed. By doing so, performance is compared to a "correct" benchmark. This means that we will identify correct production workloads. Once these have been established, and a solid base to which the performance of a line can be compared has been identified, the study will focus on improving this performance. The end goal is to give valuable advice on how the performance of the filling lines can be improved. With the study conducted, management should, in the future, be able to adequately monitor and steer the production output of the filling lines themselves through a realistic OEE. Combined, this should enable the company to steer towards its identified goal of realizing a constant overall OEE-score of 60% by the end of 2022. In addition, there is yet another aspect of this study which is not to be forgotten. By means of the newly determined workloads, the study will also provide the accompanying production norms. This will aid in the communication between departments and enable the company to present customers with a solid indication of not only the time needed to produce their order, but a precise and adequately determined unit production cost. Hereby, the number of orders not being delivered on time, and the suppression of the organization's profit will be reduced.

1.4 Problem solving approach

When the research question proposed in Section 1.3 is adjusted to fit the scope of this study, this results in the following research question:

> *"How can Euroma improve the performance of the filling lines 709, 710, and 711?"*

In order to be able to provide an answer to this research question, we must be able to answer the following (sub-)questions:

Question 1 (Chapter 2)**:** *"How does the way in which Euroma measures OEE relate to commonly used methods of measuring OEE?"*

- Question 1a (Section 2.1): "How can OEE be used to measure productivity losses?"
- Question 1b (Section 2.2): "How can OEE be used to measure performance losses?"
- Question 1c (Section 2.3): "How is OEE implemented at Euroma?"

If we want to analyze the performance of the filling lines based on the performance-score within OEE, we must have an adequate understanding of the way in which this performance is measured. In order to put this performance-score into perspective, we need to know how Euroma measures its overall OEE (question 1c). This question is answered by conducting interviews with the technical application manager, who is the administrator of the MES system, and by analyzing the MES system itself. Questions 1a and 1b are answered by means of a structured literature review. The goal of the first research question is to reveal any company-specific components or definitions within the calculation and/ or measurements of the OEE-scores which need to be considered in the analysis of these scores.

Question 2 (Chapter 3)**:** *"How should the new production norms of the filling lines 709, 710 and 711 be determined?"*

In order to be able to analyze the performance of the filling lines, this performance should be compared to a correct benchmark. Therefore, the OEE scores have to be readjusted to fit reality. For this study, this means that the workloads included in the performance score of OEE have to be adjusted. Therefore, these need to be adequately and objectively determined. However, question 2 is focused on identifying production norms. These two concepts are related. By means of the workloads, the production norms can easily be determined by means of the formula shown in *Equation 5*. The production norms are included within this study as one of its goals is to create a uniform use of these norms to hereby aid the communication between the different departments. Of course, the performance-score within OEE could also serve as a uniform communication measure, however this is not common practice as production norms are more visual and useful for departments not occupied with improving performance. Research question 2 focusses on finding a method to determine the new production norms. The use of the method is then illustrated. Questions 2a, 2b, and 2c focus on determining the new workloads, through which the production norms will be determined (Question 2). In order to determine the new, adequate, workloads of the filling lines 709-711, the following sub-questions need to be answered:

- Question 2a (Section 3.1): "*What should the new workloads exactly entail?*"

It is important to determine exactly what the new workloads should entail. In order to answer this question, an interview is held with the unit manager, who can be identified as the problem owner. In this interview the level of aspiration within the workloads is discussed.

- Question 2b (Section 3.2): "*How can we determine the new workloads?*"

This question is answered using the answer to question 2a. Based on this answer the data within MES that is appropriate to use in further analysis is identified. The actual method of identifying new workloads based on this data will be decided upon by consulting with the data-analyst who has performed a similar study for the mixing department. Before deciding on the final method to choose, the method will be explained to and discussed with the unit manager. As problem owner, it is important that the method, and accompanying results are in line with his expectations.

- Question 2c (Section 3.3): "*What are the new workloads for the filling-lines 709,710, and 711?*"

This question is answered by using the method identified under question 2b.

Question 3 (Chapter 4)**:** "*How do the filling lines 709, 710, and 711 perform?*"

- Question 3a (Section 4.1): "*What are the biggest losses in the performance category?*"
- Question 3b (Section 4.2): "*What are potential causes for these losses?*"

Question 3a is answered by means of analyzing the performance of the filling lines. By focusing on the performance category within OEE, the largest losses are identified. It should be noted that the analysis is performed with the new workloads in place. This means that past performance is readjusted based on these new workloads. In order to answer questions 3b, a literature study is performed to identify potential causes of the losses identified in question 3a. In addition to this literature study, the filling lines are observed. By doing so, the potential causes identified within the literature are compared to the "real-world" situation. The identified losses and causes for these losses are readjusted based on these observations.

When the potential causes of the losses experienced within the performance category of OEE have been identified (question 3a), and the magnitude of these losses are in line with reality as a consequence of implementing, and comparing to, the new workloads (question 2c), it is time to focus on the main research question (Chapter 5):

"*How can Euroma improve the performance of the filling lines 709, 710, and 711*?"

The losses, and their causes, as identified by questions 3a, and 3b respectively are the subject of study within this question. In searching for ways to minimize these losses, interviews are conducted with operators, and technical service personnel to identify practical solutions. In addition, the literature is studied to identify other possible approaches. The study is naturally focused on solutions which are feasible given the specific way in which Euroma measures its performance and conducts its production. In answering the main research question potential solutions are distinguished after which they are compared, and an advice is formed on which steps Euroma is to undertake.

The main deliverable of this study consists of an advice on how to improve the performance of the filling lines 709, 710, and 711. The production norms are included in the report to aid the communication on the performance of the filling lines between the different departments of the company. The report itself is also a deliverable as it will not only fulfill the function of explaining the methods used, and research conducted, for educational purposes. The report will also be sent to the company so that the method of determining adequate workloads, and analyzing the performance of the filling lines in relation to these new workloads, can be extended to the filling lines outside of the scope of this study. The report can therefore be used as a tool. This will be considered in writing the report, which means that the steps taken to identify the workloads, and conducting the analysis in relation to these workloads, will be explained and explicitly listed.

Chapter 2 focusses on the first research question. It therefore compares the way in which Euroma measures OEE to common methods of measurement. Chapter 3 investigates and determines adequate workloads, and production norms. The research questions considered within this chapter are questions 2, 2a, 2b, and 2c. Chapter 4 concerns the third research question. This means that it elaborates on the current performance of the filling lines (research question 3), divines the biggest loses within the performance category (research question 3a), and finds potential causes of these losses (research question 3b). Chapter 5 revolves around the main research question. It is thus concerned with identifying in which way Euroma can improve the performance of the filling lines 709, 710, and 711. In doing so, potential solutions are drafted and compared. Chapter 6 holds the conclusion, and recommendations. In addition, it contains the discussion in which the reliability, validity, shortcomings, and interesting additional findings are discussed. Both Chapter 2 (Section 2.1), and Chapter 4 (Section 4.2) contain a literature study. These chapters start by considering the literature, after which they shift toward the case study (Euroma). Including a separate chapter for all literature studies is a more common approach. However, the choice to incorporate the literature within the main text of the report itself was made as it provides for a more logical setup. Within Chapters 2, and 4, the literature serves to set a frame of reference. A similar approach is used in the introduction of the report (Chapter 1). Separating the literature from the main body would only degrade the understandability of the report.

Chapter 2: Euroma's OEE measure

This chapter addresses the first research question. It therefore compares the way in which Euroma measures OEE to standard methods proposed in the literature. In Section 2.1, the central concept of OEE is discussed. In addition, several methods of measurement are considered. Section 2.2 dives deeper into the performance losses which can be measured and identified by means of OEE, and Section 2.3 describes how OEE is implemented at Euroma. In Section 2.4, the way in which Euroma measures OEE is compared to the methods identified by the literature and the main research question is answered.

2.1: OEE and productivity losses

This section is focused on the following research question:

"How can OEE be used to measure productivity losses?".

The Overall Equipment Effectiveness metric (OEE) has originally been developed to measure equipment performance and reveal productivity losses. Since its birth, it has become a well-known measure within the production industry and an important driver upon which organizations set and formulate improvement projects. However, there are several ways in which OEE can be measured and implemented. Within this study, three commonly used systems are presented and compared. These include the original Nakajima-method, and two other standardized measurement systems. The standardized methods considered are the methods as defined by the French organization AFNOR, and the International Organization for Standardization (ISO). Throughout these different methods, the fundamental calculation of OEE does not deviate (*Equation 6*). The difference lies within the losses that are included within the different categories of OEE. In order to create a thorough understanding of the concept of OEE, this study will give a brief introduction before the original definition and method, as presented by Nakajima, is explained. Thereafter, the other methods are shown and compared.

OEE is a metric that measures losses of crucial parts in a manufacturing process. To be more precise, it measures losses in terms of a process's availability rate (A), performance rate (P), and quality rate (Q) (Ngadiman, Hussin, & Izaidin, 2013). The score within each of these three categories is expressed as percentage, where the overall OEE score is merely the product of the three (*Equation 6*). This automatically means that an OEE score is within the [0,100]% range.

$$OEE = A * P * Q$$

Equation 6: Fundamental OEE calculation

All of a product line's, or equipment's productivity losses ought to be captured in one of the three categories. As such, OEE can be seen as a measure that captures the total productivity and serves as an indication of the total production time that has truly been productive. A 100% score indicates perfect production where machines produce perfect products as fast as possible all the time. OEE can be implemented within different levels. It can map the performance of a manufacturing plant in general, of a specific manufacturing line, and even of individual machines. The intended use of OEE is twofold. First of all, it can be seen as a benchmark that can be used to compare the productivity of different companies within the same sector. Additionally, it can be used internally to track performance as its development in time serves as an indication of the success of a company in eliminating waste in its production. As founder of the concept of OEE, Nakajima identified optimal OEE figures. He argued that under ideal circumstances organizations should score at least 90% on availability, 95% on performance, and 99% on quality. This results in what is known as the "World-class" OEE score, which is set at 85%. Within the literature, there is a constant debate as to how realistic these figures are. There are several opinions when it comes to an "acceptable" OEE performance, with various studies arguing that an ideal score ranges between 60-75% (Dal, Tugwell, & Greatbanks, 2000). Since there is no consensus in terms of a "benchmark" OEE due to varying norms is industries, it is difficult to establish a solid frame of reference. However, this does not take away from the fact that an organization can establish its own target scores and use the metric to track performance. The next paragraphs discuss three commonly used methods of measuring OEE.

Method 1: *Nakajima*
In 1988, Nakajima launched a total productive maintenance concept (TPM) to offer a quantitative metric for measuring productivity of individual equipment within a manufacturing plant. This quantitative metric is known as OEE (Overall Equipment Effectiveness). According to the original definition of Nakajima, OEE is a bottom-up approach through which a workforce strives to eliminate six big losses (Dal, Tugwell, & Greatbanks, 2000). These losses are listed and explained in *Table 2*. It should be noted that most OEE measurement methods incorporate these losses, be it in different terminology.

Loss	Definition
1: Equipment failure/ breakdown	Time losses caused by defective machinery
2: Set-up/ adjustment	Time losses resulting from downtime and defective products as a result of equipment adjustments made in shifting production towards another item
3: Idling and minor stoppages	Time losses incurred due to a machine temporarily stopping or idling
4: Reduced speed	The time loss incurred by the difference between equipment design speed and actual operating speed.
5: Reduced yield	Time losses incurred from the machine startup to stabilization phase
6: Quality defects and rework	Quantity losses in output based on products not adhering to quality standards as a consequence of malfunctioning production equipment.

Table 2: The Six big losses (Nakajima)

The measurement system as proposed by Nakajima starts by identifying the loading time. This is done by excluding planned downtime such as scheduled maintenance and non-production time from the total amount of time available (TotalPossibleTime). These "planned" losses are therefore excluded in the OEE calculation. The operating time is then computed by deducting the unplanned downtime losses from the loading time. The theoretical cycle time captures the amount of time it ideally takes to produce one unit of output. Traditionally this time is based on the NPCs of the machines used. By multiplying the theoretical cycle time by the processed amount, and comparing this to the operating time, the performance score is calculated. The quality score is determined by comparing the processed products that adhere to quality standards to the total processed amount. OEE is therefore calculated by means of the formula depicted in *Equation 7*, and is expressed in terms of time and quantity. *Figure 3* is a visual representation of the OEE measure according to Nakajima.

$$OEE = \frac{OperatingTime}{LoadingTime} * \frac{TheoreticalCycleTime * ProcessedAmount}{OperatingTime} * \frac{ProcessedAmount - DefectAmount}{ProcessedAmount}$$

Equation 7: OEE calculation Nakajima

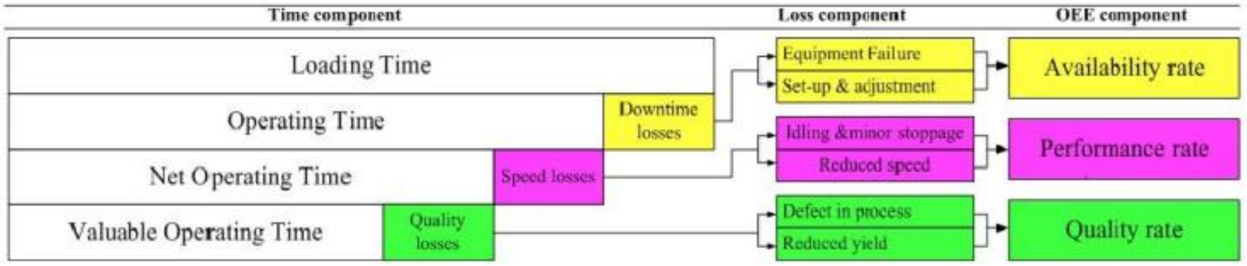


Figure 3: OEE components Nakajima (Mohammadi, Rai, & Gupta, 2019)

Method 2: *ISO*

ISO (International Organization for Standardization) develops and publishes international standards. The ISO22400 standard was published in 2014. Within this standard, several key performance indicators are defined. The standard imposes two definition of OEE. Within this study, OEE_A is considered. OEE_A is seen as the "normative" indicator *(Varisco & Schiraldi, 2020)*. The formula used to calculate OEE based on the ISO standard is depicted in *Equation 8*. Note that the ISO method expresses OEE in terms of time and quantity.

$$OEE = \frac{ActualProductionTime}{PlannedBusyTime} * \frac{PlannedRunTimePerItem * ProducedQuantity}{ActualProductionTime} * \frac{GoodQuantity}{ProducedQuantity}$$

Equation 8: OEE calculation ISO

Table 3 provides the concepts that are used, or required to understand the terms that are used, in *Equation 8*.

Concept	Definition	Formula
ReferenceTime	The time period considered e.g., a day, week, or month	
PlannedTime	The theoretical total amount of time available within the ReferenceTime. In one week, the PlannedTime would equal 168 hours.	
NoProduction	Planned unavailable time (planned no-production periods & planned downtime).	
PlannedBusyTime	Total time during which a machine should have been available for production	PlannedTime - NoProduction
Actual unit downtime	Time during which a material needed for production is not available + time during which the machine is idling	
Actual unit delay time	Time losses associated with malfunctions, minor stoppages, and other unplanned stops	
Actual unit setup time	Time needed in preparation of an order	
ActualProductionTime	Time during which the machine has produced	ActualProductionTime = PlannedBusyTime – (Actual unit downtime + Actual unit delay time + Actual unit setup time)
PlannedRunTimePerItem	The planned time for producing one quantity unit (also known as cycle time)	
GoodQuantity	The produced quantity that lives up to quality standards	
ProducedQuantity	The total quantity produced during the ActualProductionTime	

Table 3: OEE definitions ISO

Method 3: *AFNOR*

AFNOR is a French association that aims to lead and coordinate the standards development process and promote the application of those standards (AFNOR, 2020). According to their OEE standard, OEE should be calculated by means of the formula depicted in *Equation 9*. Note that this calculation is solely time-based.

$$OEE = \frac{OperatingTime}{RequiredTime} * \frac{NetTime}{OperatingTime} * \frac{EffectiveTime}{NetTime}$$

Equation 9: OEE calculation AFNOR

Table 4 provides the concepts that are used, or required to understand the terms that are used, in *Equation 9*.

Concept	**Definition**	**Formula**
ReferenceTime	The time period considered	
CalendarTime	The theoretical total amount of time available during the time period considered. In one week, the CalendarTime would equal 168 hours.	
PlannedDownTime	Planned unavailable time such as maintenance, meetings, and unworked shifts.	
RequiredTime	Total time during which a machine should have been available for production	CalendarTime - PlannedDownTime
Equipment losses	Time lost due to equipment breakdown	
Environment losses	Time lost because of inadequate or missing (production) materials necessary for production	
OperatingTime	Time during which a machine has produced	RequiredTime – (Equipment losses + environment losses)
PerformanceLosses	Time losses caused by reduced speeds and idling	
NetTime	Time production should have taken when there would have been no performance losses	OperatingTime - PerformanceLosses
QualityLosses	Time losses caused by products not adhering to quality standards	
Effective Time	Time it should have taken to produce the amount of qualitatively sound products produced during the NetTime	NetTime - QualityLosses

Table 4: OEE definitions AFNOR

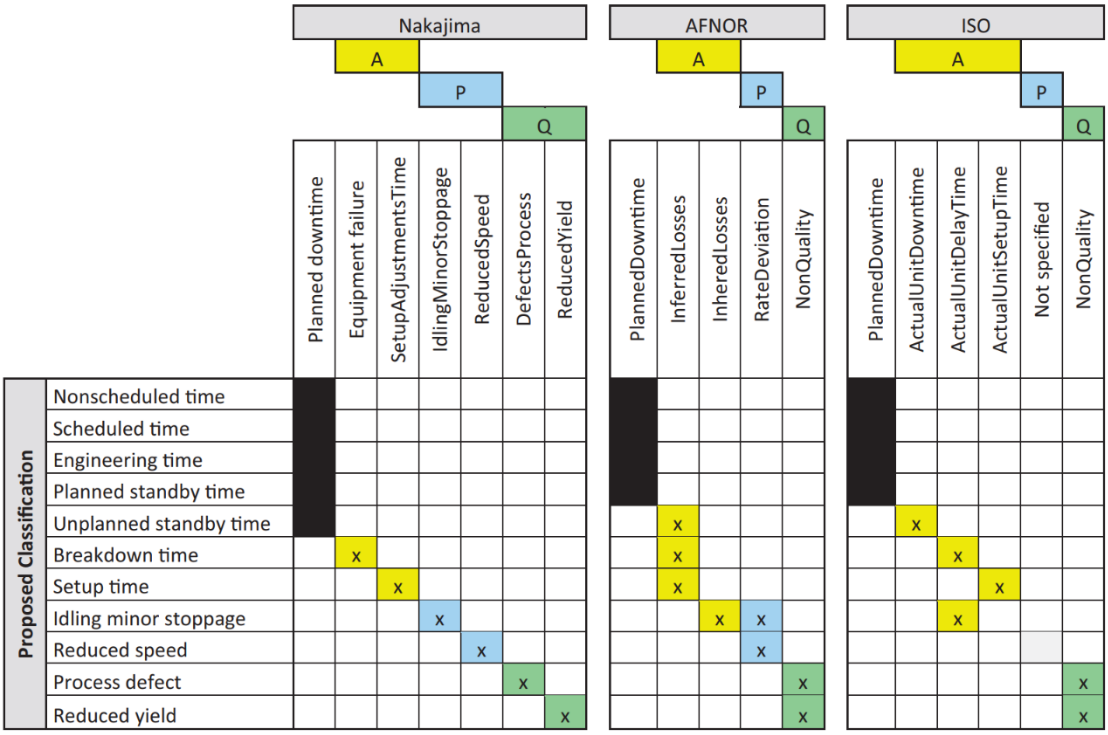
Comparing the three methods
The three methods are compared in line with a comparative study found in the literature (Kechaou, Addouche, & Zolghadri, 2022). This article reflects on four OEE measurement systems. In addition to the three systems mentioned within this study, it reflects on the method proposed by SEMI. SEMI stands for Semiconductor Equipment and Material International. It is an industrial organization which publishes standards for the semiconductor industry. These standards are therefore industry specific. Within this study, a metric specified on the semiconductor industry is irrelevant, which is why the choice has been made to exclude the OEE measure as presented by SEMI.

In comparing the Nakajima, ISO, and AFNOR-method, we see that all three methods make use of the central concept of OEE. That is, OEE is the product of the availability, performance, and quality scores. The difference lies in what is included in each of the three categories. However, directly comparing the three methods is difficult as they make use of different concepts within their calculation of OEE. We therefore have to find a way in which this semantical barrier is overcome. This problem is solved by introducing eleven encompassing loss families, which are listed in *Table 5*.

Class	Definition
1: Non-scheduled time	Time during which no production is scheduled (weekends, holidays,
2: Scheduled downtime	Time during which equipment cannot be used due to planned shutdowns (maintenance)
3: Engineering time	Equipment is used for experimentation
4: Planned standby time	Equipment is ready for use, but is not used due to planned downtime (breaks, tests, meetings)
5: Unplanned standby time	The equipment is available for use, but is not used due to unplanned environmental issues (wrong production material, lack of operators)
6: Breakdown time	Time during which equipment is broken
7: Setup and adjustment time	Time during which equipment is set up and adjusted (between different orders)
8: Idling and minor stoppages	The equipment is temperately unusable because of a malfunction or idling.
9: Reduced speed	Time lost due to equipment running at a lower than optimal speed
10: Defect losses	Quantity of products not adhering to quality standards in addition to time losses on rework
11: Reduced yield	Losses incurred due to equipment having to start-up

Table 5: The 11 loss families (Kechaou, Addouche, & Zolghadri, 2022)

Loss classes 1-5 are concerned with the environmental effectiveness losses of production, whereas classes 6-11 concern the equipment effectiveness losses itself. Now that the loss families are identified, they can be compared to the concepts used within the Nakajima, ISO, and AFNOR-method. The results are shown in *Figure 4*. This figure relates the eleven losses to the concepts used in the three methods considered. In doing so, each loss is assigned to the availability, performance, or quality category of OEE dependent on the method used.



	Nakajima							AFNOR					ISO					
		A		P		Q			A		P	Q		A			P	Q
Proposed Classification	Planned downtime	Equipment failure	SetupAdjustmentsTime	IdlingMinorStoppage	ReducedSpeed	DefectsProcess	ReducedYield	PlannedDowntime	InferredLosses	InheredLosses	RateDeviation	NonQuality	PlannedDowntime	ActualUnitDowntime	ActualUnitDelayTime	ActualUnitSetupTime	Not specified	NonQuality
Nonscheduled time	■							■					■					
Scheduled time	■							■					■					
Engineering time	■							■					■					
Planned standby time	■							■					■					
Unplanned standby time	■								x					x				
Breakdown time		x							x						x			
Setup time			x						x							x		
Idling minor stoppage				x						x	x				x			
Reduced speed					x						x							
Process defect						x						x						x
Reduced yield							x					x						x

Figure 4: Comparing concepts (Kechaou, Addouche, & Zolghadri, 2022)

Looking at the figure, we see that all three methods exclude the first four loss classes within their OEE-calculation. However, difference arise when we consider what the different methods capture under each OEE-category. When we take a look at the availability category, we see that the AFNOR and ISO-method both include breakdown time, setup time, and unplanned standby time, whereas the Nakajima-method excludes unplanned standby time. The ISO and AFNOR-method are therefore not solely equipment oriented. They include environmental influences in the form of missing production materials, operators, or faulty input. More differences arise when the performance category is analyzed. According to Nakajima, the performance category captures Idling time, minor stoppages, and reduced speed. However, the ISO-method houses both minor stops and idling under the availability category. This leaves only the reduced speeds within the performance category (note that there is no concept within the ISO-method which directly captures this loss). The AFNOR-method positions itself right between the two methods by capturing reduced speeds, and idling in the performance category, but minor stoppages either in the availability or performance category. The decision to which category to allocate a minor stop is made based on the duration of the stop. According to the AFNOR-method each company should define a limit as to the duration of minor stoppages falling under the performance category (Kechaou, Addouche, & Zolghadri, 2022). This differs from the Nakajima method which only states that minor stops should be considered as stops that last a brief period. The quality scores of the three methods examined are identical. All three quality scores capture quality in terms of defect products and reduced yield. However, not all three measures capture quality in terms of quantity. The AFNOR-method expresses quality losses in terms of time.

Based on these differences, we conclude that the Nakajima method is merely focused on equipment whereas the AFNOR and ISO-method include environmental effectiveness losses. The Nakajima and ISO-method furthermore capture OEE in terms of quantity and time, whereas the AFNOR-method is solely time based. This is visualized in *Figure 5*. In addition, the methods differ in what they capture under the performance category. Out of the three methods, the Nakajima captures most aspects within the performance category, whereas the ISO-method, by shifting the idling losses and minor stoppages to the availability category, captures least aspects under the performance category.

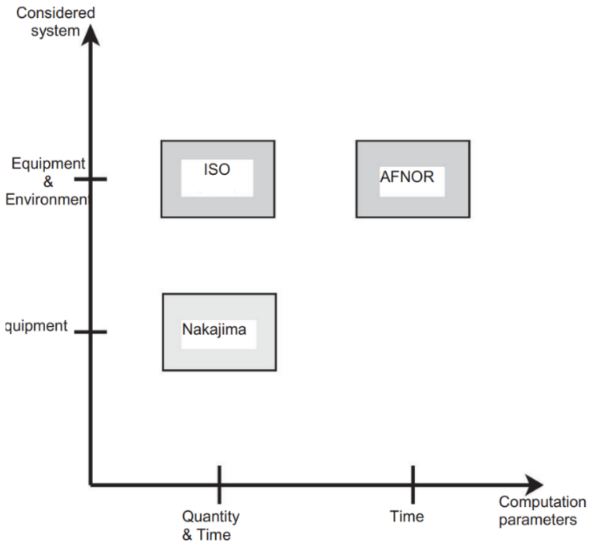


Figure 5: Computation parameters (Kechaou, Addouche, & Zolghadri, 2022)

2.2: OEE and performance losses

This section is focused on the following research question:

"How can OEE be used to measure performance losses?"

When we consider the overall concept of OEE, "performance losses" relate to the losses incurred in the performance category of OEE. Within the literature, these performance losses are sometimes referred to as "Speed losses" (Trubaciute, 2020). However, this study will adhere to the more unambiguous term of "Performance losses" to refer to the losses incurred in the performance category, and use the term "Speed losses" only when the performance losses related to reduced speeds are considered. In addition, the performance losses identified within this study are in line with the concept of OEE as identified by Nakajima as out of the three methods considered in Section 2.1, this method encompasses most losses under the performance category. According to Nakajima, there are two types of losses that ought to be captured under the performance score. These are reduced speeds, and idling & minor stoppages to be discussed hereafter.

Reduced speeds

Reduced speeds, or "Speed loss", is caused by the difference between the designed speed of a machine and its actual operating speed. A lot of manufacturers experience speed losses. According to the literature, reduced capacity from reduced production speeds is expected to be higher in larger automated production environments, with cases in which it is responsible for 9-15% loss of total available capacity (Trattner, Hvan, & Haug, 2020). However, speed losses are amongst the least examined of the six efficiency losses identified by Nakajima. How come? Most of the time, management is focused on the elimination of large production stops. The smaller continuous losses incurred by variations in production speed are therefore often overlooked. In addition, speed losses are often hard to identify, and a small loss is perceived as "allowable". However, even small losses become of large influence depending on the time period considered. The article: "Why slow down? Factors affecting speed loss in process manufacturing" (Trattner, Hvan, & Haug, 2020) identifies fifteen causes of speed losses and relates them to either of three categories: Human, Technology, or Product (see *Table 6*).

Category:	***Cause:***
Technology	Machine reliability & production stops
	Equipment age & wear
	Improper maintenance
	Technological & environmental limitations
	Queue capacity for work in progress
Human	Operator training & inefficiency
	Measurement error
	Production scheduling
	Ideal cycle time set too low
	Capacity utilization
Product	Material availability and quality
	Raw material mix
	Quality finished goods
	Product variety
	Natural process variations

Table 6: Speed losses (Trattner, Hvan, & Haug, 2020)

Within the calculation of OEE, speed loss is calculated by means of the ideal cycle time (see). The ideal cycle time represents the ideal time in which a process produces one unit of output. It is based on the designed speed of the machinery and does not encompass any losses. The ideal cycle time is best determined by either of two means, the first being a time study, the second a machine's NPC (Vorne Industries, sd). This means that we should either identify the ideal cycle time by performing field tests as to what speed the machinery can handle, or base it on the nameplate capacity. This nameplate capacity is the theoretical maximum speed as specified by the manufacturer of the equipment. We must consider that this is not always equal to the absolute theoretical maximum speed. Suppliers of equipment often provide their customers with a realistic number in order to meet expectations and cover deviations (Trubaciute, 2020). Therefore, the NPC might be slightly lower than the actual theoretical maximum speed. Note that the ideal cycle time should be used as a frame of reference and not for planning purposes. For planning purposes, the standard cycle time is more suited. The standard cycle time, "the expected time it takes to produce one unit of output considering the typical losses including planned stops, unplanned stops, small stops, slow cycles and defects", should always exceed the ideal cycle time. Otherwise, it would enable the performance score to exceed 100%.

Idling & minor stoppages

Idling and minor stoppages concern the situations in which equipment either runs without producing, or stops due to a temporary problem (Euromotor Virtual College, sd). We can think of a jam or faulty sensor read. The stoppages concern standstills which can easily be dealt with and do not require maintenance personnel. Often, there is little effort made in eliminating minor stoppages and idling. This mainly has to do with the fact that the causes are hard to identify, and management is usually unaware of the total amount of time that is lost due to minor stops and idling. But why are minor stoppages included in the performance score in the first place, should they not fall under the availability score? This is a valid question. Minor stops are mostly different in that they are stops not caused by a machine breakdown of small duration, and chronic of nature (Industry Forum, 2015). However, within the literature the time limit that is to distinguish between a minor stop and short down-time stoppages is not mentioned explicitly. According to (Ljungberg, 1998) "It depends on how short stoppages are that are registered by the operators. However, short stoppages are not necessary to note, it is appropriate to regard stoppages shorter than 5 or 10 minutes as minor stoppages."

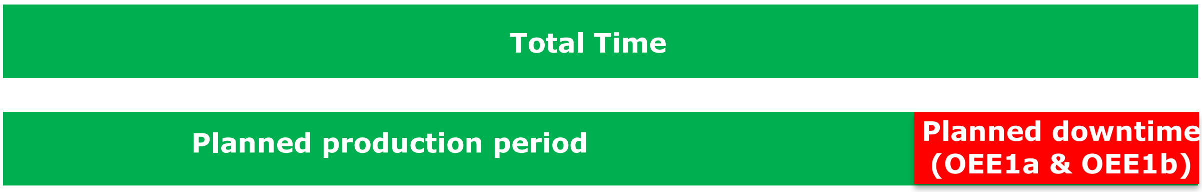
2.3: OEE at Euroma

This section is focused on the following research question:

"How is OEE implemented at Euroma?"

In measuring OEE, it is important to receive information about the status of the equipment considered. At Euroma, this "equipment data" is gathered by the MES system. This is a semi-automatic process. But what does this exactly mean? It means that a part of the information is gathered automatically, and that other information needs to be collected by the operators. All filling lines are equipped with screens. These screens provide the operators with information about the current, and future orders. This information is provided by the MES system. However, the screens are not only used to provide operators with information, but also enable the operator to collect and upload information. Before we dive deeper into the exact data that is gathered, we must first understand the build-up of an order.

Euroma defines planned production periods. These are the periods in which production is planned. This means that out of the total time available that is considered, planned downtime is excluded.



All activities that fall under planned downtime are registered under the class: "OEE1". The activities labeled under this class are excluded within the calculation of OEE and therefore do not influence the OEE scores. A distinction is made between "OEE1a" and "OEE1b". "OEE1a (GEEN PLANNING)" captures the time periods in which no orders are scheduled by the scheduling department, whereas "OEE1b (GEPLANDE STILSTANDEN)" is used for time periods in which the equipment cannot be utilized due to planned stoppage. All time that remains is considered as planned production period. Within this period, an order is processed and its OEE is measured. An order starts as soon as the operator presses the "Begin order" button on its screen. The status of the filling line now changes into "Setup". This period includes all activities that have to be performed before production can start. These activities are classed under "OEE2a (SETUPS)". As soon as these activities have been performed, the filling line can start producing products. The status of the filling line is now "Production". Once the order is done, the operator has to set the status of the filling line into "Reset". During this period, the order has to be closed. The reset period is also captured under "OEE2a (SETUPS)". After closing the order, the operator has to either begin a new order, or indicate that there are no new orders planned. This ends the time period used in the OEE computation of the (now produced) order.

The steps that are described in the previous paragraph are all manual. However, as soon as a filling line is in its "Production" state, the PLCs take over some of the work. Every filling line is equipped with its own set of PLCs, all of which are connected to the MES system. The lines have a PLC which registers whether there are products moved along the conveyer. If no products pass this point, the PLC transmits a signal to the MES system. The system now recognizes an "unplanned stop" and starts to register the duration of this stop. As soon as the equipment is back up, and the PLCs detect moving products, the timing of this unplanned stop is halted. The system registers the stop as 'Unknown'. It is up to the operator to select the correct reason of the unplanned stop via the screen. Unless all 'Unknown' stops are account for, the production line cannot be set to the "Reset" phase, and the production line therefore remains in the production state. All unplanned stops fall under "OEE2b (OPERATIONELE STILSTANDEN). However, it should be noted that the stops are only registered as unknown when they exceed a three minute time limit. All stops with a shorter duration fall under "OEE3b (MICROSTOPS)" which do not require an explanation by an operator. An overview of all possible explanations an operator can give for a standstill is provided in *Table 26* (Appendix A). It includes the reason, additional explanation, class, and category of OEE on which the standstill has an influence. As only unplanned standstills have an influence on the availability score of OEE, and all of these standstills, initially registered as 'UNKOWN' by the MES system, need an operator to define them, all factors influencing the availability score are included within *Table 26* (Appendix A). Once the availability losses have been accounted for, we are left with the available production period, also known as the operating time.

When we consider *Table 26*[1] (Appendix A), we see that there are no factors mentioned which influence the quality score, and only one factor which influences the performance score. How can this be the case? The answer can be found in the way in which the quality, and performance score are calculated.

The performance score is influenced by two variables: (OEE3b: "MICROSTOPS"), and (OEE3a: "Snelheidsverliezen"). Micro stops capture all unplanned stops with a duration shorter than three minutes. We can think of jams, faulty sensors, quick cleans, or material miss-feeds. In addition, the operator can also manually set disruptions to micro stops when the stop was not caused by equipment failure but took longer than three minutes. The speed losses (OEE3a) are computed by the MES system. This is done by multiplying the produced quantity (Total count) by the ideal cycle time to determine the required operating time and deduct this required operating time, and the micro stops form the actual operating time (See *Equation 10*, and *Equation 11* respectively).

$$Speedlosses = Operating\ time - Required\ operating\ time - Minor\ stoppages$$

Equation 10: Speed loss computation

$$Required\ operating\ time - Ideal\ cycle\ time * Total\ count$$

Equation 11: Required operating time computation

At Euroma, the ideal cycle time used in this calculation is dependent on the NPC of the dosing-machine. This machine marks the start of the filling line and doses the product to its required dosage. It is thought of as the machine with the lowest NPC and therefore the machine which determines the maximum pace of the entire line.

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[1] *Table 26* contains Dutch terminology as the information was directly loaded from the MES system which is set in this language.

Up and until this point, OEE is entirely time-based. This changes when we take a look at the quality score. The intended setup for the computation of this quality score is now discussed. Section 6.3 discusses deviations from this format.

Quality is calculated by comparing the "Goodcount" to the "Totalcount". MES gathers this information by means of the PLC: "Free weigh". This PLC counts and weighs every individual package which is moved along the conveyer belt. If the weight of the package does not fall between the upper and lower bound as defined by the operator, the machine will push the package off the conveyor. The PLC is linked to the MES system which keeps track of the total number of products produced in addition to the number of faulty products. In computing the quality score, the total amount of good products is compared to the total count. Products deviating from the norm on other aspect than weight, or batches that are discarded later in the process need to be manually "booked" in the MES System which then alters the Quality score accordingly. When all information provided in the previous paragraphs is combined, we can see that OEE is calculated by means of the formula depicted in *Equation 12*.

$$OEE = \frac{Operating\ time}{PlannedProduction\ period} * \frac{Ideal\ cycle\ time * Totalcount}{Operating\ time} * \frac{Goodcount}{Totalcount}$$

Equation 12: Euroma's OEE measure

2.4: Comparing methods

This section answers the first research question as defined in Section 1.4. It therefore answers the question around which chapter 2 evolves:

> *"How does the way in which Euroma measures OEE relate to commonly used methods of measuring OEE?"*

When we relate the eleven loss families (*Table 5*) to the way in which Euroma measures OEE, we see that the company does not include the first 4 loss classes as these fall under their OEE1. Classes 5,6, and 7 fall under the availability category (OEE2), classes 8, and 9 under the performance category (OEE3), and class 11 under Quality. Class 10 is not explicitly caught under either of the three categories but is represented in the computed speed losses. The way in which Euroma measures OEE is therefore most in line with the Nakajima-method. This is explained by considering the way in which OEE is expressed, and the scope that is considered. Euroma measures OEE in terms of quantity and time. This excludes the AFNOR-method. In addition, OEE is largely equipment oriented as any material or operator shortages are excluded within the calculation of OEE (OEE1a & OEE1b). The only environmental factor which is of influence is the "unplanned break" (OEE2b). When we consider the performance category, we can furthermore see that idle times and minor losses are included in this category. This excludes the ISO-method which captures both losses under the availability category. However, it is interesting to see that Euroma does set a limit to the minor stoppage duration which is to be captured under the performance score. The limit, which is set at three minutes, determines whether the system registers the stop as a minor stop, or as an 'UNKNOWN' breakdown. The fact that an operator can always adjust an 'UNKNOWN' breakdown to a minor stop is a sign that the criteria upon which the company decides whether a stop qualifies as a minor stop is to be found in the reason of the stop, not solely the duration. Whenever the stop is not caused by a machine breakdown, it is ought to be captured under the performance category.

Chapter 3: The new production norms

This chapter focusses on the second research question. It is therefore concerned with identifying new production norms that are to be calculated by means of new workloads. In this process, the study shows and elaborates on the method that is used. In Section 3.1, we investigate the meaning and level of aspiration that ought to be captured in the new workloads. Section 3.2 discusses the method that is used to identify new workloads in Section 3.3. The accompanying production norms are determined in Section 3.4.

3.1: Definition of a workload

This section is focused on the following research question:

"What should the new workloads exactly entail?"

A workload should capture the time it ideally takes to produce one unit of output. However, this workload ought to be an achievable target. Within a production line, this means that it should take the different processing times of the machines placed in series into account. Hereby, it becomes a measure of what is technically feasible given the machines used in production. As these machines differ across the filling lines considered, a workload is to be determined for each filling line.

3.2: Method

This section is focused on the following research question:

"How can we determine the new workloads?"

A workload, or ideal cycle time, captures the amount of time it ideally takes to produce one unit of output. This time is influenced by the capacity of the equipment used in production. As the machines of the 709, 710, and 711 differ, it is possible that the workload of these lines is not identical. Therefore, a workload ought to be determined for each individual line. Within this study, the technical specifications of the machines used are examined for each production line. In addition, an analysis on the achieved production speeds is performed to identify the real-life performance of the filling lines. The outcome of this analysis, together with the technical specifications are considered in determining the new workloads. The technical specifications are used as a frame of reference and form the basis for the new workloads, the analysis of the achieved production speeds is used to validate, and compare the specifications to real-life performance.

3.3: Workloads

Section 3.3 is divided into Sections 3.3.1, 3.3.2, and 3.3.3. These discuss the current performance of the filling lines, the technical maximal capacity of these filling lines, and a relation between these two, respectively. The central question within Section 3 is the following:

"What are the new workloads for the filling-lines 709,710, and 711?"

3.3.1: current performance of the filling lines

First, we analyze the current performance of the 709, 710, and 711. By identifying workloads, we are in search of ideal cycle times. Therefore, the achieved cycle times are of interest within the analysis. However, MES does not register cycle times during the production process of an order. Therefore, we need to approach the analysis by means of a registered, or calculable attribute related to the cycle time. Cycle time is the reciprocal of production speed (see *Equation 13*). The production speed can be calculated based on the information gathered in the process of producing an order. The analysis is therefore focused on the achieved production speeds. The next paragraphs describe the method used to calculate the production speeds of the orders that have been processed by the filling lines 709,710, and 711. In addition, the process of outlier detection and elimination is described. The performance of the filling lines is evaluated thereafter. However, prior to indulging on the analysis, the reader is provided with a short summary and recap of the most important concepts.

$$CycleTime = \frac{1}{Production\ speed}$$

Equation 13: Cycle time calculation

Within this section we determine the new workloads. Given the definition of a workload as provided in Section 3.1, these workloads embody the time it ideally takes to produce one unit of output given the technical capabilities of the machines used within the production process. Within this study, the definition of a workload is the same as that of the "ideal cycle time". The concepts may therefore be used interchangeably. Currently, the workloads of the 709, 710, and 711 are set at 0.005. This corresponds to an "ideal production speed" of 200 fills/min, and a production norm of 96000 fills. The evaluation provided within the next paragraphs sheds light on the representativeness of these numbers. For this evaluation, it is important to consider the following:

- Machines considered: 709, 710, and 711
- Time period of data collection: January 2020 – May 2022
- Orders considered: OEE ≠ 0%

The OEE data of the orders produced on the machines 709,710, and 711 was exported from the MES system. In doing so, the time period considered was stretched to a maximum. It turned out that the earliest data dates back to November 2019. This correlates with the time period in which the production facility became operational. The data used in this study captures the time period of November 2019 – May 2022. However, the MES system does not directly provide an order OEE. Instead, the system registers OEE for every shift in which the order has been produced. If an order is finished or started during a shift, this does trigger a new read. For every shift, the MES system stores information on the time spent in the states (OEE1a-OEE3b). The order OEE can be calculated by aggregating these times across the different shifts and applying the formula depicted in *Equation 14*.

$$OEE = \frac{Operating\ time}{PlannedProduction\ period} * \frac{Ideal\ cycle\ time * Totalcount}{Operating\ time} * \frac{Goodcount}{Totalcount}$$

Equation 14: Euroma's OEE measure

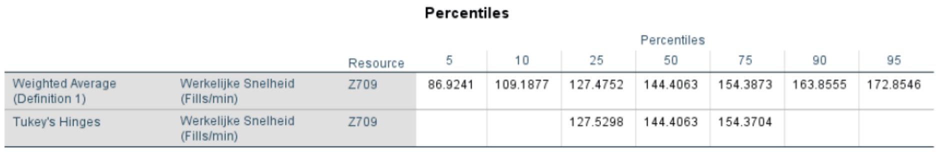
The orders produced in 2019 are excluded in the analysis as these hold extremely low performance, and thus, OEE scores. This was caused by the incorrect setting of the workloads within the system set-up. The workloads ought to be based on an ideal production speed of 200 fills/min. Instead, they were based on an ideal production speed of 200 fills/ sec. This error was fixed in the end of December. Furthermore, orders with an OEE of 0% were excluded. When an OEE score of 0% is realized, this means that no production has taken place at all. This indicates that the system should not have been in the "production state" to begin with. These inputs therefore embody miscommunications and/or faulty inputs of operators and other personnel and ought to be excluded within the analysis. Information on the products produced during the order (weight, format, and filling type) was added to the order information by loading, and linking information from an Excel file to the dataset based on the article number of the product produced in the accompanying order. The data on the total amount of products produced during each order was extracted from Infor LN via PowerBI, and has been linked to the orders by means of their order IDs. It should be noted that the number of products produced is measured in the stock keeping unit of the product. Therefore, prior to analyzing this number, the total number of produced products has been expressed in terms of fills. A fill is one "bag" of herbs, a universal measuring unit across all orders. In computing the production speed, we make use of *Equation 15*. The Operating time, and Minor stops are measured in minutes.

$$Speed = \frac{Total\ number\ of\ fills\ produced}{Operating\ time - Minor\ stops}$$

Equation 15: Production speed calculation

By considering the total number of fills (including faulty products), losses caused by producing unsound, discarded, products are excluded in the calculation. This means that the proportion of faulty products does not influence the performance score as these are counted as "normal", produced units. The speed is expressed in a number of fills/min. This is equal to the way in which the speed of the machine is to be set by the operator.

Prior to analyzing the performance of the filling lines in terms of their production speed, we must eliminate potential outliers from the dataset. For this purpose, the data on production speed was loaded into SPSS. For each of the three machines, the data was analyzed. To give an indication of the spread, and absolute values of the achieved production speeds, the achieved production speeds of the 709, 710, and 711 are mapped in a boxplot. In addition, the percentiles are considered. The result are shown in *Figure 6*, *Figure 7*, and *Figure 8* respectively.



Percentiles

			Percentiles						
		Resource	5	10	25	50	75	90	95
Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z709	86.9241	109.1877	127.4752	144.4063	154.3873	163.8555	172.8546
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z709			127.5298	144.4063	154.3704		

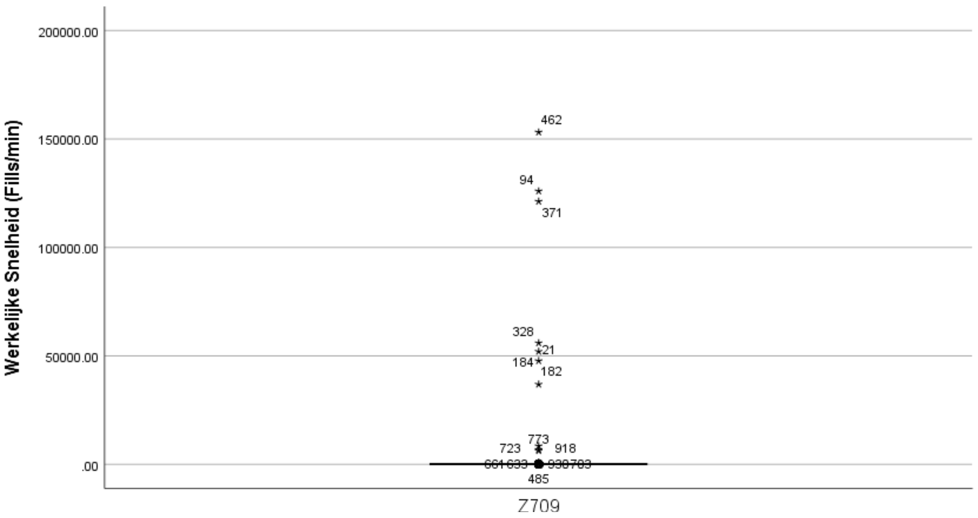
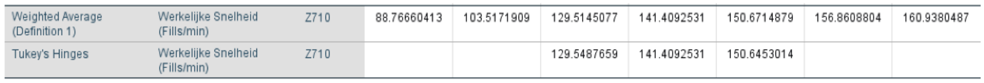


Figure 6: Outlier detection 709



Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z710	88.76660413	103.5171909	129.5145077	141.4092531	150.6714879	156.8608804	160.9380487
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z710			129.5487659	141.4092531	150.6453014		

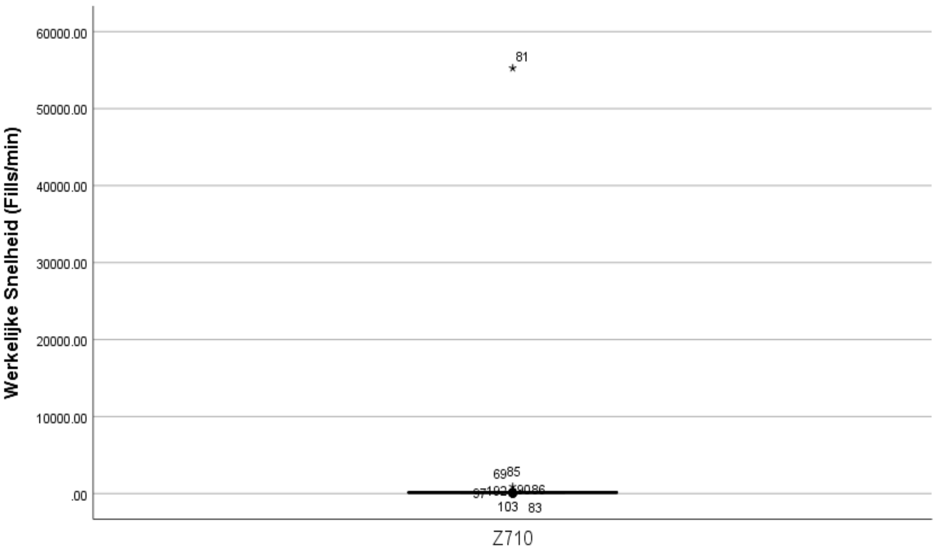
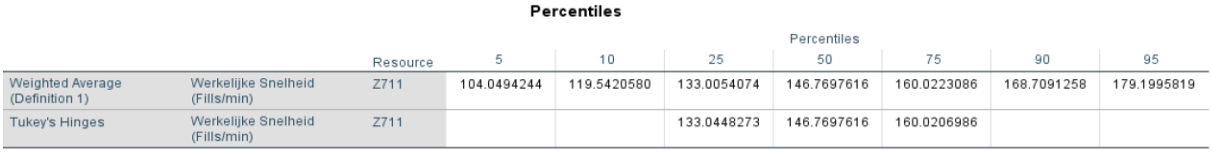


Figure 7: Outlier detection 710



Percentiles

		Resource	Percentiles 5	10	25	50	75	90	95
Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z711	104.0494244	119.5420580	133.0054074	146.7697616	160.0223086	168.7091258	179.1995819
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z711			133.0448273	146.7697616	160.0206986		

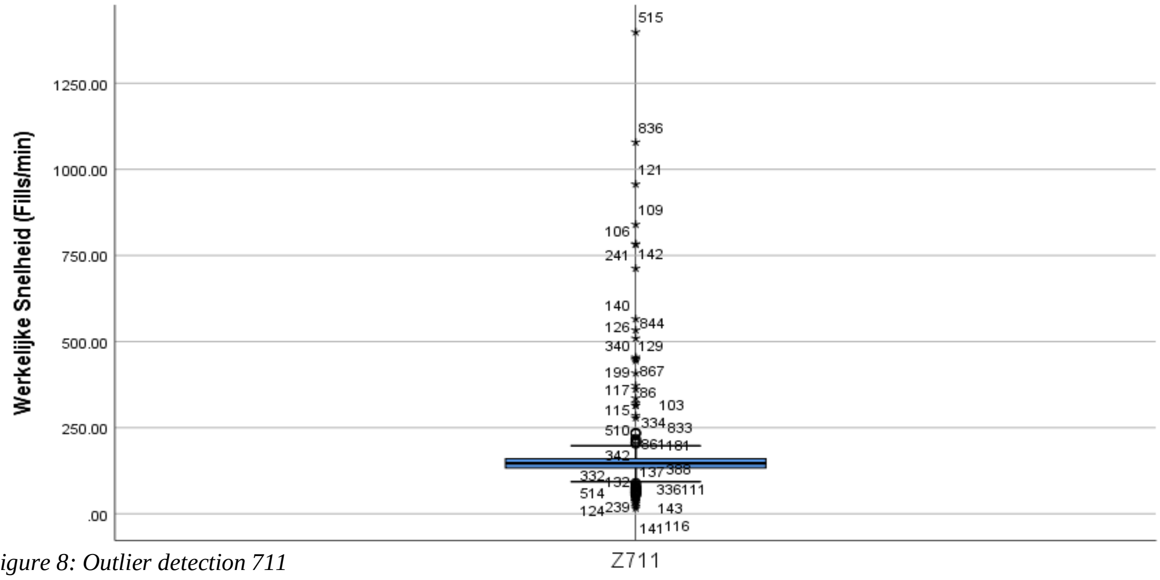


Figure 8: Outlier detection 711

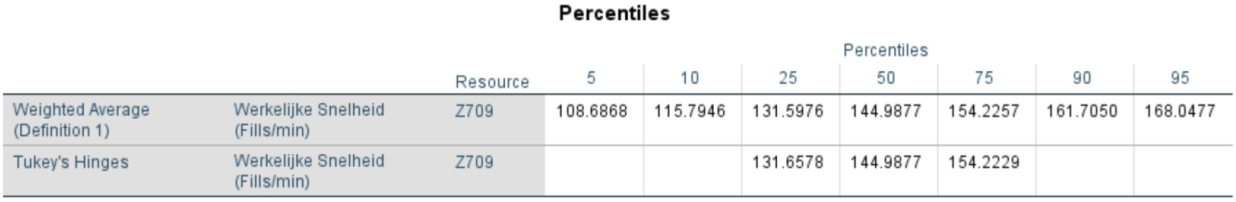
Figure 6, *Figure 7*, and *Figure 8* do not give an accurate indication of the achieved production speeds as the figures are to stretched. This is caused by the presence of the outliers within the graphs, which are shown as little stars (*). The accompanying number indicates the order which this star represents. To provide better insight into the spread of the production speeds, these need to be re-evaluated while excluding the outliers. In order to delete the outliers from the dataset, we need upper- and lower bounds. These incorporate the values as of which we assume the input to be an "outlier". The upper- and lower bound have been identified by the 1.5 x IQR-rule. This means that the lower bound is set at: (25th percentile -1.5 x IQR), and the upper bound at: (75th percentile + 1.5 x IQR). The IQR "Inter quartile range" captures the central 50% of the observations. It is calculated by deducting the 25th percentile from the 75th percentile. This 1.5 x IQR-rule rule was used to delete outliers from the dataset. Within the evaluation of the production speeds of the filling lines 709, 710, and 711 (*Figure 9*, *Figure 10*, and *Figure 11*), and further analysis these outliers are excluded. This means that only measurements within the range identified in

Table 7 were considered (LowerBound-Upperbound). The percentiles used within the outlier detection are based on the "Weighted Average (Definition 1)" method (see *Figure 6*, *Figure 7*, and *Figure 8)*. The other method of determining the percentiles is a standard output of SPSS. This Turkey's Hinges method does however not yield an advantage over the weighted average in this particular situation. In addition, it is less commonly used. Therefore, this study builds on the "Weighted average" method.

	709		710		711
25%	127.475	25%	129.514	25%	133.005
50%	144.406	50%	141.409	50%	146.77
75%	154.387	75%	150.671	75%	160.023
IQR	26.912	IQR	21.157	IQR	27.018
UpperBound	194.755	UpperBound	182.4065	UpperBound	200.55
LowerBound	87.107	LowerBound	97.7785	LowerBound	92.478

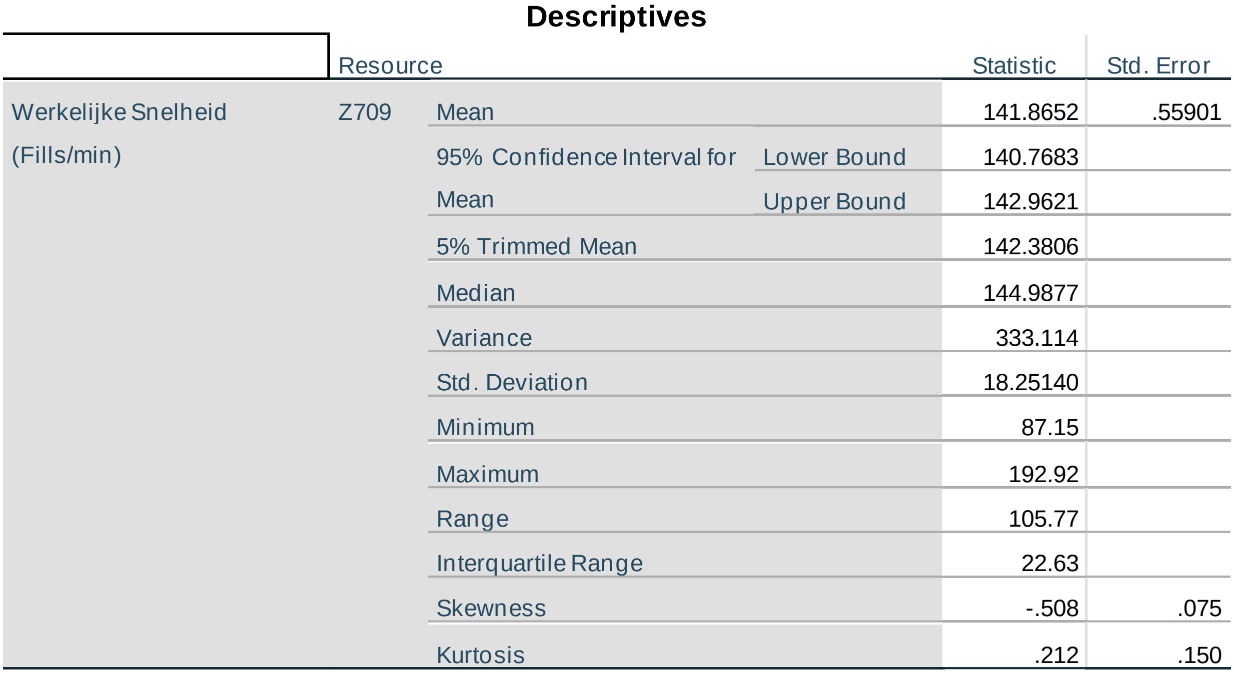
Table 7: Range and outliers

709:



Percentiles

		Resource	Percentiles 5	10	25	50	75	90	95
Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z709	108.6868	115.7946	131.5976	144.9877	154.2257	161.7050	168.0477
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z709			131.6578	144.9877	154.2229		



Descriptives

	Resource			Statistic	Std. Error
Werkelijke Snelheid (Fills/min)	Z709	Mean		141.8652	.55901
		95% Confidence Interval for Mean	Lower Bound	140.7683	
			Upper Bound	142.9621	
		5% Trimmed Mean		142.3806	
		Median		144.9877	
		Variance		333.114	
		Std. Deviation		18.25140	
		Minimum		87.15	
		Maximum		192.92	
		Range		105.77	
		Interquartile Range		22.63	
		Skewness		-.508	.075
		Kurtosis		.212	.150

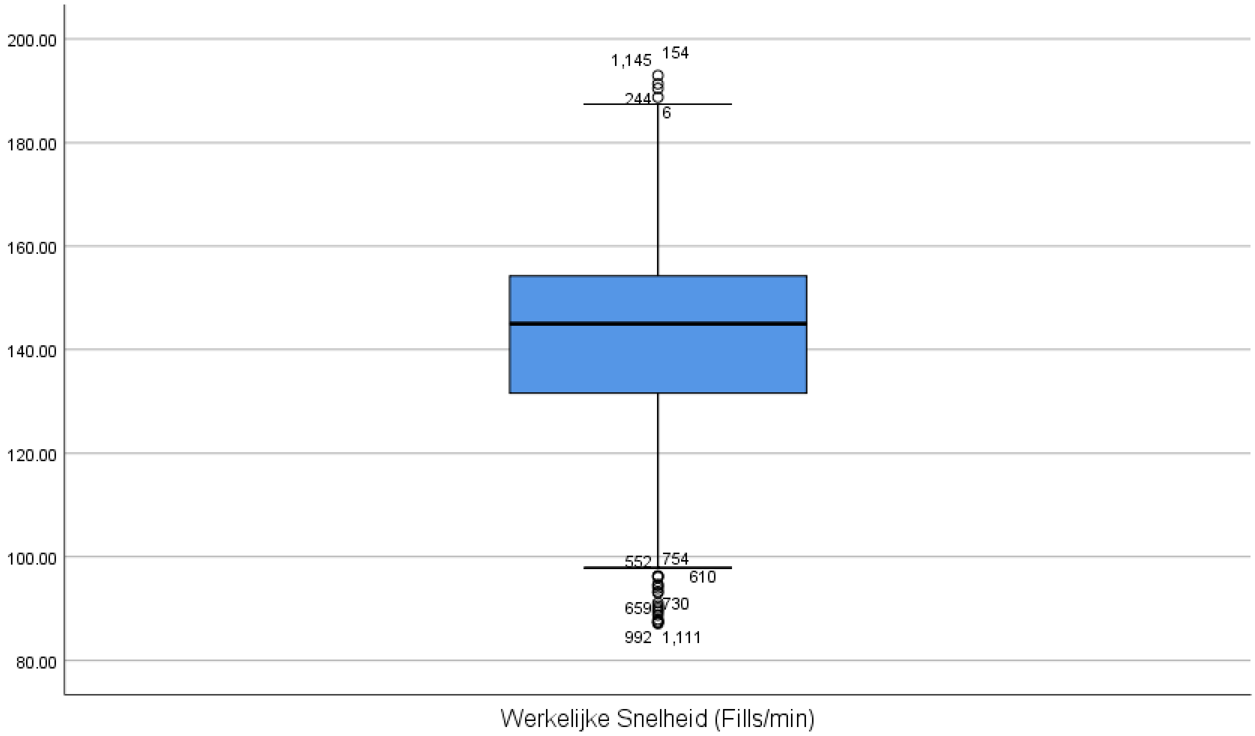
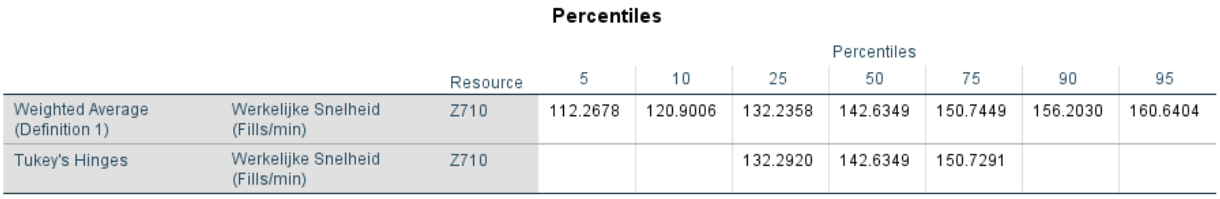


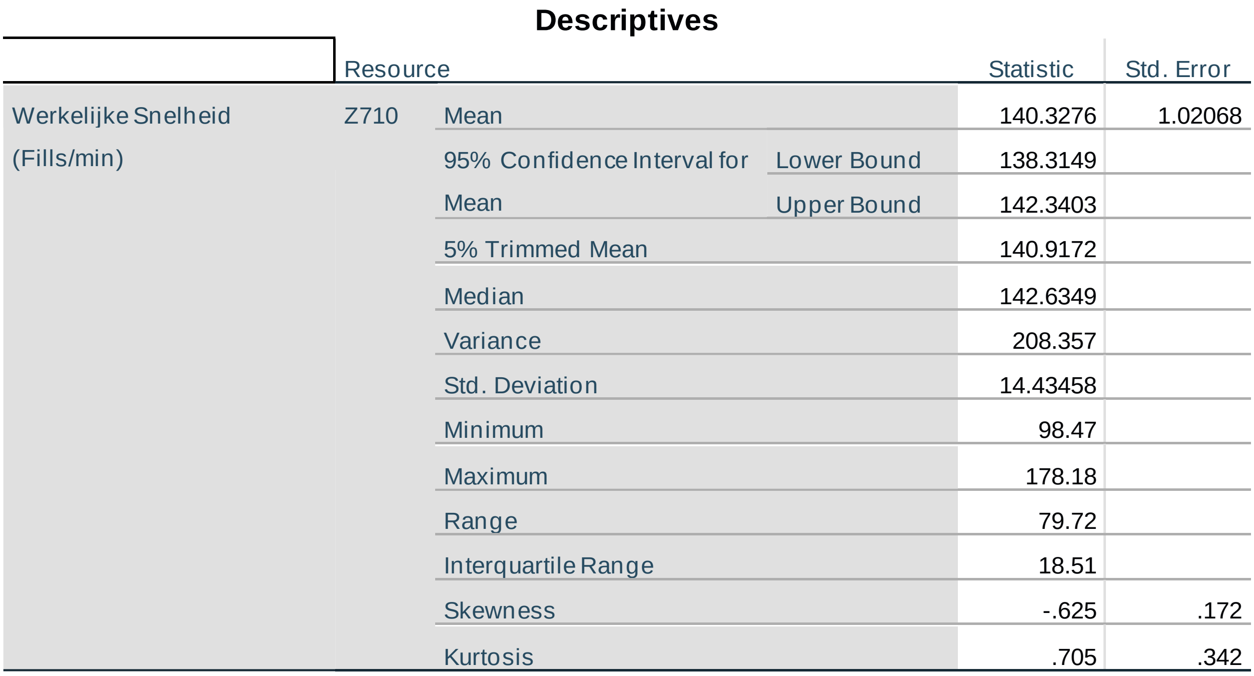
Figure 9: Evaluation production speed 709

710:



Percentiles

		Resource	Percentiles 5	10	25	50	75	90	95
Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z710	112.2678	120.9006	132.2358	142.6349	150.7449	156.2030	160.6404
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z710			132.2920	142.6349	150.7291		



Descriptives

	Resource			Statistic	Std. Error
Werkelijke Snelheid (Fills/min)	Z710	Mean		140.3276	1.02068
		95% Confidence Interval for Mean	Lower Bound	138.3149	
			Upper Bound	142.3403	
		5% Trimmed Mean		140.9172	
		Median		142.6349	
		Variance		208.357	
		Std. Deviation		14.43458	
		Minimum		98.47	
		Maximum		178.18	
		Range		79.72	
		Interquartile Range		18.51	
		Skewness		-.625	.172
		Kurtosis		.705	.342

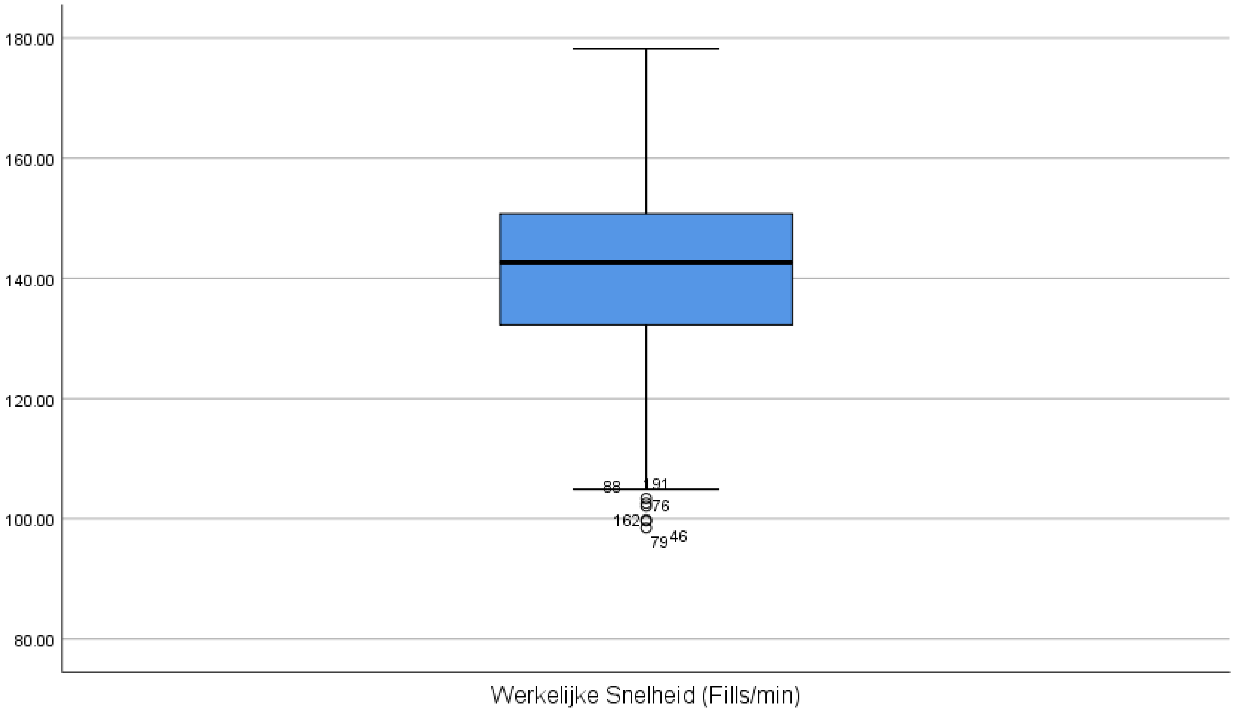
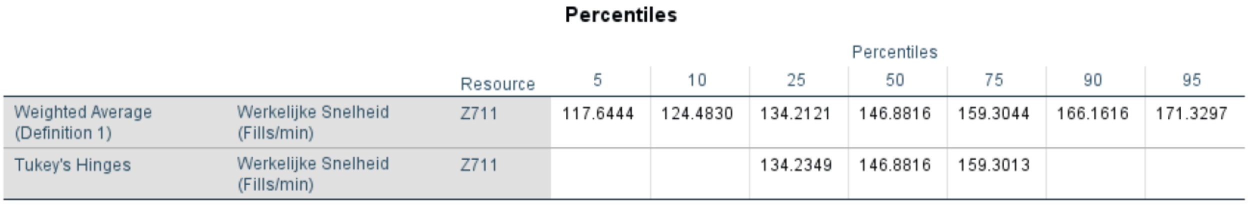


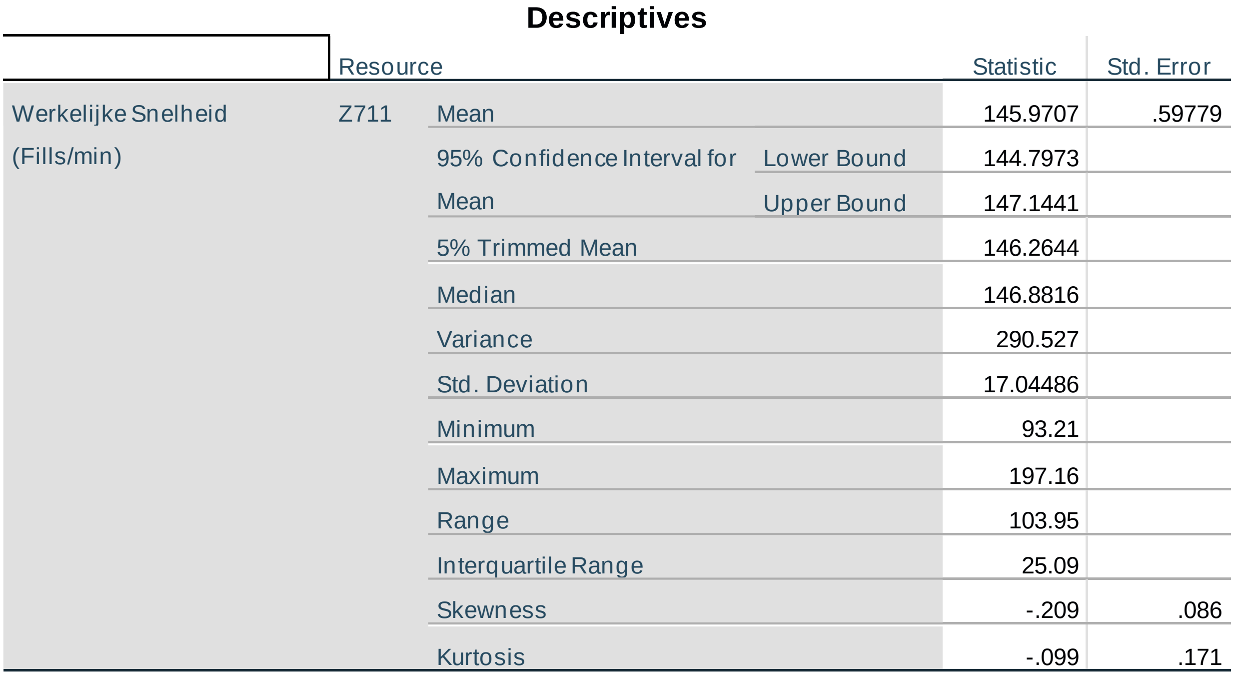
Figure 10: Evaluation production speed 710

711:



Percentiles

		Resource	Percentiles 5	10	25	50	75	90	95
Weighted Average (Definition 1)	Werkelijke Snelheid (Fills/min)	Z711	117.6444	124.4830	134.2121	146.8816	159.3044	166.1616	171.3297
Tukey's Hinges	Werkelijke Snelheid (Fills/min)	Z711			134.2349	146.8816	159.3013		



Descriptives

	Resource			Statistic	Std. Error
Werkelijke Snelheid (Fills/min)	Z711	Mean		145.9707	.59779
		95% Confidence Interval for Mean	Lower Bound	144.7973	
			Upper Bound	147.1441	
		5% Trimmed Mean		146.2644	
		Median		146.8816	
		Variance		290.527	
		Std. Deviation		17.04486	
		Minimum		93.21	
		Maximum		197.16	
		Range		103.95	
		Interquartile Range		25.09	
		Skewness		-.209	.086
		Kurtosis		-.099	.171

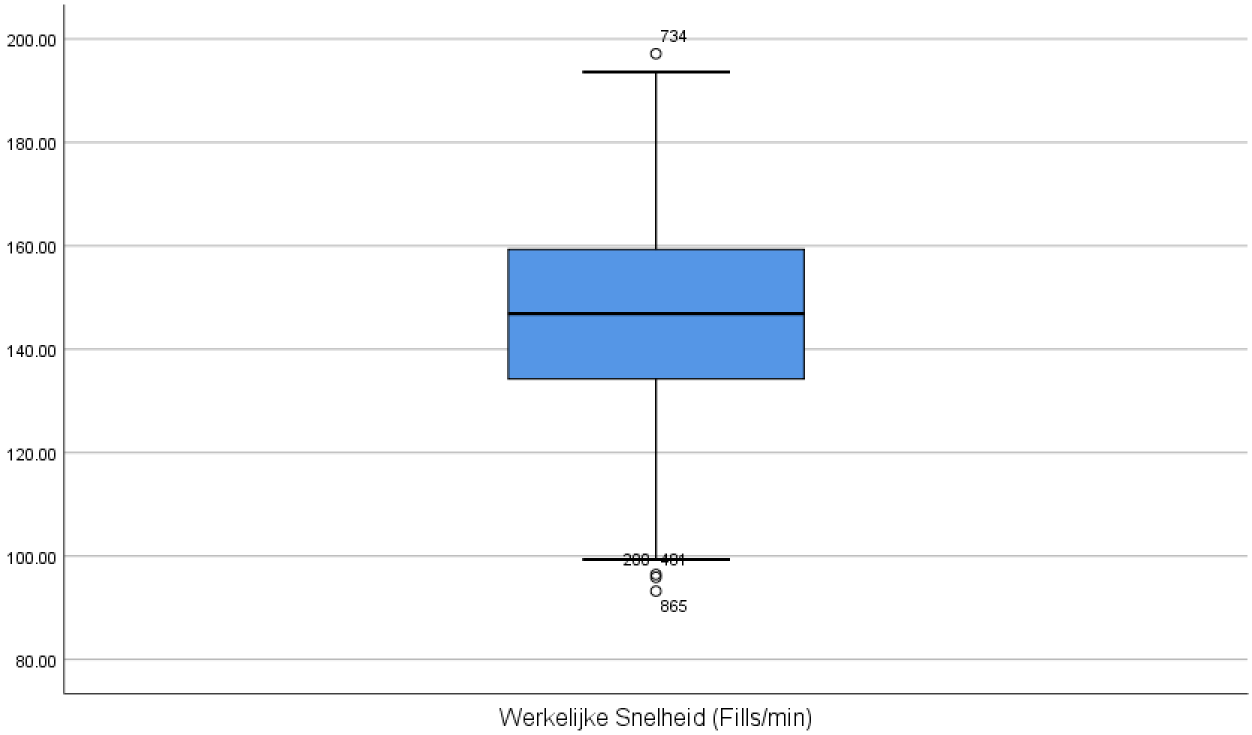


Figure 11: Evaluation production speed 711

Table 8 summarizes the most important characteristics of the achieved production speeds[2].

	Achieved speed			
	709	710	711	
Mean	141.8652	140.3276	145.9707	
Median	144.9877	142.6349	146.8816	
variance	333.114	208.357	290.527	
St. Deviation	18.2514	14.43458	17.04486	
Min	87.15	98.47	93.21	
Max	192.92	178.18	197.16	
Skewness	-0.508	-0.625	-0.209	
Kurtosis	0.212	0.705	-0.099	
Coefficient of variation	12.87%	10.29%	11.68%	

Table 8: Characteristics speed filling lines 709, 710, &711

We see that the 710 has the lowest average speed (140.3276 fills/min, when compared to 141.8652, and 145.9707 fills/ min of the 709, and 711 respectively). In addition, it is the most stable line with the lowest coefficient of variation. When we consider the percentile scores of the 710, we furthermore see that in 95% of the time, this machine achieves a speed lower than 160.64 fills/min, when compared to 168.05, and 171,3297 of the 709, and 711, respectively. The overall speed is therefore centered around a lower speed. In general, the speed of the filling lines is relatively stable with low coefficients of variation. The distribution of the speed is slightly skewed to the left for all three machines. This means that the "tail" of the lower speeds is larger, but that the production speed of most orders produced is concentrated at relatively higher speeds.

3.3.2: Technical feasibility

An overview of the build-up of the filling lines 709, 710, and 711 is presented in *Figure 12*. As is explained in Section 3.1, we are interested in the "slowest" machine as this machine determines the pace of the entire line. For the 709, the combined output of the two parallel filling machines is compared with the other machinery. A common approach to compare the capacities of machines is to compare their NPCs based on the serial numbers of the equipment. However, within this study, only limited information on these NPCs could be found online and within the archives of the company. An interview with a technical service employee shed light as to the cause. He explained that the filling machines, and all other machines, of the 709, 710, and 711 were originally bought by customer X. Originally, the filling machines of the 709, and 710 were manufactured by BOSCH. However, they were revised by Laudenberg which "upgraded" the machines. Euroma then bought the machines from customer X. The influence of the "upgrade" was not specified by the manufacturer. Currently, Euroma makes use of a maximal speed of 200 fills/ min. The reason that Euroma makes use of this speed is because customer X stated that the lines could run at these rates. As we are not able to reevaluate this maximum speed based on the NPCs of the equipment used, we require a different approach.

With two different technical service employees (both experienced employees with work experience prior to Euroma moving to Zwolle), the maximum capacity of the machines was discussed. Both explained that most machines have been altered or rebuilt which is why there are no technical specifications. Within *Figure 12*, the bottlenecks, as identified by these technical service employees, are encircled.

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[2] In *Figure 6*, *Figure 7*, *Figure 8*, *Figure 9, Figure 10*, and *Figure 11* the achieved production speed is referred to as "Werkelijke snelheid (fills/min)" as the information was loaded to SPSS from a Dutch file.

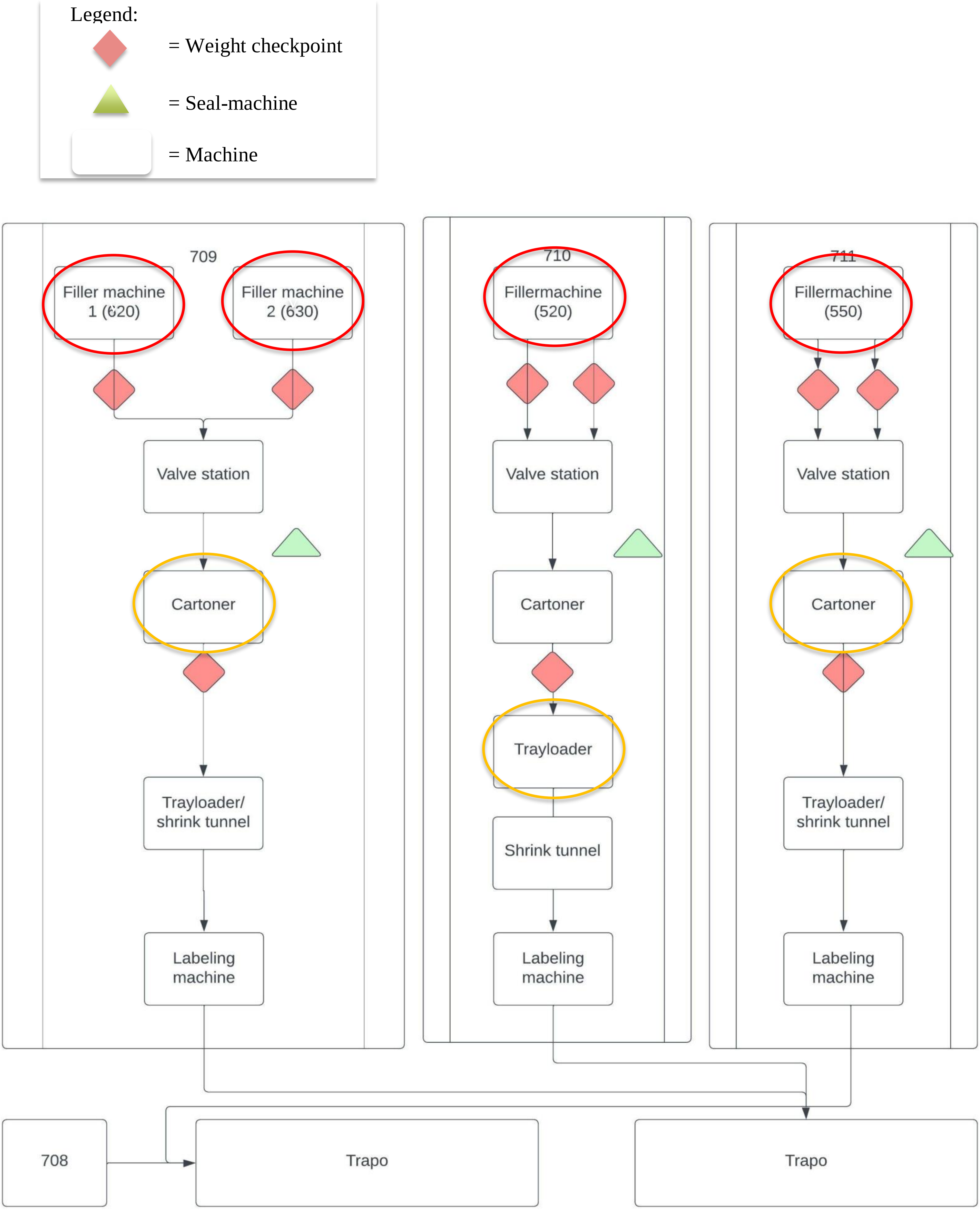

Figure 12: Line-overview

As to the rate with which the filling lines are able to operate, these would come down to 180, 170, and 190 fills/min for the 709, 710, and 711, respectively. Note that these are the output rates of the filling machines. As these machines all have two filling points, this would come down to 90, 85, and 95 per point.

When we consider the 709, the maximum rate is determined by both the cartoner, and filling machine. The cartoner machine is required to operate at a higher pace than the filling machine to compensate for buffers created at the valve station, and/or additional input of "rework" products by the operators. The technical employees both indicated that this machine cannot reasonably exceed speeds higher than 185-190 fills/min. They explained that this corresponds to a filling speed of around 180 fills/min. The technical staff also explained that the filling machines itself cannot operate at higher speeds even if the cartoner could. The maximum pace of the 710 is determined by the tray loader. This machine cannot exceed speeds in excess of 170-175 fills/min. This corresponds to a filling speed of around 170 fills/min. However, the technical employees indicated that the filling machine itself is better not run at a higher speed even if the tray loader were to keep up. The reason of this can be found in the way in which the machine opens the bags that are to be filled. The machine holds the bags on one side only, as opposed to the two-sided clamp which is used at the other lines. As the rotational speed increases, the opening of the bags deforms which makes the filling points miss or crumble the shape of the bag which troubles proper sealing.
The maximum speed of the 711 is determined by the filling machine and/or the cartoner. At its absolute maximum, the cartoner machine can handle speeds up to 195 fills/min. this corresponds with a filling speed of around 190 fills/min. This is also the maximum with which the filling machine can reasonably operate.

3.3.3 Technical feasibility vs achieved production speeds

Based on the interviews with the technical staff, we would set the technical maximum speed of the filling lines 709, 710, and 711 at 180, 170, and 190 fills/min, respectively. However, within *Figure 9*, *Figure 10*, and *Figure 11*, the maximum achieved production speeds exceed these numbers. Therefore, the production speeds at an order level were reconsidered, and the percentage of orders exceeding the technical maximum speeds was calculated. The result are shown in *Table 9*. Outliers are not considered in this analysis.

Line	Technical max. speed (fills/min)	Orders produced	# Of orders with production speed > tech. max. speed	% Of orders with production speed <= tech. max speed
709	180	1066	10	99.06%
710	170	200	3	98.50%
711	190	813	5	99.38%

Table 9: Production speed vs tech. max. speed

The number of orders in which the production speed exceeds the technical maximum speed as identified by the technical personnel is very low. In addition, it is questionable whether the data upon which this information is based is 100% accurate. Especially since there is always a human element involved in collecting the data (see Section 2.3). Therefore, we adhere to the identified technical maximum speeds. The accompanying workloads are found in *Table 10*.

Line	Max speed (fills/min)	Workload (minutes)
709	180	0.005555556
710	170	0.005882353
711	190	0.005263158

Table 10: Workloads 709. 710, and 711

3.4: Production norms

This section answers the second research question as defined in Section 1.4. It summarizes and reflects on the method that ought to be used to determine the new production norms prior to providing these new norms. It therefore answers the question around which Chapter 3 evolves:

> *"How should the new production norms of the filling lines 709, 710 and 711 be determined?"*

A production norm captures the number of products that ought to be produced during an eight hour shift, when the availability and quality scores are considered to be 100%. This production norm is expressed in a number of fills. This is a universal measure between all products produced, and stands for the number of individual bags "fills" produced.

The new production norms ought to be calculated by means of the formula depicted in *Equation 16*, and should therefore be based on the workloads presented in Section 3.3[3]. These workload are determined by considering the technical specification of the equipment used in production, and validating these technical specifications by comparing them to real-life performance of the filling lines. This means that the production norms are to be based on workloads reevaluated based on the technical, validated, capabilities of the filling lines. *Table 11* provides the new production norms for the filling lines 709, 710, and 711 that are determined by this means.

$$Production\,norm = \frac{480}{Workload}$$

Equation 16: Production norm calculation

Filling line	Production norm (fills)
709	86400
710	81600
711	91200

Table 11: Production norms 709-711

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[3] *The definition of a workload, as identified in Section 3.1, is not the definition that was specified by Euroma at the start of this study. Initially, the company wanted to establish "product-dependent" workloads. The meaning, and implications of this product-dependency within the workloads is explained in the discussion of the research (Section 6.3.1).*

Chapter 4: Performance of the filling lines

This chapter focusses on the third research question. It analyses the performance of the filling lines with the newly determined workloads in place. Section 4.1 identifies the biggest losses in the performance category, whereas Section 4.2 finds potential causes of these losses. Section 4.3 answers the main research question: "How do the filling lines 709, 710, and 711 perform?"

4.1: Losses in the performance category

This section focusses on the following research question:

"What are the biggest losses in the performance category?"

The introduction of the readjusted workloads has an influence on the speed losses incurred. Therefore, the performance score before, and after the introduction of these new workloads differ. We must first understand this influence prior to indulging in the buildup of the losses within the performance category. In *Table 12*, the difference is shown. As the adjusted workloads are higher than the original workloads, and the ideal speeds thus lower, the speed losses are reduced, and the performance scores increase. The overall OEE score is therefore also higher after the implementation of the new workloads.

	709		710		711	
Situation	*old*	*new*	*old*	*new*	*old*	*new*
Workload	0.005	0.005555556	0.005	0.005882353	0.005	0.005263158
Speed given workload (fills/min)	200	180	200	170	200	190
OEE	41.82%	46.53%	24.96%	29.39%	30.14%	31.73%
Availability	66.55%	66.55%	43.59%	43.59%	48.43%	48.43%
Performance	63.68%	70.76%	57.56%	67.72%	62.52%	65.81%
Quality	98.68%	98.81%	99.47%	99.55%	99.54%	99.57%

Table 12: Influence of workloads on OEE

As the objective of this chapter is to identify the losses within the performance category with the newly defined workloads implemented, any further analysis is based on these new workloads as presented in Section 3.3.

Table 12 shows the overall performance score of the 709, 710, and 711. At Euroma, there are two variables which influence the performance score: microstops, and speed losses. Microstops are stops with a duration smaller than 3 minutes, whereas speed loss is incurred as a consequence of running at sub-optimal speeds. *Table 13* shows the percent point influence of the speed losses, and microstops on the performance score. In addition, it shows the percent point influence of the performance score on the overall OEE score. This gives insight as to the effect which reducing the performance loss completely would yield. We see that the influence of speed loss on the performance score is higher than that of microstops for the 709, and 711. For the 710, the influence of the microstops is higher. Speed loss is accountable for a decrease of the performance score of -18.60%, -14.29%, and -19.31% for the 709, 710, and 711, respectively. The microstops for an additional -10.64%, -17.99%, and -14.88%. As both variables influence the performance score in a similar fashion and magnitude (for the 709, and 711 the speed losses are more dominant, whereas microstops are more dominant at the 710), this study divides its attention equally between the two.

Line	Influence SPEEDLOSS (OEE3a) on performance score	Influence MICROSTOPS (OEE3b) on performance score	Performance loss	A*Q	A*Q*P	Influence on OEE (percent point)
709	-18.60%	-10.64%	-29.24%	65.763%	46.534%	-19.229%
710	-14.29%	-17.99%	-32.28%	43.393%	29.386%	-14.007%
711	-19.31%	-14.88%	-34.19%	48.217%	31.730%	-16.487%

Table 13: Influence on performance score

Now that we have seen the effect of the microstops, and speed loss on the performance, and overall OEE score, we zoom out. We need to provide a frame of reference when it comes to the magnitude of this influence in relations to other losses, such as machines breakdowns, and setups. Therefore, we now consider the buildup of the average order for the 709, 710, and 711.

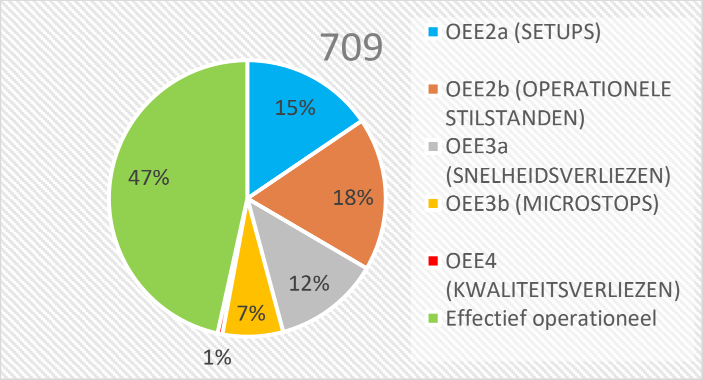

Figure 13: Buildup order 709

Figure 13[4] represents the planned production period of the average order on the 709. This means that planned downtime (OEE1a, &OEE1b) is excluded. The average planned production period equals 14:52:17 (measured in hh:mm:ss). We see that 7% of this time is lost on microstops, and 12% on speed loss. In comparison, 18% is lost on machine breakdowns, and 15% on setups. The average duration of a microstop on the 709 is 50 seconds. Within an order, around 76 microstops are experienced.

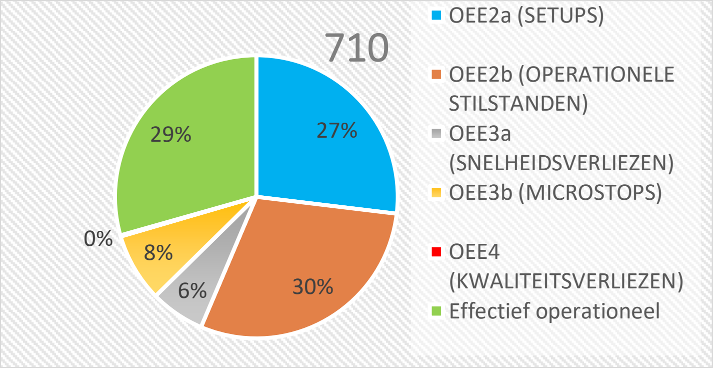

Figure 14: Buildup order 710

The average planned production period of an order on the 710 amounts to 19:56:14 (measured in hh:mm:ss). We see that 8% of this time is lost on microstops, 6% on speed loss. In comparison, 30% is lost on machine breakdowns, and 27% on setups (see *Figure 14*). The average duration of a microstop on the 710 is 1 minute. Within an order, around 94 microstops are experienced.

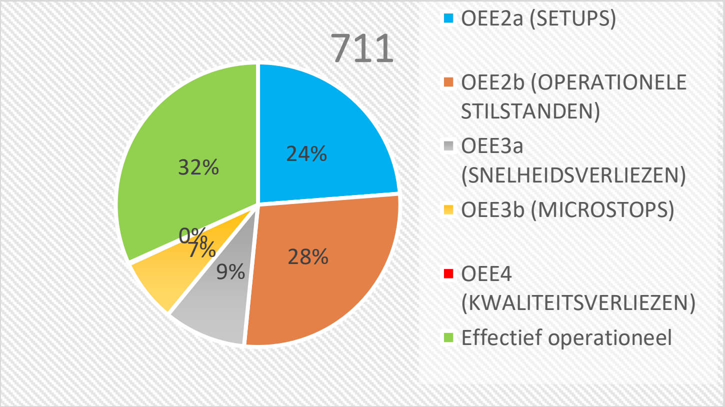

Figure 15: Buildup order 711

The average planned production period of an order on the 711 is 18:03:26 (measured in hh:mm:ss). 7% of this time is lost on microstops, and 9% on speed losses. In comparison, 24% of this time is lost on setups, and 28% on machine breakdowns (see *Figure 15*). The average duration of a microstops equals 1 minute. Within an order, around 78 microstops are experienced.

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[4] The terminology used in *Figure 13*, *Figure 14,* and *Figure 15* is in Dutch. This is caused by the data being loaded from the MES system which is set up in this language. The definition are: OEE 2a (Setup), OEE2b (Unplanned standstills), OEE3a (Speed losses), OEE3b (Microstops), OEE4 (Quality loss), and Effective operational.

Euroma is currently focused on the reduction of the time lost in the setup phase of production. However, the previous paragraph shows that the influence of the performance category on the total time lost is not to be forgotten. While no attention is given to this category, we see that during the planned production period the performance category (microstops + speed loss) is accountable for a time loss of 19%, 14%, and 16% for the 709, 710, and 711, respectively. While these losses receive no attention, the losses of 15%, 27%, and 24% caused by the setups are thoroughly examined. The company is curious as to the total time lost within these categories annually, as this is a measure of importance and serves as an indication of the cost which can be saved by tackling these losses. The total time lost within the categories OEE2a-OEE3b is provided in *Table 14*. This table presents the losses of the orders produced in the time period of (January 2022 – May 2022).

CATEGORY	**709**	**710**	**711**
Planned production period	2534:18:20	1788:08:11	2183:46:50
OEE2a (SETUPS)	432:08:52	391:28:51	327:28:53
OEE2b (OPERATIONAL LOSSES)	455:38:04	598:40:22	585:43:34
OEE2 (AVAILABILITY LOSS)	***888:02:43***	***990:09:13***	***913:12:27***
OEE3a (SPEED LOSSES)	339:06:24	115:49:58	223:53:17
OEE3b (MICROSTOPS)	163:34:07	159:07:10	196:59:02
OEE3 (PERFORMANCE LOSS)	***502:40:31***	***274:57:08***	***420:52:19***
Total time lost during planned production period	1390:43:14	1265:06:21	1334:04:46

Table 14: Losses January - May 2022

In *Table 14*, we see that the total time lost within the performance category (OEE3) is even more comparable to the time lost within the setup phase of production (OEE2a). The losses within the performance category even exceed the setup losses on the 709, and 711. Overall, the losses within the performance category itself (microstops, and speed losses) are of comparable magnitude and thus importance. Within the further course of this study, attention is therefore equally divided amongst the two.

Remark: *Something interesting came to light when the time lost within the different OEE categories was examined. We found that no time is booked under the OEE1b category (GEPLANDE STILSTANDEN) in 2022. Within Table 26 (Appendix A), we see that there is no disruption which can be booked under this category. The option to do so seems to have been removed from the options which an operator can select for a disruption within MES in the course of 2020.*

4.2: Causes of the losses

Section 4.2 identifies potential causes of the losses incurred within the performance category. First, causes mentioned within the literature are examined (Section 4.2.1), after which these are complemented by the real-world observations (Section 4.2.2). Section 4.2.3 compares the literature to the real-world observations. Section 4.2 focusses on the following research question:

"What are potential causes of the losses within the performance category?"

4.2.1: Causes identified by the literature

First, common causes of speed loss are examined, after which focus is put on common causes of microstops.

1. **Speed losses**

Table 6 (Section 2.2) lists potential causes of speed loss within a manufacturing environment (Trattner, Hvan, & Haug, 2020). The fifteen causes listed are categorized in three categories: Technology, Human, and Product. Out of the fifteen causes, two are not further discussed. These are: (1) natural process variations, and (2) Raw material mix. The first is excluded as it embodies a "rest" category in that it holds unavoidable, unexplainable/ probabilistic causes of speed losses. The losses "that just naturally, and randomly" occur. The second was not defined thoroughly enough to be included. The three categories, and remaining 13 causes, are now discussed:

- Technology: *(1)*Equipment age, and wear in combination with *(2)*improper maintenance procedures can cause *(3)*low machine reliability and increase production stops. Generally speaking, production stops decrease the production speed as speed losses are incurred as a consequence of an observable "warm-up" period of the machinery. Technological and environmental limitations*(4)* are also of influence on the production speed. Examples of these limitations are downstream bottlenecks, or local legislation. *(5)*Queue capacity for work in progress (over capacity) of machines can also be a reason for incurred speed losses on a machine-level. However, within this study, the speed losses are analyzed across the entire filling line based on the "slowest" machine which renders this cause obsolete.
- Human: within this category we find speed losses incurred as a consequence of human decisions and/ or actions. Low levels of operator training and efficiency *(6)* is a cause captured in this group. Examples are found in operators not setting/ tweaking machines to their optimal state due to unawareness, or lack of focus put on production speed in training. In addition, the ideal cycle time as determined by management can be set too low *(7).* As a consequence, speed losses are incurred but not detected and therefore overlooked. Another influence is found in production scheduling *(8).* Especially when producing multiple products with different ideal production speeds, it is critical to sequence production such that large shifts in production speeds are avoided. Changes in capacity utilization *(9)* can also be responsible for incurred speed losses. Measurement errors *(10)* on actual production speed are also found to influence the perceived production speed, and therefore indirect the computed speed loss. This is caused by the difficulty to register the actual achieved production speeds.
- Product: issues with material availability and quality *(11)* within production influences production speed. Whenever material availability, or quality, is low, production speeds tend to decrease. Product variety of the raw materials *(12)* (characteristics) are also of influence. The last influence which is discussed is that of quality *(13)*. Quality restrictions on end-products can be of influence on the production speed which an operator sets. Especially when producing at higher rates increases the chance of products not adhering to quality regulations.

2. Microstops

The occurrence of microstops tends to increase as manufacturing is more automated. They are amongst the least examined stops by management as identifying their underlying causes is difficult and time-consuming (See section 2.2). Potential causes are too numerous to list, but common reasons include misfeeds, jams, incorrect setting, misalignments or blocked sensors, equipment design issues, and periodic cleaning (Vorne Industries, sd).

4.2.2: Observed causes

The filling lines 709, 710, and 711 were monitored for a duration of two shifts each (16 hours). The causes of microstops, and speed losses presented within the next paragraphs are based on the observations within this period. The line-specific findings are discussed, after which more general findings are debated, and a comparison is made with the literature. However, prior to indulging on the observed causes of microstops, and speed loss at the filling lines, we provide a high-over understanding of the process of filling.

The filling lines process and package products. Within this section, the setup of the 709 filling line is used to serve as an example. *Figure 16* shows this setup. The process start at the filling machines. These receive a constant supply of powder, and or vermicelli/ vegetables via big bags (containers) which are elevated above the supply funnels of these machines. The filling machines then correctly dose the ingredients and deposit the raw material in pre-formed bags "sachets". The dosing takes place by either alternatingly opening a set of valves (709), or the rotational speed of the screw dispenser present within the supply funnel (710/711). The sachets are then moved along a conveyor belt, via a checkweigher which checks their weight, towards the valve station. This station consists of a set of valves placed in series. The relative opening and/or closing of these valves determines the throughput sequence of sachets. The conveyor succeeding the valve station is built up of compartments. The timing of the valve station is set so that exactly one end-product, consisting of either one, two, or three sachets, is deposited within a single compartment. The cartoner shoves the sachets present within a single compartment into a carton package, and closes the carton. These cartons are moved along another checkweigher which performs yet another weight check. The cartons which pass this check are transported toward the tray loader. Here, the correct number of cartons, depending on the type of product produced, are placed on a tray. The shrink tunnel wraps the trays in a thin layer of foil, and the labeling machine provides the tray with a label which holds, amongst others, the batch number and time of production. The trays are now transported across the factory toward the palletizer "Trapo" via a set of conveyors. The palletizer stacks the trays on a pallet, which is moved towards the warehouse where it is temporarily stored prior to transportation/delivery to the customer.

Now that we have a basic understanding of the filling process, it is time to discuss the line-specific observations. These are presented in the next paragraphs.

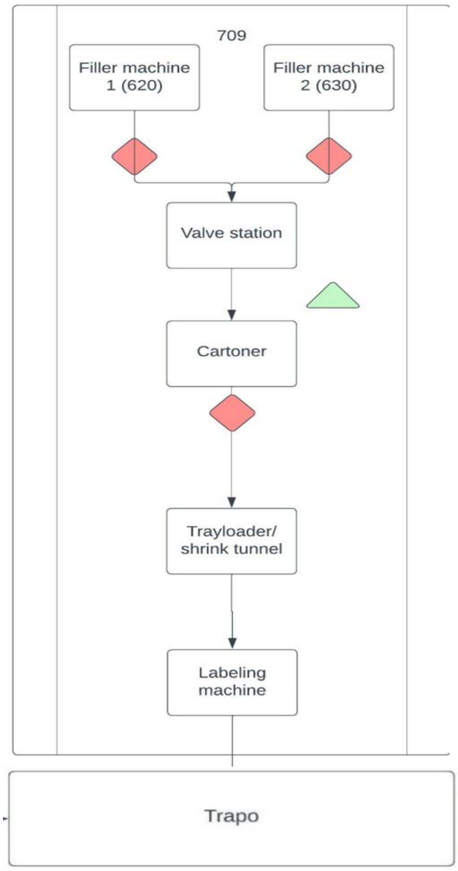

Figure 16: Setup filling line 709

709

Table 15[5] presents the observed microstops on the 709, and their relative duration during the time period in which the production line was observed ("Duration observation", Table 15). The microstops are numbered and explained in the next paragraph. Details on the individual orders are found in the overall overview of the observed microstops (Appendix C).

709						
	Observation 1 Order M00012025		Observation 2 Order M00012033		Observation 3 Order M00012034	
Duration observation	01:45:00		04:52:00		01:21:00	
Microstop	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
Sensor fill station 630 (1)	-	00:08:00	2	00:04:00		
Carton twisted on conveyor belt (2)	4	00:03:00	1	00:00:45	2	00:01:30
Cartoner misfeed bag (3)	3	00:07:30	4	00:10:00	6	00:15:00
Restart after misfeed (3)	3	00:02:15	4	00:03:00	6	00:04:30
Improper sealing carton cartoner (4)	1	00:02:00	3	00:06:00		
Jam valve fill station (5)			4	00:06:00		
Timing/ sensor valve station (6)			1	00:00:45	4	00:03:00
Sensor sachets cartoner (7)			1	00:01:00		
Material shortage (8)			1	00:02:00		

Table 15: Microstops 709

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[5] The total occurrence of the failing sensor of the 630 is unknown for the first observation as the machine was restarted numerous times to try and solve the problem, and the MES system did not accurately register these stops. The total duration is based on the total time period in which the sensor was examined, and production was (re)started.

The observed microstops, listed in *Table 15*, are now revisited and explained.

1. There is a sensor in the funnel of the filling machine (630). This sensor "measures"/ detects the level of raw material within the "powder" funnel. Whenever the level drops beneath a certain threshold, the valves above the funnel open, and new raw material flows from the big bag into the funnel. This sensor consist of plates which "feel" whether they make contact with the powder. When this is the case, the valves are kept shut as enough raw material is present. When there is no contact, the valves open. The system itself seems simple. However, when the powder is sticky, and attaches to the sensor, the valves do not open even though the raw material level is beneath the threshold. As a consequence, the machine halts as there is not enough powder to continue.
2. The sachets are placed in cartons by the cartoner, after which they pass the last checkweigher. During this passage some of these cartons get twisted. When an operator detects the twisted product on time, it can be taken of the conveyor. However, when the product is not detected on time, the tray loader to which the conveyor leads gives an error, and production is halted.
3. The cartoner shoves the sachets inside carton boxes. Especially when multiple sachets are pushed in one carton, there is a chance of them crumbling. This problem is not caused by the opening of the cartons itself, which is done correctly. Instead, it is caused by either the position of the sachets within the compartment of the conveyor leading towards the cartoner, or the "unguided" push of the sachets towards the carton. As a consequence of the "crumbling", production is halted to remove the jammed bag, or clean the cartoner. When an operator opens the lid to do so, production is partially halted. This means the cartoner, and filling machine automatically fall in a standstill. The conveyor leading towards the valve station does however not automatically hold. As a consequence, the products that were being transported from the filling machine towards the valve station at the time of the standstill, need to be pushed of the conveyor. This happens automatically. When production is now continued, the products present within the cartoner are packaged, the machine then idles until the newly produced products of the filling machine are transported towards the valve station and onwards. This takes an excess of 30 seconds, which makes that within the succeeding startup phase of a jam, production is "halted" one more time, and a second microstop is registered.
4. Several cartons were not closed properly by the cartoner. As a consequence, production was halted several times to adjust the closing mechanism. In addition, several produced pallets had to be checked as the possibility existed that the failure had occurred prior to it being detected by the operator.
5. The fill station makes use of a set of valves, which open and close alternatingly, to dose the correct amount of powder. The lowest valve touched the preceding pipeline. This yields in friction, which made that the valve did not close properly. As a consequence, the filling machine halts.
6. The valve station consists of a set of three valves placed in series. The relative opening and closing of these valves ensure that the correct number of sachets, produced by the fill station, are deposited within the compartments of the conveyor towards the cartoner. There were several small stops caused by jams of bags between the different layers of valves within the valve station.
7. Prior to the sachets reaching the valve station, a sensor checks whether the correct number of bags are present within a compartment. This sensor has to be set by the operator prior to production. Production was halted to adjust the setting of this sensor as a consequence of the inadequate setting of the sensor prior to production.
8. Production is halted when the flow of raw material is interrupted. This happens when the big bag supplying this flow is not replaced in time.

710

The 710 has been the subject of study for a project group drafted by Euroma prior to the period in which the microstops were observed. As part of the project, the line received extensive maintenance. As a consequence, the total number of disruptions caused by machine failure and/ or adjustments, as observed, was lower when compared to the 709, and 711. Nevertheless, several microstops were distinguished. *Table 16* lists these microstops, and their relative duration. The time period during which the 710 was observed is also included. Order details are incorporated in the overall overview of the observed microstops (Appendix C).

710						
	Observation 1 Order M00011939		Observation 2 Order M00011797		Observation 3 Order M00012142	
Duration observation	04:46:00		08:00:00		00:45:00	
Microstop	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
Sensor/ restart fill station (1)	2	00:02:30				
Carton twisted on conveyor belt (2)			1	0:00:45		
Jam + reset valve station (3)					7	00:10:30
Solas foil problem (4)			Unknown	Unknown		
Solas foil change (5)	2	00:01:30				
Solas fallen carton (6)			1	0:01:30		
Solas loss of count (6)	1	00:02:30				
Solas readjustment setup conveyor (6)	1	00:01:30				
Changeover foil + reset fill station (7)					2	00:04:00

Table 16: Microstops 710

The microstops, listed in *Table 16*, are now revisited and explained.

1. The sensor regulating the vegetable supply on one of the funnels of the fill station malfunctioned several times. As a consequence, the supply either continued to flow, or did not flow at all. To clean/ adjust the sensor, production had to be halted.
2. When the bags are placed in the cartons, which then pass the last checkweigher, some of these cartons get twisted. When this is not detected on time by the operator, the tray loader gives an error and production is halted.
3. Jams within the valve station (see explanation (6) 709).
4. There were a lot of microstops (and disruptions) caused by problems at the tray loader (Solas). This machine is placed at the end of the line, and wraps the produced trays in a foil so that the individual cartons do not fall off the trays during further transportation. However, on several occasions, the foil of subsequent trays was still “glued” together. As a consequence, these trays got stuck on the conveyor belt succeeding the shrinking tunnel, product flow got interrupted, and the tray loader, or shrinking machine gave an error. The trays in question had to be reopened and repacked. This happened so frequent/ continuous that the production was halted numerous times. These microstops cannot be listed/ counted as it would only cloud the understanding of the influence of microstops on production effectiveness. The problem is better regarded as a machine “failure”, and ought to fall under the OEE2b category.
5. The Solas serves as a tray loader. The machine furthermore wraps the trays in a layer of foil. This requires a constant supply of this foil. When the supplying roll has to be replaced by the operator, production is halted.
6. We observed three microstops which were caused by flaws and/or errors of the Solas. One microstop was caused by the inadequate setting of the conveyor belt leading towards the Solas. The error was solved by readjusting this setup, which was done by the operator. Two other microstops were caused by the Solas losing track of the carton count present within the machine, and a jammed carton within the machine itself.
7. The fill station makes use of foil to create the sachets in which the raw material is deposited. This foil is supplied by a big roll. When the end of this roll is near, the filling machine halts, and an operator is required to replace the roll. Replacing this role takes

under three minutes, which makes that it is registered as a microstop. The same holds for the microstop(s) experienced after the roll is changed. These include fine tuning, and tests.

711
Table 17 shows the microstops that were observed on the 711. In addition, it displays the number of occurrences, and total duration of these microstops. The time period in which the microstops were observed is also included. For the order details we refer to the overall overview of the observed microstops, which is found in Appendix C.

711				
	Observation 1 Order M00012212		Observation 2 Order M00012213	
Duration observation	01:47:00		05:01:00	
Microstop	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
Fill station reset disruption sachets (1)	11	00:16:30		
MAS disruption Muerer (2)	1	00:02:00		
Ventilation filling machine (3)	1	00:01:30		
Checkweigher jam sachets (4)	8	00:08:00		
Seal cleaning fill station (5)	1	00:01:30		
Closing carton cartoner (1)	1	00:01:00		
Jam bag cartoner (7)			4	00:05:00
Restart after misfeed (7)			4	00:03:00
Jam bag valve station (8)			1	00:01:15
Setting glue gun cartoner (9)			1	00:01:15
Palletizer disruption (10)			3	00:06:00
Fill station crumbles bag (11)			8	00:08:00
Error feed cartons cartoner (12)			1	00:03:00
Lose bag fill station (1)			2	00:02:00
Carton twisted on conveyor belt (13)			2	00:01:30
Muerer conveyor full (14)			2	00:01:00
Palletizer overflow (15)			2	00:03:00

Table 17: Microstops 711

The microstops, listed in *Table 17*, are now listed and explained.

1. The sachets rotate through the filling machine. After being filled, suction clamps transport the bags towards the nearby conveyor belt. However, this is a frequent cause of trouble with bags either not being picked up, being dropped within the filling machine, or falling of the conveyor. All of these problems suffer the same consequence as the filling machine has to be opened by the operator to remove the “fallen” bags, and/or adjust the setting of the suction clamps. The opening of the machine automatically stops production.
2. The tray loader (Muerer) fell in an unknown error: “MAS”. The problem was solved by resetting the machine.
3. Within the filling machine, a ventilation system vacuums the excess dust. This excess material flows through a pipeline into a vacuum cleaner. When the pipeline is blocked, and the ventilation does thus not work properly, the filling machine has to be opened in order to be able to clean the pipeline. This halts production.
4. After the fill station, the sachets pass a checkweigher. Between this checkweigher and the conveyor belt towards the valve station, bags get stuck and/ or twisted. An operator has to manually remove the bags. This required the fill station to be halted in order to stop the flow of products towards the jam.
5. After depositing the raw material into the sachets, the filling machine seals the bags via a heated sealing bar. However, when to much powder attaches to this bar, the sachets

are not sealed properly. The operator then has to open the filling machine to clean the seal. This halts production

6. The cartoner was opened to remove an improperly closed carton.
7. Within the cartoner, several sachets got crumbled while being shoved into their respective cartons. The cause of this problem is found in the positioning of the sachets within the compartments leading to the cartoner machine. This, in its turn, is influenced by the setup of the valve station. For an explanation on the "restarts after misfeed", see explanation (3) 709.
8. See explanation (6) 709.
9. The cartoner shoves the sachets into a carton box after which this box is sealed via a glue gun. The glue gun has to be correctly set up by the operator depending on the type of product produced. When the glue gun is not setup properly, the cartons are not closed correctly, and production has to be halted for adjustment.
10. The trays are transported towards the palletizer. Whenever a tray falls off, or blocks the conveyor belt, production is halted to sort the error.
11. The fill station doses the materials. This is done by spinning the sachets around a wheel which is positioned under a set of funnels supplied by big bags of the required raw material types. While on this wheel, the sachets are held by clamps. However, the left clamp crumbled, and therefore deformed the opening, of the sachets. As a consequence, powder is not deposited correctly. The combination of the deformation, and incorrect position of the clamps gives rise to several problems. First of all, not all powder is deposited into the sachet as the opening is deformed. This contaminates the machine which is ought to be opened more regularly for cleaning. Second, the powder contaminates the opening of the bag, which is than not properly sealed. Thirdly, several bags are dropped within the machine. To clean the machine, the seal balk, or remove the fallen bags, an operator has to open the machine which automatically halts production.
12. The cartons used by the cartoner are supplied via a rail. One of the cartons was somewhat twisted, which blocked this supply. As a consequence, production was halted.
13. When the cartons pass the last checkweigher some of these cartons get twisted. When this is not detected on time by the operator, the tray loader gives an error and production is halted.
14. Whenever the conveyor toward the tray loader is full, the tray loader gives an error so that production is halted, and. This is meant to prevent jams occurring prior to the tray loader. The sensor, which is used in this process, detects whether products block its laser. However, when the sensor is dirty, it continuously "detects" products. An operator is then required to stop production and clean the sensor.
15. The palletizer palletizes the trays. There are two palletizers, one for the 709 & 710, and one for the 708 & 711. However, when the 708, and 711 are both operational, the palletizer cannot keep up with the supply of trays. As a consequence, the tray loaders of these lines cannot "get rid" of their products. In order to prevent a jam, production is automatically halted. This happens at (one of) the filling lines 708, and/ or 711.

The previous paragraphs are mainly focused on observed microstops, whereas this study ought to focus on speed losses as well. The speed losses have been excluded up until this point as they are more difficult to observe. Speed loss incurred by the setup of the machines is observable, the reason for reducing the speed with which the machine is set, and speed loss incurred as a consequence of warmup periods is not. Therefore, an important source of information is found in interviews with operators and team leaders. The main findings are discussed in the next paragraphs.

The operators set the speed with which the fill station fills the bags. The speed of the valve station, cartoner, and tray loader is adjusted to match this "fill-speed". Operators do not initially determine this speed, but follow an instruction book. This book includes all articles produced and prescribes an advised "optimal" speed. However, nobody seems to know when, or how these speeds were determined. In addition, the book contains all kinds of scrabbles and operators are free to adjust the "optimal" speed settings by pen. In the field study, there were no operators who altered the fill speed once it had been set. The speed of the 711 can even barely be observed as the display is not functioning properly. Within the entire study, the attitude towards the setting of speed is best described as indifferent. Not only by operators, who were probably most involved, but also by team leaders. When it comes to production speed, both were often completely unaware of the speed of current production. It is safe to say that there is no, or little, stimulus for operators to increase and experiment with fill-speeds. If at all, the speed was mostly preventatively reduced to minimize the possibility of machine breakdowns. When we examined the filling lines with an experienced technical service employee, he increased the fill speed by 5 fills/min without any difficulties. On an eight hour shift this increases output by 2400 fills. While examining the production speeds of the filling lines, we did find out that the speed loss is not solely caused by the setup of the machinery. As the advised fill speeds approach the identified technical max speeds of 180, 170, and 190, there had to be another explanation for the incurred speed losses. The answer is found in the disruptions of the production process. After each disruption in production (be it a microstop, or a breakdown), the fill stations experience a warm-up period. Therefore, speed loss is automatically increased as the number of short stops and/or malfunctions increases. With a lot of the microstops, and malfunctions caused by changeovers of articles, a changeover has a direct influence on the observed speed loss. The changeover itself is captured in the availability category. However, the incurred warmup period after each microstop caused by a preceding changeover is captured in the performance category via the speed loss.

Both operators, and team leaders furthermore explained that the fill speed is largely influenced by the weight of the product being filled. The weight of products ranges from 20-150 grams. According to the operators, problems arise when one (of possible three) fills exceeds 100 grams. Troubles also arise when the total weight of products is low (less than 40 gram). Filling weights of more than 100 grams takes more time. This means that the fill of one bag takes longer, and output is thus reduced. Light bags do not fall quick enough in the valve station, which means that the fill speed is lowered to prevent jams.

When we summarize the findings of the observatory study, we see that:

- The setting of the speed of the dosage machine by the operators determines the production rate of the entire production line. Operators are not, or barely encouraged to experiment with the advised settings, or miss the experience to recognize situations in which the production speed can be increased. If at all, production speed is preventatively lowered to avoid machine malfunctioning. Malfunctioning equipment, in combination with minor adjustments and quick cleans for which production is halted, are a main cause of speed loss as a result of the incurred "warm-up" period. Another big influence on production speeds is found in the product characteristics of the product being processed. Especially the weight of a product is leading.
- Microstops are frequently experienced as a consequence of a changeover period. In addition, lack of experience amongst operators can cause microstops, caused by incorrect adjustments of machinery, to occur for a prolonged period. There are also several microstops whose occurrence is generated by technical "flaws" within the setup of the production lines. An example is the section of unguided rail between the checkweighers and attached conveyor belt, which gives rise to frequent jamming.

4.2.3: Observations vs literature

When we compare these observations with the literature, we agree that the causes of microstops are found in numerous areas. With regard to the speed losses, we see that there are several causes identified within the literature that are applicable to the field study.

- The majority of speed loss incurred is caused by production stops. Within the study, most production stops occurred as a consequence of low machine reliability (3), production scheduling (8), and operator training and efficiency (6). But how do these factors influence speed loss?
    a. When machine reliability is low, possibly as a consequence of equipment age (1), and improper maintenance (2), production stops are experienced on a regular interval.

After each production stop, the equipment experiences a “warmup period”. Within this period, the equipment runs at a lower speed.

b. The small batches of orders run, in combination with the need to adjust the machinery based on the fill type of the article produced, gives rise to frequent tweaking’s of machinery. This constant need of adjustment of the machinery is therefore mainly caused by the production scheduling. Especially the 709 experiences many conversions. It is safe to say that whenever a conversion has occurred, production is halted more frequently within the first 1 to 2 hours of the shift thereafter. Both the number of microstops, and the incurred speed loss hereby increase.
c. Within the field test, (micro)stops were often solved by the operators without help of the technical staff. However, it did occur that the operator directly assigned to the production line did not know how to solve the problem. A fellow, more experienced, operator was then required to solve the problem. This might be incidental, but could also be caused by the (lack of) operator training (6).

- The stops experienced at the 711, as a consequence of the overflow of the palletizer downstream, are an example of a technological limitation (4).
- According to the operators, and team leaders, the most important influence on production speed is that of product characteristics. The raw material, and especially the weight being filled, directly influences the production speed. This vision is supported by the technical staff. As the fill station relies on either valves, or a dosage screw, to deposit the powder in the bags, larger weights (volumes) take more time to deposit. Especially since the rotational speed of the screw (responsible for the dosing of the powder) cannot be increased limitlessly. When the speed, or size of the screw is increased, the accuracy of the dosage weight decreases. As products are checked on their weight, this gives rise to an increase of rejects. These findings correspond to the product variety (12), and quality (13) aspects identified within the literature.

A complete overview of the observed microstops, and set production speeds is found in Appendix C. We see that the time period of the orders considered does not add up to sixteen hours for each line. The main reason is found in the buildup of orders. Microstops and speed losses are incurred during the production phase. This means that during a setup-up and/ or changeover period the losses cannot be adequately recognized as such. Therefore, Appendix C is a summary of the finding within the production state of the filling lines and excludes setups and changeover times. In addition, it is interesting to see that the total number of microstops observed does not equal the number of microstops registered by the MES system. There are two factors which play a role here.

1. The discrepancy between the observed number of short stops, and the registered number of short stops is a good indication of the difficulty of recognizing short stops by operators. Short stops are often chronic of nature, occur often, and are sometimes solved without intervention. Therefore, not all stops are easy to identify when observing production.
2. The number of short stops as registered within the MES system is somewhat biased. Whenever production is halted, there are still products on the conveyor belts. When the cartoner, tray loader, shrinkage tunnel, and/or palletizer experiences a disruption, all bags prior to the valve station are pushed of the conveyor so that they do not get jammed in the machine itself. When production is then restarted, the initial short stop is registered in addition to the ”false” short stop caused by the gap in products on the conveyor belt. An operator or observer would note one short stop, whereas the system registers two. The same phenomenon is observed when the filling machine is experiencing troubles, or when its foil is replaced, as production is then often started and stopped multiple times. This phenomenon has partially been accounted for, by assigning “setup” microstops after jams of the cartoner, and foil changes of the filling machines, but a mistake is easily made.

We were unaware of the discrepancy between the observed number of microstops, and the microstops registered by the MES system at the time of testing. Therefore, not all short stops were timed at first. Their duration has been estimated based on experience, and comparable timed short stops.

Section 4.3: The performance of the filling lines

This section is focused on the following research question:

"How do the filling lines 709, 710, and 711 perform?"

Losses within the performance category of OEE are responsible for an average decrease of OEE scores by 19.2, 14, and 16.5 percent point for the 709, 710, and 711, respectively. The total time lost on microstops, and speed losses is comparable to the time lost during setups (changeovers) and totaled 339, 115, and 223 hours within the period of January-May 2022. During an average order, the filling lines experience around 76 (709), 94 (710), and 78 (711) microstops with an expected duration of around 1 minute for the 709, and 711, and an expected duration around 50 seconds for the 710. The average achieved production speed of the 709, 710, and 711 come down to 141.9, 140.3, and 146 fills/min (see Section 3.3). For the 709, this is over 21% lower than its technical maximum speed of 180 fills/min. When we consider the 710, the average production speed is over 17% lower than the technical maximum speed of 170 fills/min, whereas the average production speed is even over 23% lower than the maximum production speed of 190 fills/min for the 711.

Chapter 5: Minimizing the performance losses

This chapter concentrates on the main research question. It therefore focusses on identifying how Euroma can improve the performance of the filling lines 709, 710, and 711. It does so by drafting, and comparing possible solutions to reduce the speed losses, and microstops incurred. Section 5.1 focusses on identifying possible solutions. The section also elaborates on the costs, and potential savings, of these propositions. Section 5.2 explains why some microstops, and speed losses are excluded within the scope of Section 5.1. Section 5.3 answers the main research question in that it reflects on the potential solutions provided, and selects which solutions fit, and ought to be implemented. The central question within chapter 5 is the following: *"How can Euroma improve the performance of the filling lines 709, 710, and 711?"*

5.1: Options to minimize incurred losses

Section 5.1 focusses on identifying possible solutions to the performance losses identified in this study. The section also elaborates on the costs, and potential savings, of these propositions. Section 5.1.1 introduces the propositions and elaborates on the assumptions used. In proposing potential solutions, a distinction is made between smaller, "technical" solutions, and larger, "meta" solutions. Section 5.1.2 discusses the technical solutions, whereas Section 5.1.3 focusses on the meta solution.

5.1.1: Introducing the solutions

Increasing the performance of the filling lines comes down to minimizing the losses incurred within the performance category. We are therefore focused on identifying potential ways to lower the number of microstops, and reduce the time lost on speed loss. This section distinguishes potential solutions to do so. The first four solutions are what we call "technical" solutions, which means that they propose a technical intervention in the setup of the filling lines. The other five solutions are more extensive, so called "meta" solutions. This means that they require a change in corporate policies and/ or strategy. The technical solutions have been drafted in corporation with the technical service employees, and experienced operators. The meta solutions mainly took shape following interviews with the technical service employees, the unit manager, and team leaders. The solutions are now listed.

- Solution 1: Replacement sensor 630
- Solution 2: Guidance rail conveyor belt cartons
- Solution 3: Closing mechanism cartoner 709
- Solution 4: Sachets checkweigher 711
- Solution 5: Visualization of production speed
- Solution 6: Operator training
- Solution 7: Production sequence
- Solution 8: Maintenance and TPM
- Solution 9: Availability and knowledge of technical support personnel

Within the next paragraphs, the potential savings, and additional benefits, of implementing the solutions are discussed. These savings are based on the 709, 710, and 711 alone. In collaboration with the company, it was decided to express the savings in terms of costs saved annually. Within calculating these savings, several assumptions were made. These are listed below:

- The potential savings with regard to the prevention of microstops were calculated per shift based on the relative occurrence, and duration of the observed microstops within the field study which ought to be solved by the proposed intervention.
- The total number of shifts run annually on the 709, 710, and 711 amount to 750, 480, and 650, respectively.
- The filling machines experience a warmup period after each interruption. The duration of the warmup period equals 00:01:10 (one minute and ten seconds). Within this time period, the average operating speed is half the optimal speed.
- The direct labor costs amount to €40/ hour.

- The direct machine costs amount to €80/ hour.
- The average period in which microstops and/ or speed loss can be experienced equals 6 hours per shift. This excludes the time period reserved for changeovers, tests, and/ or planned maintenance.
- 30 seconds were added to each microstop as the MES system starts to register a stop only after this time period. The actual stop is therefore 30 seconds longer. This means that the average duration of a microstop, as presented in Section 4.1, is also 30 seconds longer. It therefore equals 90 seconds for the 710, and 711, and 80 seconds for the 709. The alteration is already accounted for within the duration of the microstops as presented in, *Table 15* ,*Table 16*, and *Table 17*.
- An estimate was made as to the percentage of shifts which experience the problem, and the percentage of occurrence being solved by the proposed solution. The estimation on the percentage of shifts experiencing the problem was made based on the occurrence within the field study, and discussions with experienced operators.
- The costs are a rough estimation based on an estimate on material, and labor costs. The costs are included to serve as a frame of reference.

In addition to the potential annual savings which implementing the solutions ought to yield, the time that is saved per shift is also included to serve as a frame of reference. The solutions are listed and discussed in the next paragraphs. Solutions 1,2,3,4, and 6 are easily linked to the microstops observed within the field study. *Table 19*, *Table 20*, and *Table 21* show which microstops are prevented by which solution. Within *Table 18*, we find the legend that is used within the aforementioned tables. The nine solutions are discussed hereafter. The technical solutions are described in Section 5.1.2, the meta solutions in Section 5.1.3.

Solution	Description
1	🟩 Replace sensor 630
2	🟨 Guidance conveyor cartons
3	🟧 Closing Mechanism cartoner
4	🟦 Move/ adjust sachet checkweigher 711
6	🟥 Operator training
-	⬜ Microstop not considered in solutions

Table 18: Legend division microstops under solutions

709						
Microstop	Observation 1 Order M00012025		Observation 2 Order M00012033		Observation 3 Order M00012034	
	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
🟩 Sensor fill station 630	-	0:08:00	2	0:04:00	n.a.	
🟥 Carton twisted 🟨 on conveyor belt	4	0:03:00	1	0:00:45	2	0:01:30
🟥 Restart after misfeed	3	0:02:15	4	0:03:00	6	0:04:30
🟥 Cartoner misfeed bag	3	0:07:30	4	0:10:00	6	0:15:00
🟧 Improper sealing carton cartoner	1	0:02:00	3	0:06:00		
⬜ Jam valve fill station			4	0:06:00		
🟥 Timing/ sensor valve station			1	0:00:45	4	0:03:00
🟥 Sensor sachets cartoner			1	0:01:00		

Table 19: division Microstops 709

710						
Microstop	Observation 1 Order M00011939		Observation 2 Order M00011797		Observation 3 Order M00012142	
	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
⬜ Sensor/ restart fill station	2	0:02:30				
🟥 Readjustment setup Solas conveyor	1	0:01:30				
⬜ Reset Solas foil	2	0:01:30				
⬜ Solas fallen carton			1	0:01:30		
⬜ Solas loss of count	1	0:02:30				
🟥 Carton twisted 🟨 on conveyor belt			1	0:00:45		
🟥 Jam + reset valve station					7	0:10:30
⬜ Changeover foil + reset fill station					2	0:04:00

Table 20: division Microstops 710

711				
Microstop	Observation 1 Order M00012212		Observation 2 Order M00012213	
	Occurrence	Total duration (hh:mm:ss)	Occurrence	Total duration (hh:mm:ss)
Fill station reset disruption sachets	11	0:16:30		
MAS disruption Muerer	1	0:02:00		
Ventilation filling machine	1	0:01:30		
Checkweigher jam sachets	8	0:08:00		
Seal cleaning fill station	1	0:01:30		
Closing carton cartoner	1	0:01:00		
Jam bag cartoner			4	0:05:00
Restart after misfeed			4	0:03:00
Jam bag valve station			1	0:01:15
Setting glue gun cartoner			1	0:01:15
Palletizer disruption			3	0:06:00
Fill station crumbles bag			8	8:00:00
Error feed cartons cartoner			1	0:03:00
Lose bag fill station			2	0:02:00
Carton twisted on conveyor belt			2	0:01:30
Muerer conveyor full			2	0:01:00
Palletizer overflow			2	0:03:00

Table 21: division Microstops 711

5.1.2: Technical solutions

Solution 1: Replacement sensor 630

The malfunctioning sensor within the funnel of the filling machine of the 709 is responsible for several reoccurring microstops. This malfunctioning is caused by powder which sticks to the sensor's pitchfork, rendering the sensor uncapable of detecting a lack of raw material supply. The average duration of a microstop caused by this malfunction equals 00:02:00. However, the problem is not incurred during each shift. Based on discussion with the operators, we assume the proportion of the shifts to experience the problem to be 30%. When we replace the sensor of the 630, there will be no microstops caused by the malfunctioning of this sensor in the future. The effectiveness of the solution is therefore 100%. Based on these percentages, the total annual saving comes down to €9,404 This saving is spread across two categories. €7,281 is saved on the prevention of microstops, €2,123 on the prevention of the warmup period experienced thereafter. The saving with regard to the prevention of microstops is based on an expected time saved per occurring shift of 00:16:11. The savings on the reduced speed losses is based on 8 microstops per occurring shift. There are no additional benefits, and the estimated costs of replacing the sensor amount to €300. The idea of replacing the sensor originated by observing the process and talking to experienced operators. The feasibility was checked by the technical service personnel who agreed that the sensor currently in place is prone to errors. This sensor is also used on other filling machines. However, the problems experienced on these machines are not comparable to the problems incurred on the 709. This could indicate that the sensor itself is broken.

Solution 2: Guidance rail conveyor belt cartons

The 709, 710, and 711 experience microstops caused by the presence of twisted cartons on the conveyor belt leading towards the tray loader. The average duration of the microstops in question equals 00:00:45. The cause of the problem is found in two things: (1) when the cartons pass the checkweigher, there is a section of "unguided" conveyor belt. (2) Operators do not adequately set and maintain the conveyor, and preceding glue machine. The latter causes a disruption of smooth product flow. By placing a guidance rail on the now unguided section of the conveyor belt, the problem is partially solved. The problem is assumed to be experienced in 70% of the shift. The potential annual savings of placing a guidance rail come down to €5,362. This saving is spread across two categories. €2,098 is saved on the prevention of microstops, €3,264 on the prevention of the warmup period experienced thereafter. The saving with regard to the prevention of microstops is based on an expected time saved per occurring shift of 00:02:50. The savings on the reduced speed losses is based on 4 microstops per occurring shift. The estimated costs of placing a guidance rail amount to €500, and there are no additional benefits. The solution came about discussing the problem with experienced operators, and the technical service employees. These shed light to the second cause of the problem, being the inadequate setting of the glue machine and conveyor belt by the operator. For this reason, the problem is also partially solved by solution 6: Operator training. Therefore, the microstops caused by twisted cartons are also included within this solution. Both solution 2, and 6 contribute 50% to solving the problem.

Solution 3: Closing mechanism cartoner 709

The cartoner closes the cartons in which the sachets are placed. This is done by a rotating closing mechanism" (See *Figure 17*). The tabs used within this process are fragile, and non-fixated, which enables jammed products to influence the relative position of the tabs. When this position is altered, the cartons are not closed properly. Several stops are caused by an operator having to readjust the settings of the tabs. Fixating these tabs, or changing the type of tab used would solve this problem. Both these options require little adjustment of the mechanism itself. Introducing a gliding sloth could already proof sufficient. The tabs currently in place are only used for specific product formats, namely the 2/7, 2/8, and 3/30. These numbers stand for the number of sachets within a carton, and cartons within a tray, respectively. Within 2021, 64 orders fit this description. With an average duration of 16 hours per order this amounts to an expected 128 shifts per year. Operators are free to select another closing mechanism which means that the tabs are probably not used in all 128 shifts. The assumption was made that in 50% of these 128 shifts the tab is used. The proposed solution of changing the closing mechanism will solve the problem for 100%. Additional benefits include saved time on inspecting produced pallets on potential unsealed cartons. The total estimated savings come down to €4,501. €512 is saved on the prevention of microstops, €149 on the prevention of the warmup period experienced thereafter, and €3,840 on saved rework. The saving with regard to the prevention of microstops is based on an expected time saved per occurring shift of 00:04:00. The savings on the reduced speed losses is based on 2 microstops per occurring shift. In total 00:30:00 per occurring shift is reserved for the rework, and therefore included within the calculation of the additional benefits. The expected costs of the proposed solution amount to €500. According to the technical service, the solution only requires minor adjustment. The solution was drafted with help of operators and technical support personel.

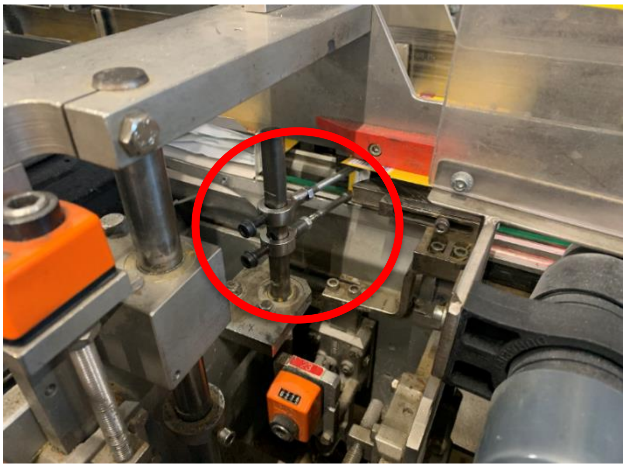
Figure 17: Closing mechanism cartoner

Solution 4: Sachets checkweigher 711

The checkweigher positioned behind the fill station of the 711 experiences frequent jams. This problem is caused by an unguided section of conveyor belt right after this checkweigher. Attaching a guidance rail would solve this problem. Another option is to reposition the checkweigher itself as it is somewhat awkwardly positioned while it is not perfectly aligned with the filling line. It could be an idea to slightly relocate the checkweigher, and/ or place it further along the line (past the machine which levels the bags). This could solve the problem. However, the problem is also partially caused by the setup of the filling machine by the operators. The bags are transported from the filling machine to the conveyor belt by means of a rotating suction clamp. The moment of release determines how a bag is placed on the conveyor. This setting can be altered. Each jam is approximately 00:01:00, and the average occurring order experiences eight jams. This makes that the time saved per occurring shift equals 00:08:00. When we assume that 30% of the orders experience the problem of sachets jamming, and 50% of the occurrence is prevented by the section of guided rail, the potential annual saving comes down to €1,690. This saving consists of €780 saved on the prevention of microstops, and €910 saved on the prevented warmup periods experienced thereafter. As the problem is partially caused by the inadequate setting of the suction clamps of the filling machine by the operators, it is also influenced by the operator training (solution 6). Both the operator training, and the repositioning/ adjustment of the checkweigher are assumed to solve the problem by 50%. There are no additional benefits, and the expected costs of repositioning and placing a guidance rail entail to around €300. The idea of repositioning the checkweigher was brought up by the technical service, the idea of placing a section of guidance rail came from observing the process.

5.1.3: Meta solutions

Solution 5: Visualization of production speed

Operators rarely alter the speed of the filling machine, and are currently not challenged and/ or triggered to do so by the team leaders. The overall attitude towards the achieved production speeds is best described as indifferent. By visualizing the production speed both for the operators, and the team leaders, the incurred speed losses and microstops are likely to be reduced. This "visualization"-procedure includes:

- Stimulation of operators to adjust the speeds of the filling machines.
- Replace/ adjust the display portraying speed 711 (not, or barely readable).
- Creating a dashboard for the team leaders. This dashboard is to include all filling lines, and portray the current speed, achieved speed on the past 8 hours, the main disruptions within the past 8 hours, the current state of the production line (setup, production, or reset), and the OEE scores.
- Capture all microstops under the availability category to increase awareness on the speed loss.
- Update the advised settings with which the operators set the filling speed of the dosing machine (Remove the old books from the filling lines and re-evaluate the correctness of the advised settings incorporated within these books).
- Incorporate these advised settings into MES so that operators cannot adjust them.

It is difficult to assign savings to these changes. Therefore, we consider a scenario. If the speed with which the machines are set increases with 2 fills/min without influencing the chances of breakdowns, and minor stops as a result of the proposed solution, this would result in a total annual saving of €18,490 found in the decrease in speed loss incurred. However, the potential additional benefits are also considerable. The dashboard does not only provide the team leaders with information on the production speed, but also on the current performance of the individual lines. Weak performance and/ or reoccurring production stops are more easily recognized which enables for a quicker response. For example: within the field test we experienced a lot of microstops on the 710 as a consequence of the foil of trays sticking to each other. It turned out that this was caused by a production error of the foil used. Whereas the team leaders were aware of this problem, the operators were not. The frequent microstops, and "tray loader" disruptions could have been observed via the aforementioned dashboard. When the operator would have been advised to use different foil, this would have saved considerable valuable production time now lost on microstops and speed loss. The total annual number of expected shifts on the 709-711 equals 1880. If due to the increased awareness on the status of the filling lines we save just an average of 2 minutes of downtime, microstops, or setup time on each shift, the total annual savings amount to €7,520. An estimate of the total costs of this solution is €5,500. The idea of creating the dashboard came forth from an interview with the team leader, who explained that he did not have a good way of monitoring the filling lines and was therefore unaware of reoccurring problems and/or ill performance.

Solution 6: Operator training

A majority of the observed microstops can be traced back to improper settings of the machines by the operators. Amongst others these include:

- Crumbling bags cartoner: caused by the setup of the valve station and equalizer
- Jams valve station: caused by the setup of the valve station

- Jams sachets checkweigher 711: (partially) caused by the setting of the suction clamps of the 711
- Carton twisted on conveyor belt: (partially) caused by the setting of the glue gun and conveyor belt.
- Adjustments of the glue gun: microstops caused by an inadequate initial setup.

These are all microstops that could have been prevented given that the operator would have had more experience. Upon questioning, operators explained that they receive little training. The unit manager agreed, and explained that there is no "standard" training program. The team leaders are free to decide how, and how long, to train the operators. In practice, most operators are placed under the care of an experienced operator for a duration of one month. Within this time period they are expected to learn the basics of the filling line to which they are assigned. When this overall training is improved, and standardized, the total number of microstops, and overall speed loss is expected to decline significantly. In discussions with the team leader, unit manager, and technical application manager, we agreed that it would be beneficial to train operators correctly setting up the machines, how to correctly use the MES system, and how to efficiently perform a changeover. This would mean introducing a theoretical aspect in which the operators are presented with common causes and/ or solutions to machine failures etc. When the observed shifts are assumed to represent the average order, the total annual savings on the prevention of microstops caused by operator inexperience amounts to €17,404. The total annual savings on the reduced warmup periods equals €13,536. These numbers are based on an average time saved on microstops of 00:35:00 per occurring shift, with 50% of the orders assumed to experience troubles related to operators inexperience, and the training preventing these troubles with a success rate of 50%. When we furthermore assume the average production speed to increase by 3 fills/min as a consequence of an improved training program, this would come down to an additional annual saving of €27,781. However, this does not encompass all potential savings. Additional benefits could emerge for example in the form of a reduction of setup times. The influence of operator training on this variable is difficult to determine, which is why it is not included within this study. The total savings as presented within this paragraph amount to €58,722, but are potentially even larger. How about the costs? When increasing the training of operators by an additional 2 weeks, with an increased theoretical section of supervised study of 8 hours, the expected cost per operator ranges around €4,000. However, this only captures the initial investment costs. Ideally operators would receive an annual "update" training on the MES system and changed procedures. This would come down to an annual investment of €160 per operator per year based on a 4 hour course.

The influence of the first six solutions proposed can be linked to potential savings via the observed microstops which are prevented given that the solutions are implemented. However, the effects of the last three solutions are more difficult to examine. Therefore, not all savings are determined for each individual solution. The solutions are first explained, after which a frame of reference is created as to the potential magnitude of savings.

Solution 7: Production sequence
Operators claim that after each changeover, the filling lines experience "startup" trouble. This view is supported by the literature. Scheduling larger orders, and decreasing the number of changeovers could therefore be beneficial to the incurred microstops, and speed losses. Production should be scheduled so that the required adjustments of machines is minimized. Increased batch sizes, and production sequencing of products which are "alike" in their production speed is furthermore mentioned within the literature as a potential way to increase production speeds (See Section 4.1). When the number of changeovers is decreased, the machines will need fewer adjustments by the operators. The latter reduces the chances of incorrect adjustments which, in its turn, ought to cause a drop in the number of microstops experienced, and speed loss incurred.

Solution 8: Maintenance and TPM
Maintenance of machinery is of large influence on the occurrence of microstops. As we have seen, it is also of influence on the speed loss via the "warmup" period. Whereas the overall level of machine status was described as sufficient by the technical service employees, they did have a remark. Within Euroma, the filling lines are to some extend maintained by the operators. They carry out certain scheduled cleaning and small maintenance tasks such as lubrication. Within the company, this is referred to as TPM (Total Productive Maintenance). The technical service employee indicated that these maintenance activities are scheduled randomly. Officially, a technical service employee has to be present whenever the maintenance is performed so that he or she can assist the operator. Currently, the technical service cannot always be present due to the inconsistency of the planning of this maintenance. This effects the quality of the maintenance performed, and the experience gathered by the operator via the lessons which he or she learns from the more experienced technical service employee. Both factors are of influence on the number of microstops, and speed loss incurred. When the maintenance activities are scheduled on fixed times in the future, the total time lost on microstops, and speed loss incurred thereafter, is expected to decrease due to more thorough maintenance and a boost of operator technical knowhow. This idea was suggested by the technical service personnel, and supported by the unit manager.

Solution 9: Availability and knowledge of technical support personnel
Several experienced technical employees explained that within the technical service experience is somewhat lacking. Especially newer employees miss technical knowhow. This is best explained by the nature of the machines used in production. A lot of the machinery has been rebuilt or adjusted several times. This makes it difficult to "get to know the machines". Experience is therefore extremely valuable which is why Euroma should strive for an efficient handover of this experience. Especially since the number of experienced technical service employees is very limited, the company is currently too dependent on these people. The filling department furthermore has a low priority when it comes to the order in which the technical staff is to solve breakdowns. This, in combination with a low number of service engineers, is responsible for long waiting times. Within 2022 (Jan-May) the total time lost on the 709-711 due to unavailability of technical staff amounts to 153 hours. This cost the company €18,360. The annual costs of hiring an additional service employee equals € 76,800. However, since there are 21 filling lines, the costs assigned to the 709-711 only amount to € 10,971. The cost of an improved knowledge transfer is difficult to estimate. When we assign a "loss" of 4 hours of education per unexperienced service employee per week for a duration of 1 year, this amounts to an investment cost of € 8,320 per unexperienced service employee. During this time period, the less experienced technical service employees are to be placed under the care of experienced personnel to carry out a variety of maintenance and/ or troubleshooting tasks.

Solutions 7,8, and 9 all influence the probability, and duration of the occurrence of microstops. Hereby, they indirectly influence the time lost on speed losses incurred as a consequence of the warmup period experienced after these microstops. However, all three solutions also influence the probability of machine breakdown. The latter is included within the availability category of OEE. In providing a frame of reference as to the saving potential of the three solutions, it would be unfair to disregard these losses. *Table 22* shows the expected time lost on downtime, and microstops for the year 2022. Within the computation of the expected time lost on microstops, the average duration of a microstop registered within MES has been adjusted by 30 seconds (see assumption Section 5.1). This means that the average duration of a microstop equals 00:01:30 for the 710, and 711, and 00:01:20 for the 709.

	709	710	711	Total
Expected downtime 2022	1093:31:22	1436:48:53	1405:44:34	3936:04:48
Expected Microstops 2022	588:50:49	572:49:48	709:08:31	1870:49:08
Average duration Microstop	0:01:20	0:01:30	0:01:30	

Table 22: Expected Downtime + Microstops 2022

As we cannot directly assign any microstops and/or speed losses observed within the field study to either three solutions proposed (solutions 7,8, and 9), we illustrate the savings potential by means of a graph. In evaluating the savings potential of the solutions, we consider both microstops and breakdowns (OEE2b & OEE3b) as the solutions yield an influence on both of these categories. *Figure 18* shows the relationship between the percental decrease of time lost on breakdowns and microstops, and the potential costs saved annually.

The total savings are the sum of two types of savings: (1) the savings caused by a decrease of the time lost on the microstops and downtime itself (expected direct savings), and (2) the savings incurred as a consequence of a reduction in the number of warmup periods experienced (expected savings warmup period). The latter category only considers the warmup periods caused by the occurrence of a microstop. The influence of the reduction in warmup period caused by malfunctions could not be incorporated as the average duration of these breakdowns is unknown. This means that the expected savings on speed loss (warmup period) only embody the savings as a result of a decrease in the number of microstops experienced. In *Figure 18*, a 1% reduction of the total time lost on microstops, and downtime equals a reduction of 01:39 (mm:ss) per eight hour shift.

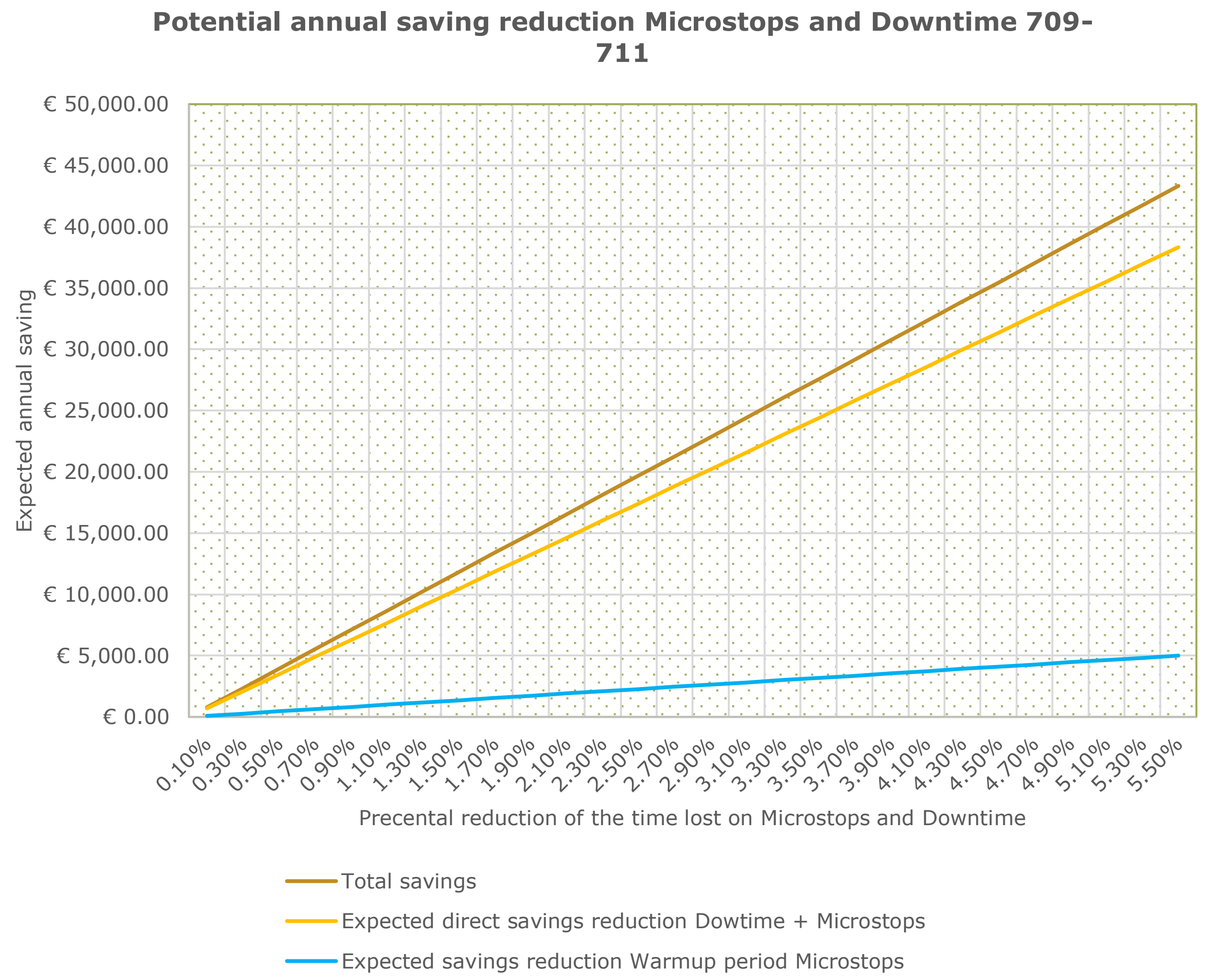

Figure 18: Potential annual savings reduction Microstops and Downtime 709-711

Table 23 portrays the potential costs, and savings of solutions 1-6. The table is drafted to serve as an indication, is based on the scenarios as discussed in the previous paragraphs, and does therefore not encompass guaranteed savings. The solutions 7,8, and 9 are not included within the table as direct savings and costs cannot be adequately determined based on the research performed.

Solution	Estimated costs	Potential annual savings Microstop	Potential annual savings speed loss	Additional benefits/ savings	Total annual saving
1	€300	€7,281	€2,123	€0	€9,404
2	€500	€2,098	€3,264	€0	€5,362
3	€500	€512	€149	€3,840.00	€4,501
4	€300	€780	€910	€0	€1,690
5	€5500	-	€18,490	€7,520	€26,010
6	€4000 per operator	€17,404	€41,318		€58,722

Table 23: Estimated cost savings solutions 1-6

Section 5.1 elaborates on nine propositions that are focused on improving the performance of the filling lines 709, 710, and 711. Solutions 1-4 are "technical solutions", whereas solutions 5-9 are so called "meta solutions". The technical solutions focus on minor adjustments in the setup of the filling lines, while the meta solutions require a change in corporate policies and/ or strategy. *Figure 18* shows the savings potential of implementing (a subset of) solutions 7,8, and 9. *Table 23* shows the costs, and savings potential of solutions 1-6. We see that solutions 1-4 require little investments, and yield small savings. They are of the type "small effort, small reward". The savings potential of solutions 5,6,7,8, and 9 is larger. However, these solutions also require larger changes.

5.2: Exclusion

Not all microstops and potential causes of speed losses mentioned in Section 4.2 are considered and/or prevented by the solutions proposed in Section 5.1. The microstops that are left unexamined are now listed, and their exclusion is explained. Thereafter, the same is done for the excluded causes of speed losses.

Microstops

1. Overload of the palletizer 711: the overload of the palletizer is excluded as we cannot influence and/ or solve this overload without major investments/ changes of the production process. These investments are not ever going to be returned based on saved time on microstops.
2. Some of the microstops observed are to be seen as normal disruption and/ or breakdowns. Within the course of conducting this study, the following microstops/ breakdowns were already solved by the technical service and therefore irrelevant for this study; (1) Sensor fill station 710, (2) "MAS" error Muerer, (3) Crumbling of bags fill station 711, (4) Lose bag fill station 711, (5) Fill station disruption sachets 711, and (6) Jam valve fill station 709.
3. Some of the microstops observed are unavoidable. This means that their occurrence is not caused by any error or fault, but is expected to happen at some point in time. These include: (1) Changeover foil + reset fill station, (2) Clean ventilation canal fill station, (3) Clean seal fill station, and (4) Changeover foil + reset Solas.
4. Some microstops were so unique, as identified by the operators, that finding solutions for these microstops is not rewarding. These include: (1) Conveyor full Muerer, and (2) Error feed cartons cartoner.
5. Some of the causes of the microstops observed could not be found, which is why they were excluded within this study. These include: (1) Solas fallen carton, (2) Solas loss of count, and (3) Palletizer disruption

Speed losses

1. Product dependent speed loss: the influence of product characteristics on production speed was examined as initial element of this research (see Appendix B). However, no possible solutions to minimize this influence were examined due to time limitations.

5.3 Evaluating the solutions

Within Section 5.1, nine solutions were introduced and explained. These solutions contribute to reducing the occurrence of microstops, and lessening the incurrence of speed losses. Hereby, they contribute to improving performance. However, some solutions might be more favorable or suitable than others. When we consider the main question of this study: *"How can Euroma improve the performance of the filling lines 709, 710, and 711?"*, we should take these aspects into consideration. Therefore, Section 5.3 assess the suitability of the solutions and compares their effects so that is possible to give a solid recommendation as to the steps which Euroma ought to undertake. For clarity, the nine solutions are briefly revisited before we further indulge on comparing the attractiveness, and fit, of the solutions.

Technical solutions:
- Solution 1: Replacement sensor 630
- Solution 2: Guidance rail conveyor belt cartons
- Solution 3: Closing mechanism cartoner 709
- Solution 4: Sachets checkweigher 711

Meta solutions:
- Solution 5: Visualization of production speed
- Solution 6: Operator training
- Solution 7: Production sequence
- Solution 8: Maintenance and TPM
- Solution 9: Availability and knowledge of technical support personnel

As all solutions proposed to improve the performance of the filling lines require a change, be it in the setup of the filling lines or corporate policy, the attractiveness of these solutions ought to be assessed. In consult with the unit manager, we agreed to evaluate the attractiveness of the options based on their cost, effectiveness, additional benefits, and expected time to implementation. The costs represent the investment that is required to implement the solution, whereas the effectiveness of a solution is expressed in terms of its annual savings potential. Hereby, we consider savings caused by a reduction of microstops, and speed losses incurred. Under additional benefits we ought to capture potential supplemental benefits in areas other than the performance category. For example: an additional benefit of improving the operator training program (solution 6), is the expected reduction of setup times between different orders. The latter does not influence the performance score, but is an auxiliary benefit influencing the availability score. The expected time to implementation ought to capture the time period required to implement, and experience effects of the solutions.

Directly comparing the nine solutions on these criteria is difficult due to the inherent difference between the technical solutions, and the meta solutions. The technical solutions require fewer investments and are focused on technical alterations of the setup of the production lines. The meta solutions on the other hand require larger commitment and are mainly focused on shifts within corporate strategy and/ or attitude. Apart from their scope, and costs, the two types of solutions furthermore differ in their savings potential, the expected time to implementation, and potential additional benefits. Comparing their costs, and benefits directly would thus result in a skewed image. Therefore, the technical, and meta solutions, are discussed individually. The technical solutions are considered first (Section 5.3.1), the meta solutions follow thereafter (Section 5.3.2). The chapter concludes with a summary, in which the main research question is answered, and the solutions which the company ought to implement are selected (Section 5.3.3).

5.3.1: Technical solutions

The four technical solutions proposed share similar characteristics. They are all focused on eliminating specific microstops observed within the study, take little time to implement, require comparable investment costs, and yield similar savings (see *Table 24*). They are of the type: "small effort, small reward". The latter does not mean that their effect is neglectable. The unit manager explained that as a policy, projects or investments that are not focused on long term strategic goals are considered given that their payback period does not exceed three years. All technical solutions fit this description. As selecting one option does not influence, or strain the capability of implementing the other solution, and not a single option is more effective than the sum of all, implementing all four solutions is most desirable. Hereby, the performance of the filling lines is improved the most.

Solution	Estimated costs	Potential annual savings Microstop	Potential annual savings speed loss	Additional benefits/ savings	Total annual saving	Expected time to implementation
1	€300	€7,281	€2,123	€0	€9,404	< 2 weeks
2	€500	€2,098	€3,264	€0	€5,362	< 2 weeks
3	€500	€512	€149	€3,840.00	€4,501	< 2 weeks
4	€300	€780	€910	€0	€1,690	< 2 weeks

Table 24: Overview technical solutions

5.3.2: Meta solutions

Whereas solutions 5, and 6 could to some extend be linked to potential savings via observed causes of microstops and speed losses, this does not hold for solutions 7-9. The effectiveness of these solutions is merely evaluated based on possible scenarios (see Section 5.1) This makes it difficult to compare, and asses the attractiveness of the solutions based on their effectiveness in reducing microstops, and alleviating speed losses. The same holds for assigning costs, an expected time to implementation, and additional benefits to these solutions. This makes it illogical to examine, compare, and assess the solutions based on these criteria alone. However, this does not mean that we cannot give an advice, as there are more aspects to consider. In assessing the attractiveness of the solutions, we reconsider the goal of this study. When we contemplate on this goal, we see that originally it is twofold: (1) to improve the *performance* of the filling lines, and (2) to enhance the observability, and communicability of this performance so that management can steer upon this metric more adequately. The solutions 5-9 are now revisited to compare their effects to these objectives.

Solution 5: Visualization of production speed
This solution is mainly focused on increasing awareness on live performance of the filling lines. By implementing this solution, both team leaders, and operators are more aware of speed losses. In addition, communicability of the performance is enhanced. These factors combined enable for more adequate steering of production. The solution also includes updated advised speed settings, and more active detection of reoccurring microstops. This ought to reduce the speed losses, and microstops incurred. The solution hereby adheres to both objectives of this study.

Solution 6: Operator training
We saw that a majority of the microstops experienced could be traced back to improper settings of machinery by the operators. Improving the operator training program to give an impulse to operator experience and knowhow, reduces the occurrence of these errors. The solution is therefore focused on the performance of the filling lines through the expected decrease of microstops. In addition, as a consequence of more thorough training, the speeds with which the operators set the machines is expected to increase. Hereby, performance is enhanced through a decrease of incurred speed losses. Beside these effects, additional benefits could be experienced for example in the form of reduced setup times.

Solution 7: Production sequence
Changing the production sequence so that littler adjustments are needed between succeeding orders, or littler different orders are processed, ought to yield in a decrease of breakdowns, setup time, and microstops. This solutions is therefore primarily focused on the availability category of OEE. The performance category is merely influenced by an expected decrease in microstops in the time period postceding a changeover.

Solution 8: Maintenance and TPM
Finding fixed moments to schedule small maintenance enables technical service employees to be present during these activities. Hereby, they can assist and teach operators boosting their technical knowhow. Due to more thorough maintenance the time lost on breakdowns, microstops, and hereby speed losses is expected to decrease. However, the effect of this solution is mostly felt in the availability category (machine breakdowns). The performance is only expected to increase slightly due to less microstops following up after a machine breakdown.

Solution 9: Availability and knowledge of technical support personnel
Increasing the availability and knowledge of the technical support personnel is expected to, similarly as solution 8, mainly translate in less and shorter lasting machine breakdowns. The effects are therefore more dominantly experienced in the availability category. The performance is again only expected to increase slightly as a consequence of littler microstops postceding machine failures.

When we compare the solutions with the goals of this study, we see that solutions 7,8, and 9 are more focused on the availability category of OEE than the performance category. In addition, the unit manager explained that they were currently already working on an improved order scheduling algorithm. This algorithm is focused on minimizing the adjustments required between, and total number of changeovers. Solution 7 is therefore already accounted for and in the process of implementation. The same holds for solution 8, as the company is currently trying to change the scheduling of small maintenance activities so that they are performed on standard times. Solutions 7, and 8 are therefore not included within the advised actions to undertake. However, persevering in the process of implementing these changes is encouraged. As the goal of this study is to improve the performance of the filling lines, the company is advised to implement solutions 5, and 6. The implementation of either of these solutions does not impose a strain or difficulty on implementing the other. As the effect of implementing both solutions is the highest, this is the advised action. Both solutions contribute to improving the performance, and the ability to observe, communicate, and act on this performance.

5.3.3: Summary

The performance of the fillings lines is improved the most by implementing all four technical solutions. This means that Euroma ought to (1) replace the sensor of the 630, (2) place a guidance rail on the conveyor belts postceding the cartoner, (3) replace the closing mechanism of the cartoner of the 709, and (4) place a guidance rail and/ or reposition the sachets checkweigher of the 711. When we consider the meta solutions, the company ought to implement solutions 5, and 6. The company should therefore strive to visualize the production speeds, and improve the operator training program. Out of the five meta solutions, these are most aligned with the goals of this study. They are expected to yield the biggest result as to improving the performance of the filling lines and/ or improving the observability, communicability, and ability to act on this performance.

Chapter 6: Conclusions, recommendations, and discussion

This chapter contains the main conclusions, recommendations, and discussion of this research. Section 6.1 focusses on the conclusions with regard to the main research question, whereas Section 6.2 discusses the recommended action for the company and introduces potential interesting areas for follow-up research. Section 6.3 contains the discussion.

6.1: Conclusions

The central question within this study is: *"How can Euroma improve the performance of the filling lines 709, 710, and 711?"*

The performance of the filling lines is captured in the performance category of the OEE scores. This score is dependent on the ideal cycle time of the products produced. This is referred to as the "workload". The workloads currently in place are based on the name plate capacity of the filling machines. Based on these workloads, the "optimal" production speed entails 200 fills/min, and the production norm is set at 96000 fills per eight hour shift. We have seen that the representativeness of the performance score is questioned by the management team, which is why the overall OEE scores are currently little used. In order to reevaluate these workloads, the overall OEE measuring method employed by Euroma was examined. Within the company, OEE is largely equipment oriented. In addition, OEE is expressed in time and quantity. The system currently employed is therefore most in line with the Nakajima method of measuring OEE.

The workloads were reexamined via the achieved production speeds of the 709, 710, and 711 within the time period of January 2021 – May 2022. The average achieved production speeds of these lines encompassed 141.9, 140.3, and 146.0 fills/min, respectively. With help of experienced technical service personnel, the technical limitations of all machines used within the filling lines were examined. The maximum production rate of a filling line is determined by the "slowest" machine used. For the 709, the cartoner and filling machine were the bottleneck, the production speed of the 710 is limited by the filling machine and tray loader, and the output of the 711 is suppressed by the filling machine. The technical maximum filling rates of the filling machines of the 709, 710, and 711 are: 180, 170, and 190 fills/min. When comparing these maximum rates with the achieved production speeds, we saw that in at least 99.1%, 98.5%, and 99.4% of the orders considered, the achieved production speed did not exceed this technical maximum speed for the 709, 710, and 711, respectively. It is likely that the remaining surpasses of the technical maximum identified are explained by inconsistencies within the data, or incorrect use of the MES system by the operators. The workloads on which the performance scores of the filling lines are based is therefore best aligned with these technical maximum speeds. Based on these workloads, the production norms of the 709, 710, and 711 come down to 86400, 81600, and 91200 fills/shift.

The average overall performance scores, adjusted for the re-evaluated workloads, for the 709, 710, and 711 on an order level come down to 70.76%, 67.72%, and 65.81%. This is a low score compared to the world class score of 95%. Within the period of January 2022- May 2022, the combined total amount of time lost within the performance category of the three filling lines amounts to around 1200 hours. As the availability category is a frequent area of interest within Euroma, the time lost on the Setup phase of production is included to serve as a frame of reference. The total time lost on this Setup phase of production (changeovers between orders) amounts only to around 1150 hours. The performance losses are therefore greater than the losses within the OEE2a category. The 1200 hours of performance loss is built up out of around 520 hours of microstops (stops with a duration under 3 minutes), and around 680 hours of speed loss (loss incurred due to running at sub-optimal speeds). These performance losses cost the company an excess of €143,000.

In order to reduce the costs incurred as a consequence of these performance losses, the filling lines 709, 710, and 711 were observed. Common causes of microstops were identified. In addition, operators were questioned about their experiences with regard to the causes of microstops and slow speeds. We found that microstops find their cause in numerous fields. The frequent changeovers, and production sequencing are one influence. In addition, the operator training, experience, maintenance, and technical setup of the filling lines all contributed to the relative occurrence of microstops. The incurred speed losses are experienced as a consequence of (1) the setup of the fill machine by the operator, and (2) the number of disruptions within the production process. Whereas the first cause influences the speed of the filling line when it is up and running, the second cause influences the magnitude of the speed loss incurred as a consequence of the warmup period experienced after each interruption of production.

Nine proposition were made to decrease the number of microstops, and lower the speed loss incurred. These include four technical adjustments of the filling lines, and five changes with regard to operator training, steering by the team leaders, production sequencing, maintenance, and technical support. The latter are referred to as "meta solutions", whereas the first category is referred to as "technical solutions". For the technical solutions, the effectiveness of the solutions on the prevention of microstops, and speed loss, was evaluated based on the expected annual savings within these fields as a consequence of implementing the solution. This effectiveness, in combination with an estimated cost, implementation time, and scale of additional benefits was used to assess the attractiveness, and fit of the proposed solutions. The meta solutions were compared on the same criteria where possible. In addition, their implications were compared to the main goal of this research. This goal is: (1) to improve the *performance* of the filling lines, and (2) to enhance the observability, and communicability of this performance to enable more adequate steering. We found that performance is most improved by implementing all four technical solutions (solutions 1-4). In addition, two meta solutions are to be implemented (solutions 5-6). These solutions are now listed, and briefly discussed:

1. Replacing the sensor of the 630
2. Guidance rail conveyor belt cartons
3. Closing mechanism cartoner 709
4. Sachets checkweigher 711
5. Visualization of the production speeds
6. Improvement of the operator training program

Implementing any subset of these solutions does not strain the capability of implementing the others. As the effect on the performance is largest when all solutions are implemented, this is the recommended action. The costs, and potential benefits of these solutions are now discussed. As Euroma normally expresses these savings on an annual basis, this format is followed. For a more detailed overview, we refer to Section 5.1.

Replacing the sensor of the 630: the annual savings incurred by replacing the sensor of the 630 filling machine (709) amount to €9,404, whereas the investment is estimated at a mere €300. The sensor fails in 30% of the shifts, in which the failure is expected to result in 8 microstops with an expected total duration of 16 minutes.

Guidance rail conveyor belt cartons: placing a guidance rail on the conveyor belt leading from the cartoner toward the succeeding checkweigher has the potential to induce an annual saving of €5,362. The investment costs are estimated at a mere €500. The saving is based on problems related to the absence of this guidance rail to be experienced in 70% of the shifts. If the problem occurs, this causes an average of 4 microstops with a duration of 45 seconds each. This makes the total time lost per occurring shift 2 minutes and 50 seconds.

Closing mechanism cartoner 709: altering the closing mechanism of the cartoner of the 709 is expected to yield an annual saving of €4,501. The costs are estimated at €500. The problem of cartons not being closed properly is only expected to arise in about 64 shifts annually. However, when the problem occurs, rework is created for which 30 minutes per occurring shift ought to be reserved.

Sachets checkweigher 711: repositioning, and placing a guidance rail toward, the sachet checkweigher of the 711 is expected to yield an annual saving of €1,690. The costs are estimated at €300. In this calculation, the time saved per shift incurring troubles (which is 30% of the shifts) is set at 8 minutes.

Visualization of the production speeds: The objective of this solution is to increase the awareness of the performance, and especially the operating speeds, of the filling lines. Current awareness on these two elements by the operators, and team leaders is low. The visualization of production speeds is to increase this awareness and hereby open up the possibility to recognize and act on slow speeds and common causes of microstops. The "visualization" procedure includes:

- Replacing or adjusting the display of the 711 filling machine
- Creating a dashboard for the team leaders that includes current speed and performance
- Capturing all microstops under the availability score instead of the performance score, hereby increasing the observability of the incurred speed losses. This shift is also justified by the observed correlation, and vague boundary between microstops and breakdowns.

We experienced that operators set the production speed based on outdated "advised" settings, and that they are not, or barely, encouraged to tweak or alter production speed upon the current circumstance of production. Updating, digitalizing, and communicating in addition to stimulating operators to play with the advised settings is therefore also included within this solution. The overall solution has the potential to save an annual €26,010. This saving is based on an increase of production speed by 2 fills/min, and a 2 minute reduction of downtime, microstops, or setup time per shift. The costs are budgeted at €5,500.00. The dashboard could furthermore serve as a tool used in the takeover of shifts in that it enables team leaders to quickly show the largest losses and peculiarities. Incorrect inputs of operators in MES are hereby also more quickly recognized and adjusted, improving the overall quality of the OEE scores.

Improvement of the operator training program: This solution is focused on the training program of the operators. Extending, and standardizing, the training program is expected to yield a positive influence on the occurrence, and duration of microstops and hereby also on the magnitude of the speed loss incurred. In addition, training the operators how to optimize the speed of the filling machines is also expected to increase the average achieved production speed. The potential savings related to the microstops and speed loss total €58,722. This saving is based on a reduction in microstops of 35 minutes per shift, and a 3 fills/min increase in production speed. This does not yet include potential savings in the reduction of setup times. Extending the program by an additional two weeks is budgeted at €4,000 per operator. Annual refresher courses are estimated at an additional €160 per operator.

The solution as presented within the previous paragraphs represent the actions which Euroma can take to improve the performance of the filling lines 709, 710, and 711.

6.2: Recommendations

As it is the wish of the company to steer more actively on OEE, this score should accurately depict the effectiveness of the filling lines. As component of the overall OEE score, the performance score should therefore be aligned with reality. The workload on which this score is currently based overestimates the maximal speed with which the filling lines operate under ideal circumstances. Whereas this speed is currently set at 200 fills/min, the research showed that these speed ought to be adjusted to 180, 170, and 190 for the 709, 710, and 711, respectively. We therefore advise the company to readjust the workloads based on these re-evaluated maximum speeds, and implement this change within the MES system. The company is furthermore advised to standardize and/ or clearly define the meaning of a "production norm" as used by the different departments so that miscommunications and over, or underestimations of the output of the filling lines are prevented. Within this study, production norms capture the number of fills that ought to be produced on a line during an eight-hour shift when the availability and quality scores of that line are considered to be 100%. These production norms entail to 86400, 81600, and 91200 fills/shift for the 709, 710, and 711, respectively.

The “world class OEE score” is set at 85%. Currently Euroma scores in the 25-50% range. If the company wants to steer towards the world class score, they need to persevere in their notion to increase the level of steering based on the OEE scores. Currently, little to no attention is given to the valuable information contained within these scores, and underlying registration. By updating the workloads within the performance category, the presentiveness of the OEE scores is improved. However, this is of little use when the OEE scores continue to be utilized as little as they currently are.

With regard to improving the performance of the filling lines 709, 710, and 711, we advise the company to:

1. Replace the sensor of the 630 filling machine (709)
   The malfunctioning of this sensor was identified as a frequent cause for the occurrence of a microstop. Adjusting or replacing the sensor therefore decreases the number of microstops incurred, and hereby speed losses experienced.
2. Place a guidance rail on the conveyor belt succeeding the cartoner
   The absence of a guidance rail on this conveyor was identified as a frequent cause for the occurrence of microstops, and hereby also influences the experienced speed losses.
3. Replace the closing mechanism of the cartoner of the 709
   The inadequate design of the closing mechanism of the cartoner of the 709 is responsible for little microstops, and speed losses. However, as the consequence of cartons not being closed properly are large (in the form of rework and risk of delivering faulty products), adjusting the closing mechanism is rewarding for the company.
4. Sachet checkweigher 711
   The awkward position of the sachet checkweigher postceding the fill machine of the 711, in combination with the unguided section of conveyor leading toward this checkweigher is a frequent cause of jams (microstops). If the company places a guidance rail on the conveyor belt, and repositions the checkweigher, the occurrence of these microstops are prevented. As a consequence, littler speed loss ought to be experienced.
5. “Visualize” the production speeds
   The unawareness of actual performance of the filling lines is a cause of “slow speeds”. The operators are not, or little, challenged to experiment with production speeds. In addition, team leaders are not always aware of the current performance of the filling lines which hinders active steering and involvement. Visualizing the production speed ought to prevent these losses.
6. Improve the operator training program
   A lack of operator training and/ or experience is found as a common cause of the occurrence of microstops. In addition, it has an influence on the duration of the microstops, and the speed losses incurred.

This study demonstrates the potential benefits of analyzing the performance scores. Investigating the reasons behind common microstops, and speed loss by observations and actively questioning employees holds large annual saving potentials. As a frame of reference, the total amount of money lost on the performance losses of the 709, 710, and 711 within the first 5 months of 2022 amounts to over €143,000. We would therefore advise the company to take a more active, and frequently reoccurring role in investigating and/ or analyzing the performance of these, and other, filling lines. Even though abolishing this loss completely is not possible, this study has demonstrated that sometimes small interventions can already have quite an effect.

Several operators indicated that production speeds are largely influenced by product characteristics. This view is supported by research performed on the influences of both product, and order, characteristics. The study showed that especially products with a max weight between 35-90 grams are produced with higher speeds on the 709, and 711. In addition, the order size seemed to influence the production speed of the 711. The magnitude of these influences has not been determined. This might be a potential interesting area for further research. Additional interesting areas for future research are included within Section 6.3.5. The company is advised to carefully examine these findings.

We conclude with the recommendation to use this study as a guide and carry out a similar study, including the reevaluation of the workloads, focusing on the filling lines which were not considered within this research.

6.3: Discussion

Section 6.3 contains the discussion. The section is divided into five sub-sections. Section 6.3.1 elaborates on the change within the scope of the project, 6.3.2 discusses the validity and reliability of the research, 6.3.3 addresses limitations of the research, 6.3.4 elaborates on the implications of the research, and section 6.3.5 addresses supplementary findings.

6.3.1: Scope of the project

The definition of a workload, as identified in Section 3.1, is not the definition that was specified by Euroma at the start of this study. Initially, the company wanted to establish "product-dependent" workloads. This means that Euroma wanted ideal cycle times not only dependent on the specifications of the machine used, but also on the characteristics of the product being processed. The setup of the study was therefore focused on identifying several categories of products for which workloads were to be determined. This made these workloads "product-dependent".

In practice, this means that in addition to the technical limitations of the machines, the workloads were to capture speed losses incurred due to specific product characteristics. It was the wish of the company to capture all "normal" or "unavoidable" speed losses in the workloads. Hereby, the performance score was to only capture "abnormal" speed losses in the future. According to the production department, abnormal losses were to be seen as "unknown" or "unforced" losses. This meant that these losses do not include losses which can be explained by characteristics of the product being processed. To give an example: if we consider a product from which we know that due to its low density and tendency to "dust" while filling, production rates are structurally lower, this should not influence the performance score as this is a "known", "unavoidable" loss. However, this view changed over the course of the study.

The main reason of this change is found in the use of OEE throughout the company. If OEE is solely used as KPI in the production department, we could accommodate the speed losses caused by product characteristics in the workloads as the scores are only used to compare performance to the "normal" situation. In this setting OEE serves solely as an internal benchmark. However, if the OEE score is to be used throughout different departments, including the finance and sales department, the underlying workloads cannot hold any losses as this would endanger correct pricing of the production of these products. High performance scores could mislead other departments into thinking that the products are produced at high speeds, unless of course everyone is very well aware of the different underlying workloads upon which the score is based. As the latter is difficult to realize, and the metric will, in the future, be used company wide, the operations manager decided that workloads were to only be based on technical limitations of the filling lines and were to exclude losses caused by product characteristics.

As this change of view manifested at a later stage, clusters of products had already been determined and the influence of product characteristics were already revealed. The process of defining clusters and analyzing the influence of product characteristics on production speed took a large amount of the available time. In addition, it holds valuable information for the company, even now that the definition of a "workload" has shifted. Therefore, the full procedure, and its findings, are described in Appendix B. The appendix focusses on the following research question:

"What are the new, product-dependent production norms of the filling lines 709, 710, and 711?"

Although the new product-dependent productions norms were not determined, interesting links between product characteristics and production speed were found. Especially products with a max weight between 35-90 grams are produced with higher speeds on the 709, and 711. The order size is furthermore an aspect influencing the production speed of the 711. The magnitude of both influences has not been determined.

6.3.2: Assessment of validity and reliability

When examining this research using the checklist on good research (Cooper & Schindler, 2013), the following can be said. The purpose of the research, the research process and research design have been clearly identified and are thus in line with the checklist on 'good research'. The findings, and conclusions, presented within the study have been thoroughly explained. Assumptions used within the analysis of the achieved production speeds, and/or calculations of the savings of the interventions proposed to increase the performance of the filling lines are mentioned as such. Any data inconsistencies and/ or biases are listed within Section 6.3.3. We will now take a look at the validity, reliability, and shortcomings of the research.

When we assess the validity of the study, we must make a distinction between internal validity and external validity. Internal validity can be explained as the extent to which the observed results, variables and measures capture the objective that is studied. Within this study, the objective is to study, and improve, the performance of the filling lines. In doing so, the study makes use of the OEE performance-scores. OEE is a metric specifically fit for capturing a line's performance and identifying (productivity) losses. The variable used in this study therefore perfectly captures the objective that is studied. Therefore, internal validity is high.

External validity reflects the extent to which a study's findings can be generalized to other situations or settings. Or to rephrase, it answers the question on whether or not the findings of the study can be applied to a broader context (Bhandari, Understanding external validity, 2021). When we consider that this study uses a definition of workloads, and production norms as identified by Euroma, the findings of the study might not be usable outside of the company given that other companies do not share these exact definitions. Therefore, external validity is low. This can be considered as a limitation of this study. It does, however, not mean that this study is completely useless in other business cases, as the study can still serve as a guideline. Other companies might therefore still find the systematics of this study helpful, and adjust the study to their personnel preferences where deemed necessary. It is also important to note that the findings can be generalized onto the other filling lines of Euroma itself.

Within this study OEE, and more specifically the performance category within this OEE, is considered and analyzed. These performance measurements are gathered by the MES system by means of PLCs. With the same inputs, these PLCs would measure the exact same value over and over again. This makes the reliability of these measurements extremely high. Analyses based on these measurements, such as this study, can therefore be considered reliable. The analysis conducted is explicitly explained so that any biases or inconsistencies are clearly visible, and shortcomings of the research are addressed in a separate section of the report. The methods used to analyze the data on the achieved production speeds, including the outlier detection, the clustering algorithm, and the statistical test are all scientific, unbiased methods.

6.3.3: Limitations of the research

Within the calculation, and analysis, of the achieved production speeds, the speed loss, OEE, and microstops, there are several elements which might have influenced the results. In addition, the calculations of the potential savings of the proposed solutions are, to some extent, subjective. These influences, and potential biases are listed and briefly explained hereafter. For a more detailed explanation of the first two points, we refer to Appendix D.

1. Achieved production speed
   Within the calculation of the achieved production speed, we made use of: (1) the total number of fills produced, (2) the operating time, and (3) the minor stoppages. However, these three elements are influenceable, for example by faulty inputs of operators.

2. Quality
   The quality score is influenced by the total number of units produced (Totalcount), and the number of good units produced (Goodcount). Within the current setup of the production lines, it is questionable whether the information on these two attributes is correctly gathered and therefore in line with the actual performance on "quality".

3. Clustering
   The clustering has been mainly focused on factors influencing the fill-speed. Potential influences on the speed of the other machines were not considered. In addition, there was little information on product characteristics which is why the influence of only a limited number of characteristics could be examined.

4. Cost estimation
   Within Section 5.1 nine propositions are made to increase the performance of the filling lines. The study also elaborated on the costs, and potential savings, of these propositions. The effectiveness of the solutions are evaluated hereafter based on these costs and savings. The estimated time to implementation is also included in this evaluation. These elements were difficult to objectively determine. Within the evaluation of the potential costs, and savings of the proposed solutions several assumptions were made, listed in the aforementioned paragraph. The number of assumptions is quite large, which makes the representativeness of the findings questionable. The calculations therefore serve as an indication. This has been discussed with, and explained to, the unit manager who agreed that this method is the most representative/ objective method available. However, the actual costs and/ or savings of the solutions might deviate.

6.3.4: Implications of the study

Within this study the workloads upon which the performance score is based are reexamined. Within the production industry, a workload is most commonly defined by the NPC of the "slowest" machine. It is uncommon for companies to reevaluate these workloads. However, this study has shown that as a consequence of equipment age, and changed production circumstances, these workloads might render themselves unrepresentative. The study has presented a structural way in which companies are able to reassess these workloads based on analyzing the achieved production speeds, and comparing these to the technical limitations of the equipment. This is a new approach that is not yet described in the literature. In addition, a light is shed on the importance of addressing performance losses by identifying the overall magnitude of the incurred speed losses and microstops within the operational production time. Whereas these two factors are the least examined losses of OEE within the industry, this study provides an insight into the potential savings which addressing these losses could bring. In addition, it proposes ways to identify and tackle these losses by considering frequent causes mentioned in the literature, comparing, and supplementing these causes by observations in real-life. The research that has been performed could therefore well serve as a guideline for other production and manufacturing companies in search of boosting performance scores.

6.3.5: Additional findings/ experiments

During the course of performing the research, we observed several phenomena not directly linked to this study that ought to be of interest to Euroma. These are now briefly discussed.

1. All filling lines are equipped with multiply checkweighers. The first is located after the filling machine. This PLC measures the weight of the individual bags. Whenever this weight deviated to much from the set "nominal weight", the product is rejected and

pushed of the conveyor belt. The second checkweigher is positioned in series of the cartoner. This checkweigher weighs the cartons and performs a similar check. However, the range of weights that is accepted is quite narrow, especially since the only check that needs to be performed is whether the carton contains (the right amount) of bags. Since the individual bags already passed the first check, this narrow range is a cause of unnecessary rejects. Removing the second checkweigher, or using broader bounds, will lower the number of cartons being falsely rejected. This is the advised action.

2. A sample product was taken from several production runs. The weight of the individual product was compared to the weight as listed on the consumer package. As the consumer weight stands for the total weight of the ingredients, the measured weight has been adjusted so that the weight of the packaging material is excluded. The results are shown in *Table 25.*

Product	Weight consumer package (Gram)	Measured weight (Gram)	Avg. giveaway (Gram)	Giveaway %
A	85	91, 107, 107	16.67	19.61
B	74	85	11	14.86
C	41	51	10	24.39
D	112	121	9	8.04

Table 25: Giveaway

This giveaway is influenced by the operator, who sets the dosing of the filling machine. All giveaway up to 10% is covered by the customer. All giveaway above this percentage needs to be covered by Euroma. Especially since the production speed is also influenced by the weight of this dosing, it is interesting to examine optimal settings. This entails a balancing act between production speed, material savings, and percentage of rejects. Currently, there is little attention for this potentially large area of savings. It is advised to train, and actively point operators on correctly setting up the dosing of the filling machines and examine advised settings.

3. The outcomes of the calculations on the order OEE performed within this study deviate from the order OEE that is registered in PowerBI. Further investigation pointed out that this discrepancy was found in the method of calculation. Within this study, the individual inputs of the shifts which form one order were clustered. Therefore, the times spent in each state OEE1a – OEE3b were aggregated, and a weighted average order OEE was computed. Within PowerBI, the individual inputs are treated equally, and the order OEE is calculated as the average OEE across the different shifts. The total duration of production during any given shift is therefore not of influence on the weight of that shift on the order OEE. Chances are that a similar method is used in the day OEE, week OEE, month OEE, and year OEE. This provides a biased, and incorrect, view on performance. As it is the wish of the company to steer more actively on an OEE score which is as representative as possible, we advise Euroma to reexamine/correct the method used to calculate the OEE scores within PowerBI.
4. The format notation is non-uniform. An example format is the 1/12. The first digit represents the number of bags within a carton, whereas the second stands for the number of carton on a tray. Whereas most formats follow this rule, there are several exceptions. For some products, the finance department makes use of a "number * weight" notation. However, even within the production department we find deviations. The 3/30, and 4/24 notation for example. The first holds 3 bags within a carton, and 10 on a tray. The second holds 4 bags in a carton, and 6 on a tray. This differs from the 1/12 notation and causes confusion amongst the operators. For clarity reasons it is advised to use a uniform method across, and within, the different departments of the company.

5. The categorization, and menu used by the operators to define disruptions within the MES system is experienced as unclear. The large number of options, slight differences between the options, and poor formulation result in faulty inputs. Within the time period of 01-01-2022 till 30-06-2022, a total of 10.000 hours was booked wrong across 18 production lines. In consultation with the unit manager, technical application manager, and a team leader, the options were examined, and an alternative menu was created. Whereas the original system held 39 options, the improved version only held 28. The system was tested within a controlled digital test environment of MES. Multiple operators were confronted with 12 cases. These cases described an occurrence/ disruption which had to be booked in the MES system. They were not given any explanation about the new menu to test the instinctiveness of the system. Their scores using the new system were compared with the scores of them using the old system. All scores remained equal or increased. The continuous improvement manager will evaluate the feedback of the operators in the upcoming weeks to further optimize the menu. A common error within the data relates to the decision of when to put the production line into the "Setup", "Production", and "Reset" phase. This is not perse influenced by the menu created as it relates to the setup of the MES system, and is not concerned with disruptions. This setup is best altered. However, the system does not directly support a change of these phases. A good alternative would be to write a clear guide for the operators which explains when to put the production line into which state and what steps are to be taken within these states. Another important step in reducing the wrong input lies within the training of the operators. Operators should be trained more regularly in navigating the systems.
6. The calculation, and representativeness of the quality score is questionable. Both the Totalcount, and the number of rejects are underestimated. In addition, the checkweighers fail to upload complete reports on the weight distribution, and number of products produced (see Section 6.3.3). When the accuracy of the quality score is not improved, a potentially interesting link between dosing weight, production speed and quality is difficult to examine (See pointer 2). We therefore advise to carefully examine the way in which the quality score is build up, decide whether this is in line with expectations, and sort the technical problems of the checkweighers failing to upload their reports.

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Appendix A: Unplanned stops OEE

Reason	Discription	Class	OEE category
Gepland onderhoud TPM	Ploegleider zet lijn stil voor gepland onderhoud TPM.	OEE1a (GEEN PLANNING)	-
Formaat Ombouw		OEE2a (SETUPS)	Availability
Stilstand in pauze, niet gepland.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Schoonmaken extra onder productie		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Materiaal niet aanwezig bij de lijn.	Geen verpakking/Mix aanwezig bij de lijn.	OEE1a (GEEN PLANNING)	-
Gepland onderhoud TD.	Ploegleider zet lijn stil voor gepland groot onderhoud TD.	OEE1a (GEEN PLANNING)	-
Geplande testen	Ploegleider zet lijn stil voor testen.	OEE1a (GEEN PLANNING)	-
Geplande Stilstand in pauze.	Ploegleider zet lijn stil in de pauze.	OEE1a (GEEN PLANNING)	-
Gepland geen order of dienst stil	Er zijn geen orders meer.	OEE1a (GEEN PLANNING)	-
Geplande vergadering	Ploegoverleg of andere vergadering met ploegleider.	OEE1a (GEEN PLANNING)	-
Wachten TD	ALS DE TD AANWEZIG IS, AANPASSEN NAAR DE ECHTE STORINGSREDEN!	OEE2b (OPERATIONELE STILSTANDEN)	Availability
Verkeerde afstelling.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Verkeerde grondstoffen gebruikt.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Uitzoeken incident na verkeerde productie.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Glasbreuk		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Folie problemen		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Open Seal.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Laser codering werkt niet.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Mes snijd niet goed.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Carousel/tangentafel probleem.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Checkweger problemen.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Doseur storing.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Kleppenstation problemen		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Transportrol problemen, bandjes problemen		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Kartoneerder problemen	Kartoneerder of Somic.	OEE2b (OPERATIONELE STILSTANDEN)	Availability
Scanner probleem		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Dozen vuller problemen.		OEE2b (OPERATIONELE STILSTANDEN)	Availability
Dozen printer/tray labelaar problemen.	Inktjet, etiketteer of label machine	OEE2b (OPERATIONELE STILSTANDEN)	Availability
Eindverpakker problemen	Kartoneerder (KT) of trayloader (Paal, Somic)	(OEE2b (OPERATIONELE STILSTANDEN)	Availability
Palletizer/Stapel Robot problemen.	Palletizer, Trapho of Spider.	OEE2b (OPERATIONELE STILSTANDEN)	Availability
Verpakkingsmateriaal niet verwerkbaar		OEE2b (OPERATIONELE STILSTANDEN)	Availability
GEEN ORDERS GEPLAND	Geen actieve jobs	OEE1a (GEEN PLANNING)	-
SETUP	Setup	OEE2a (SETUPS)	Availability
LAAD	Aanloop	OEE2a (SETUPS)	Availability
ONTLAAD	Ontladen	OEE2a (SETUPS)	Availability
RESET	Reset	OEE2a (SETUPS)	Availability
ONBEKEND	Onbekende Storing	OEE2b (OPERATIONELE STILSTANDEN)	Availability
GEEN WERKNEMERS	Geen werknemers toegewezen aan job	OEE1a (GEEN PLANNING)	-
KORTESTOP	Microstop	OEE3b (MICROSTOPS)	Performance

Table 26:OEE categories Euroma

Appendix B: Product-dependent workloads

Chapter 3A: Product-dependent production norms

This chapter focusses on the second research question. It is therefore concerned with identifying new, product-dependent production norms that are to be calculated by means of new, product-dependent workloads. In Section 3A.1, we investigate the meaning and level of aspiration that ought to be captured in the new workloads. The different product categories for which product-dependent workloads, and accompanying norms, are to be determined, are discussed in Section 3A.2. Section 3A.3 elaborates on the method that will be used to establish the workloads.

Section 3A.1: Definition of a product-dependent workload

This section is focused on the following research question:

"What should the new product-dependent workloads exactly entail?"

A product-dependent workload should capture the ideal time it takes to produce one unit of output. This workload should be an achievable target. Within a production line this means that it should definitely take the different processing times of the machines placed in series into account. In addition, product characteristics which are of influence on the production speed (and thus cycle time) ought to be captured in a products workload. It is the wish of the production department to capture all "normal", or unavoidable losses caused by product characteristics under these workloads. An example of the latter: when we produce a product that has a high volume and a tendency to "dust" while filling, and therefore structurally, and consistently, lower the filling speed of this product to compensate for/ minimize the "dusting", this is seen as an "unavoidable", "known" loss. By capturing these losses in the workload, the performance score will, in the future, only capture abnormalities in terms of speed loss. But does accommodating losses within the ideal cycle times not "cloud" your OEE scores?

OEE is solely used as KPI within the production department. Its most important goal is to capture all losses incurred in production. When we consider the ideal cycle time (and accompanying ideal production speed), these should therefore not accommodate any losses yet. However, the production department defines speed losses as: "unknown or unforced". For example: an operator accidentally sets the filling speed to low. Therefore, we can accommodate forced, or known, speed losses caused by product-characteristics within the workloads. These product-dependent losses can be accommodated within the ideal cycle time used within the performance category of OEE. This is only possible since no costs prices are determined based on overall OEE-scores. The metric is therefore not used for commercial purposes, but for internal benchmarking alone.

Section 3A.2: The different product categories

This section is focused on the following research question:

"Which product categories can be distinguished?"

The eventual goal of identifying different product categories is to determine product-dependent workloads for these categories. We therefore want to distinguish categories based on their workload. But via what means can we do so? The answer lies in the historic data of the orders produced. It is true that we eventually want to determine an ideal cycle time (the amount of time it takes to produce one unit of output), and that these cycle times are not mapped. However, a cycle time is the reciprocal of production speed, an attribute that can be computed based on the information gathered while an order is processed. These production speeds will be the main focus area in defining clusters. The goal of Section 3.2 can therefore be rephrased: we need to find out whether there are certain clusters of products that behave similarly in terms of their production speed. If the latter is the case, we can determine an ideal speed for each of these clusters, and evaluate the "ideal cycle time" ("product-dependent" workload) accordingly.

The analyzes of the production speeds (Section 3.3) was performed on an order-level. This means that every order produced on the filling line considered served as an input for the analysis. However, as the objective is to find products which behave similarly in terms of their production speed, performing a clustering on an order level does not yield usable results. Instead, we must look at articles.

Order vs. Article

The filling lines considered within this study package numerous articles. These articles all have a unique article number. This article number corresponds to a particular end product. Products with different article numbers differ in their weight, format, and/or recipe. Therefore, each article, and article number, represent a unique product. Articles are packaged in batches. These batches are referred to as orders. A unique order number is created for each order that is processed. Within an order, an article is produced in a certain quantity. When an article is produced several times over a time period, in different orders, an individual batch can therefore be identified by its unique order number (see *Table 27*).

Order number	Article number	Article description	Production start date	Production end date	Quantity produced (trays)	Production speed (Fills/min)	Cluster
01003	60116	Lasagna MIX	01-03-2020	02-03-2020	10000	119.33	1
00385	60116	Lasagna MIX	15-04-2022	15-04-2022	5000	175.45	2

Table 27: Order vs Article

Order numbers are unique. However, articles are produced numerous times. This means that there are different orders in which the same product is produced (See *Table 27*). When we are to cluster based on the achieved production speeds at an order level, and these production speeds significantly varies between the orders considered, chances are that these orders are placed in different clusters. We would then not be able to identify to which cluster the article produced in these orders is to be assigned. To solve this problem, OEE has been recalculated on an article basis. Here, the production speed of an article equals the weighted average production speed of the orders in which the article has been produced. As we want to identify several groups of products which behave similarly in terms of their production speed, this is the variable on which the clustering is performed.

Clustering

For clustering the data, the K-medoid method has been used. The K-medoids clustering method is a partitioning method which constructs K clusters. This means that the data is clustered in K groups. There are two criteria which should be considered:

i. Each group contains at least one object
ii. Each object belongs to exactly one group

The number K is specified by the user. In order to compute K clusters, the method selects K objects in the dataset. These are called the representative objects. The clusters are found by assigning each object to the nearest representative object based on the specified characteristics of the object. Not every selection of K representative object results in a "good" cluster. The K objects must therefore be chosen so that they are centrally located in the clusters which they define. In other words, the K representative objects must be chosen so that: "the average distance (or average dissimilarity) of the representative object to all the other objects of the same cluster is being minimized" (Kaufman & Rousseeuw, 1990). This is achieved by the K-medoid algorithm which works as follows:

1. Select K random points within the dataset as representative objects.
   :
   a. Associate each datapoint to the closest medoid based on its distance to the different medoids.
   b. Calculate the costs.
   c. Randomly swap one of the K-medoid with another datapoint.
   d. Re-evaluate the costs.
   e. Reject or accept the point as new medoids.
   f. Repeat.
   :
2. Repeat

This method works as an improvement heuristic. An initial solution is (randomly) provided after which this solution is improved. The quality of the solution therefore depends on the number of times that a medoid is "swapped" (steps a-f). This variable ($n \in [0,\infty]$) is chosen by the user. However, this is not the only variable of influence on the quality of the solution. The quality is also influenced by the number of times that K random point are chosen (step 1-2). This variable ($p \in [0,\infty]$) is chosen by the user. Note that for every p, n iteration of steps (a-f) are performed. For each p, the best outcome is stored. In the end, all outcomes are compared, and the clustering with the minimal costs is presented as the outcome of the clustering method. But how does the method evaluate the costs of a particular solution? The costs of a solution can be evaluated by means of the formula depicted in *Equation 17*. (ML| K-Medoids clustering with solved example, 2020).

$$c = \sum_{Ci} \sum_{Pi \in Ci} |Pi - Ci|, where$$

- C_i= medoid (C_i)
- P_i= object (P_i)

Equation 17: Cost of choosing medoid

The K-medoid algorithm therefore randomly selects K representative objects until it finds the K objects which result in the minimal total dissimilarity. The choice and appropriateness of the number K can be analyzed by a validity index. The choice to use the K-medoids method has been made as the method is one of the best suited to uncover structures that are present within data (Kaufman & Rousseeuw, 1990). In addition, the method is more suited than the K-means method in this particular situation. The main difference between the K-medoid and the K-means method is that the K-medoid method selects actual data point as representative objects, whereas the K-means selects arbitrary computed points. In addition, the K-medoid algorithm is more robust to noise and outliers because it minimizes a sum of (pairwise) dissimilarities and not a sum of squared Euclidean distances.

The program used to cluster according to the K-medoid algorithm is RapidMiner. Two models were built in this program. The first model was used to determine the optimal number K, and the second to cluster accordingly. *Figure 19*, and *Figure 24* depict these models, which are discussed in the next paragraphs.

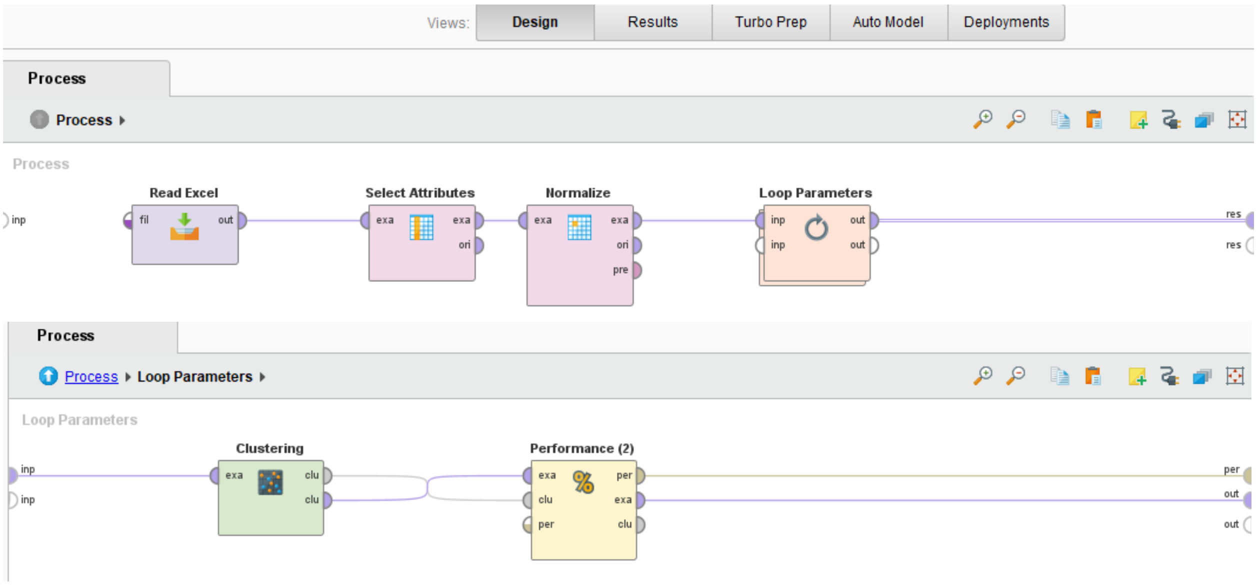


Figure 19: Identifying the number K

In order to determine the optimal number K, we need a measure to evaluate the "correctness" of a chosen value for K. Within RapidMiner, the coherence within a cluster can be evaluated based on the *"Avg. within centroid distance"*. This measure is calculated by averaging the distance between the centroid of a cluster and all of its elements. Increasing the number K will always lead to a lower *"Avg. within centroid distance"*. However, in plotting the number K against the *"Avg. within centroid distance"*, an elbow effect occurs. This means that a point can be identified in which increasing the number K any further decreases the *"Avg. within centroid distance"* by only a small fraction when compared to the impact of previous increasements. The value of this K is considered to be optimal (Dutta, 2019). In *Figure 19*, we see that the model imports the data, after which it selects the attribute to cluster on. For this study, this attribute is the achieved production speed in fills/ min. The attribute is then normalized after which the K-medoid clustering algorithm is performed. Its performance is analyzed by means of the "*Average within centroid distance*". The latter two steps are included within the "loop" operator. This operator varies the value of K from 1 till 10. For each K value, the "max runs", and "max optimization steps" (p, and n) were set at 50, and 100, respectively. This is relatively high when compared to the standard setting of 10, and 100.

The result of the model depicted in *Figure 19,* is a table which displays the average within centroid distance for K=1 till K=10. By means of this table, a graph was computed to identify the "elbow point" and accompanying K for each of the three filling lines. The graphs and tables displaying the relation between K and the average within centroid distance are shown in *Figure 20*, *Figure 21*, *Figure 22*, and *Figure 23*, *Table 28* summarizes the optimal K values.

	709	710	711
Optimal K-value	4	4	4

Table 28: Optimal K value

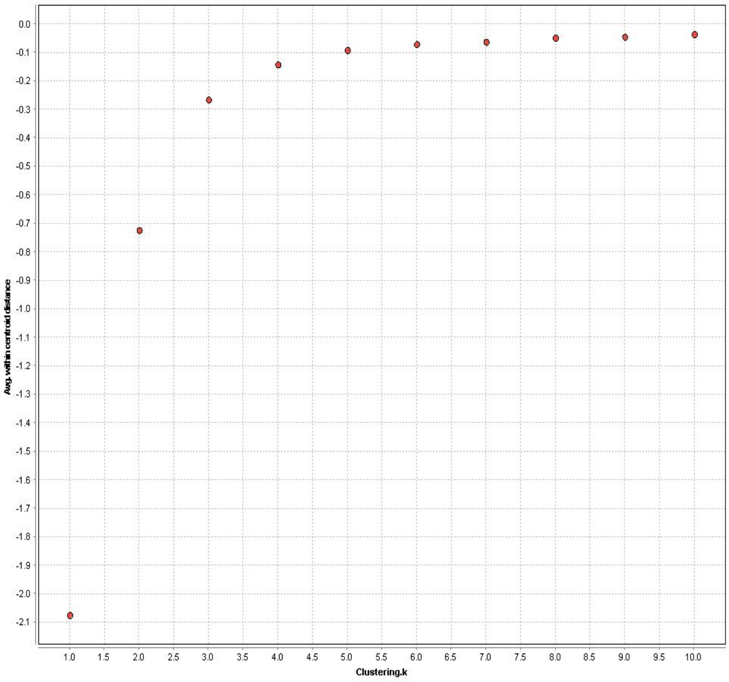


Figure 22: K-value 709

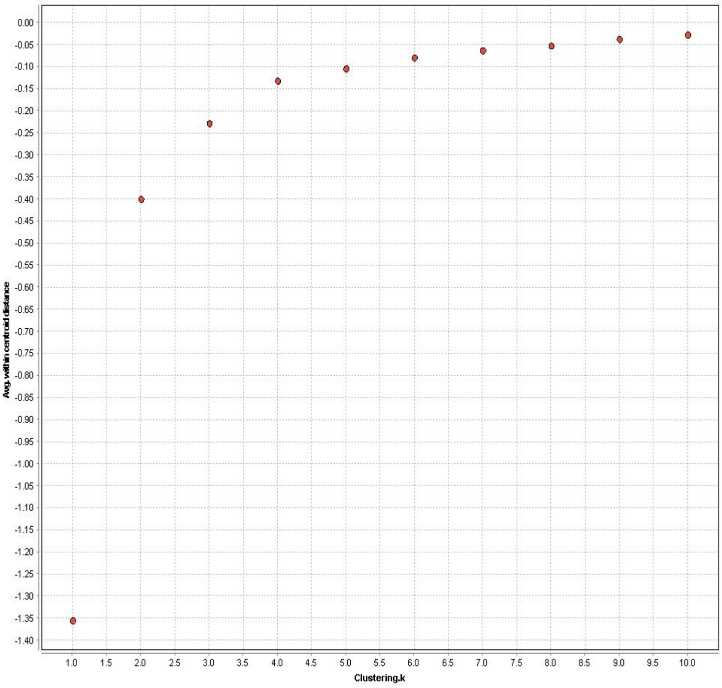


Figure 21: K-value 710

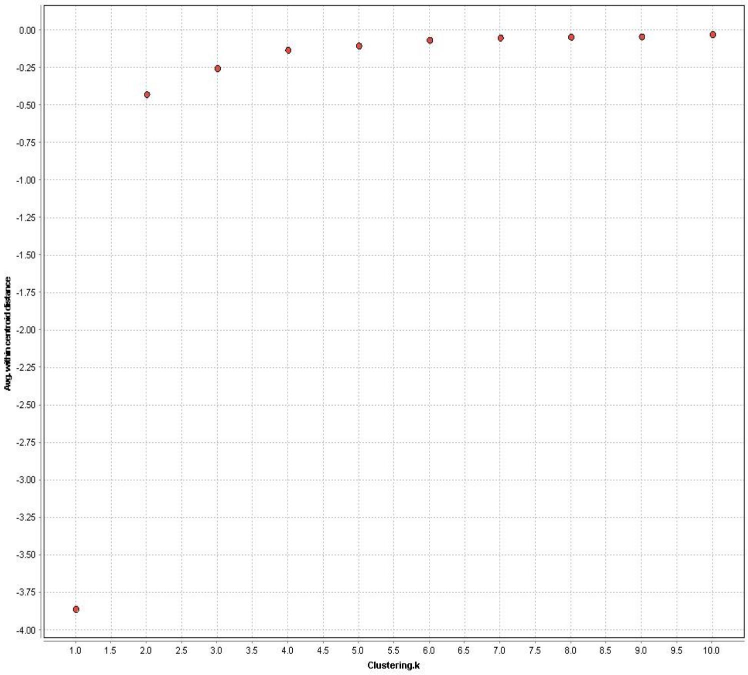
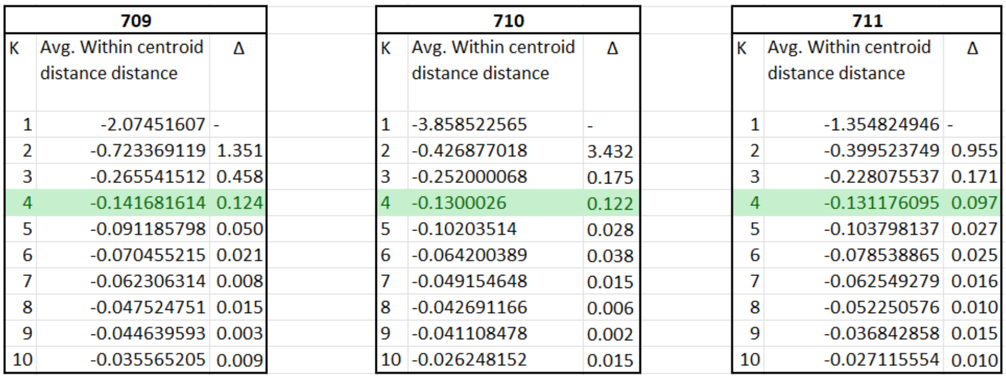


Figure 20: K-value 711



709		
K	Avg. Within centroid distance distance	Δ
1	-2.07451607	-
2	-0.723369119	1.351
3	-0.265541512	0.458
4	-0.141681614	0.124
5	-0.091185798	0.050
6	-0.070455215	0.021
7	-0.062306314	0.008
8	-0.047524751	0.015
9	-0.044639593	0.003
10	-0.035565205	0.009

710		
K	Avg. Within centroid distance distance	Δ
1	-3.858522565	-
2	-0.426877018	3.432
3	-0.252000068	0.175
4	-0.1300026	0.122
5	-0.10203514	0.028
6	-0.064200389	0.038
7	-0.049154648	0.015
8	-0.042691166	0.006
9	-0.041108478	0.002
10	-0.026248152	0.015

711		
K	Avg. Within centroid distance distance	Δ
1	-1.354824946	-
2	-0.399523749	0.955
3	-0.228075537	0.171
4	-0.131176095	0.097
5	-0.103798137	0.027
6	-0.078538865	0.025
7	-0.062549279	0.016
8	-0.052250576	0.010
9	-0.036842858	0.015
10	-0.027115554	0.010

Figure 23: Overview K-value

Having identified the optimal value of K for each filling line, clusters were constructed by means of the model depicted in *Figure 24*. This method makes use of the same “Read”, “Cluster”, “Normalize”, and “Performance” operator when compared to the method used to identify K. However, instead of looping the “Cluster” operator to find the optimal value of K, the optimal value is used to cluster. The “Multiply”, “Join”, and “Write Excel” operators link the articles, with all product and order characteristics, to their assigned cluster. The cluster data was exported to, and analyzed with, SPSS.

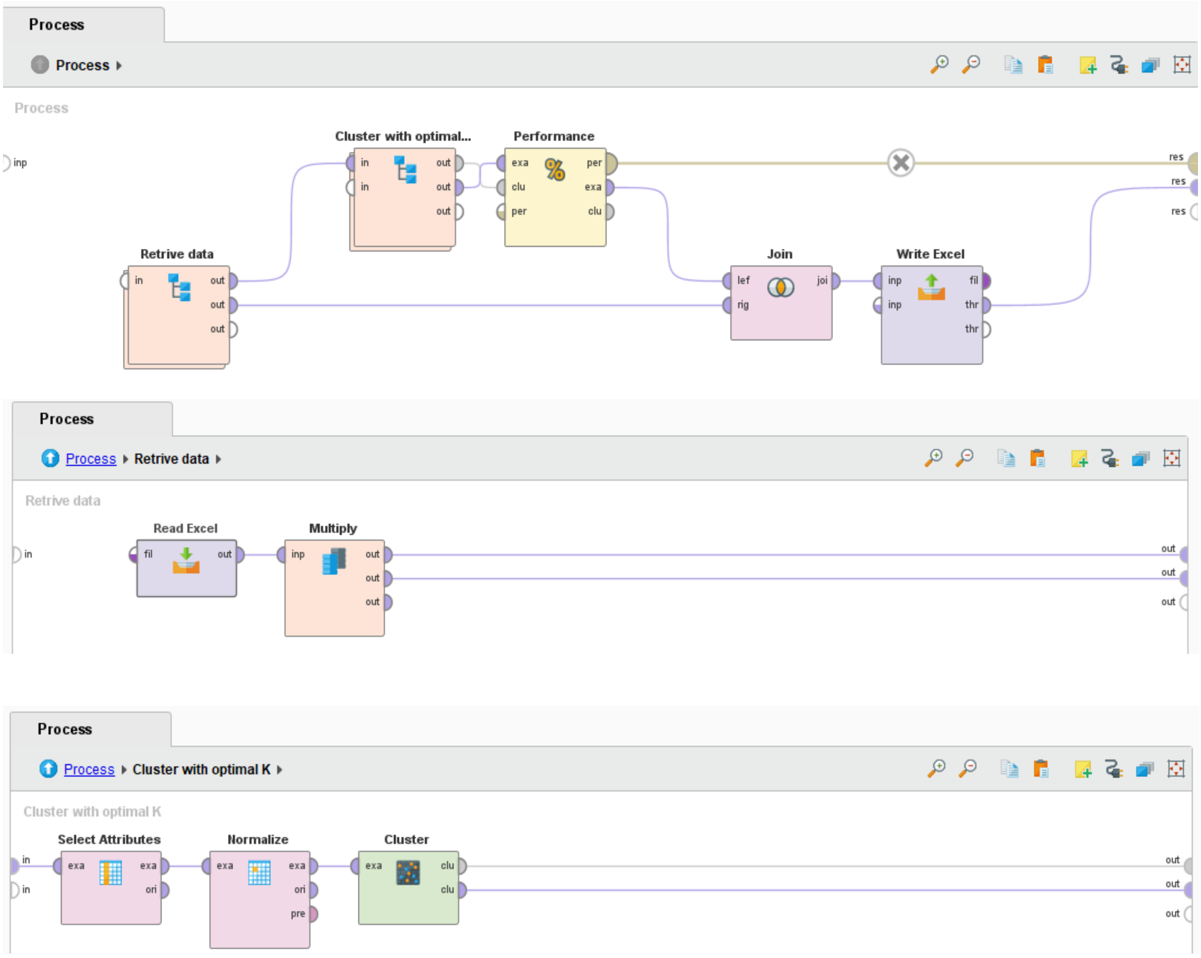


Figure 24: Clustering

With clustering based on production speed, the resulting clusters differ in the range of production speeds which they entail. The cause of these differences is yet to be determined. The product characteristics that are examined within this study are the Fill-type, Format, Max weight, and Avg. order-size. The choice to only consider the "Max weight", has been made as this weight is the most likely to determine the filling speed. As to the other three variables, these were the only characteristics that could be directly linked to the articles considered. In the next section, the filling process, and influence of the aforementioned variables on this process, is explained at a high level.

The process of filling

The filling machine, which marks the start of the filling line, dose the product to its correct weight. It creates "bags" out of a roll of foil in which the correct dosage of the product is deposited. The input is supplied by a big bag (large quantity of the required product recipe). This supply is connected to a funnel. At the bottom of the funnel, the correct dosage is determined by alternatingly opening and closing a set of valves, or by the rotational speed of a screw dispenser present within the funnel. This dosage then "falls" in the bags. The bags are moved along and shoved in a carton package. This carton package is placed on a tray, which in its turn is placed on a pallet. *Figure 25* shows a highly simplified depiction of the filling process.

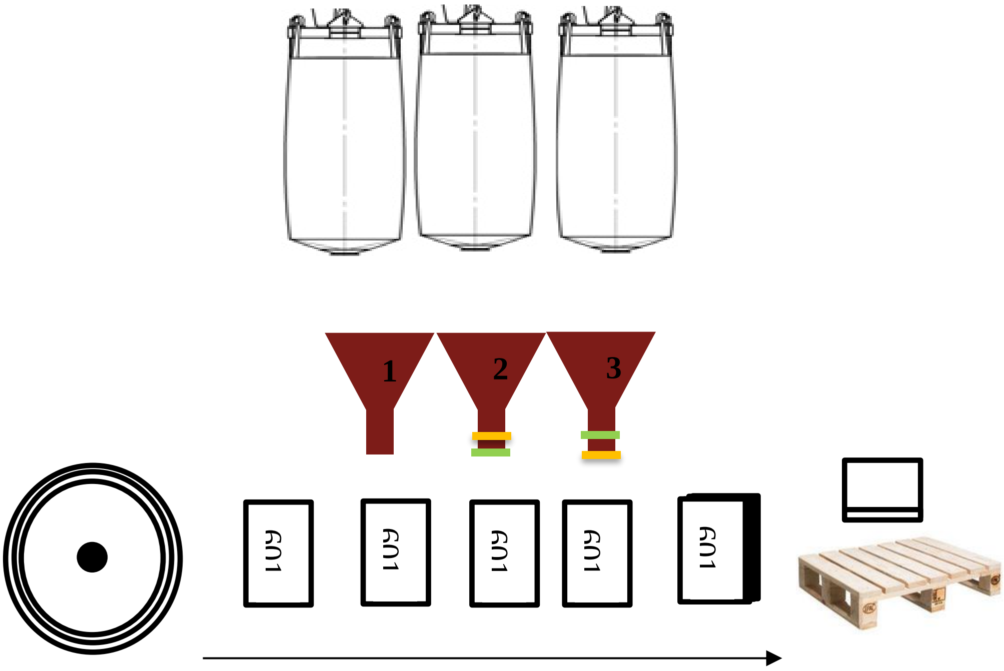


Figure 25: The filling line explained

Product characteristics

The product characteristics examined within this study are exclusively listed:

1. Format: the format of an article refers to the type of package used in production. In total, there are five different formats: (1/12, 2/12, 2/7, 2/8/, and 3/30). The first number indicates the number of bags within a carton, whereas the second stands for the number of cartons placed on a tray, except for the 3/30, which holds 10 cartons on a tray.
2. Fill type: the fill type is either 1,2, or 3. This stands for the number of funnels at which a bag "receives" raw material. A bag can contain only powder (1), powder and vegetables (2), or powder, vegetables, and vermicelli (3) for example. A product is either filled at funnel 1, funnel 1&2, or funnel 1,2,&3 (*Figure 25*). The different ingredients are therefore not mixed prior to filling but filled in series.
3. Max weight: The maximum weight of the ingredient(s) (plural for fill type 2, and 3) deposited in a bag being filled (measured in grams).

4. Average order size: The average production size of the orders in which the article has been produced, measured in the number of fills.

The format and fill type influence the way in which the filling line is set-up by the operator. The Max weight influences the timing of the dosing valves, and or, the rotational speed of the screw dispenser, and the average order size influences the processing time of the order.

To explain the dissimilarity in production speed between the clusters, we want to evaluate whether there is a difference in the distribution and scale of the four variables across these clusters. The distributions of the filling speeds, average max weight, and average order size within the different clusters are provided in *Table 29*, Table 30, and Table 31, respectively.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
709	[87.1, 114.2]	[116.3, 130.7]	[131.0, 149.1]	[150.5, 171.0]
710	[102.6, 126.3]	[129.5, 137.9]	[139.5, 148.4]	[149.6, 168.8]
711	[112.9, 136.3]	[137.4, 147.8]	[148.7, 158.1]	[159.0, 167.5]

Table 29: Distribution production speed

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
709	80.7	85.0	53.7	55.1
710	84.1	47.9	59.8	66.2
711	88.4	68.5	57.9	51.1

Table 30: Distribution average max weight

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
709	37506.8	44817.2	63354.1	58440.2
710	50569.1	53042.7	76212.2	59551.4
711	34414.0	56830.6	68298.6	85612.6

Table 31: Distribution average order size

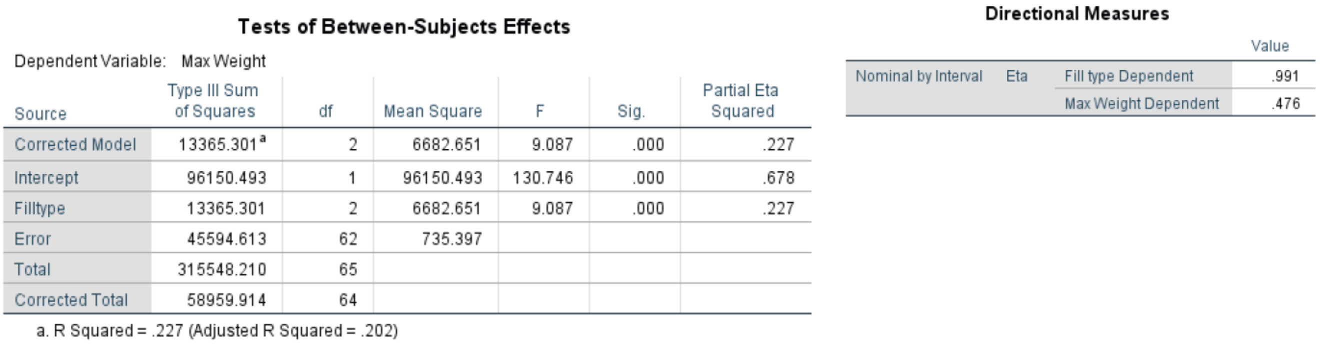
Statistical tests

“Format”, and “Fill type” are measured on a “nominal” scale, whereas “Average order size”, and “Max weight” are measured on a “ratio” scale. The objective of the statistical tests is to identify whether the distribution of the variables differs between the clusters. This would indicate a relationship between the examined variables, and the production speed. The zero hypothesis in these tests remains of the same type:

H_0: *“The distribution of variable X is the same across the different clusters.”*

In comparing the different clusters, the Pearson’s chi-square test, and Kruskal Wallis are used. The Chi-square test is used on the nominal data types, whereas the Kruskal Wallis test is used for the ratio date types. Both tests are non-parametric and therefore not influenced by the distribution of the examined variable. The null hypothesis is rejected when the level of significance < p value (0.05).

As there was a suspicion of correlation between the “Fill type”, and “Max weight”, this correlation was first examined. For this purpose, the Eta squared statistic was used. The Eta squared coefficient is a test of effect size between a categorical and a scale variable. The upcoming section describes the statistical test for the 711 as an example. In *Figure 26*, we see that the Eta squared value equals 0.227. As a rule of thumb, an eta squared value less than 0.01 indicated a small effect, a value between 0.01 and 0.06 a medium affect, and a value larger than 0.14 a large effect. The value 0.227 therefore indicates a large effect.



Tests of Between-Subjects Effects

Dependent Variable: Max Weight

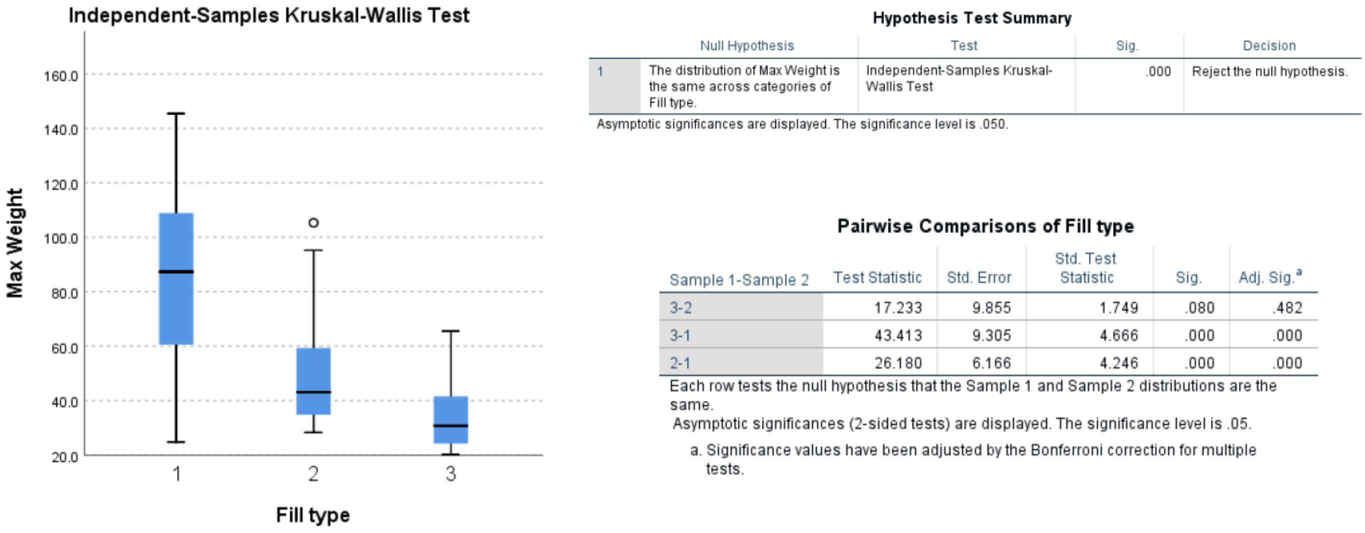
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13365.301[a]	2	6682.651	9.087	.000	.227
Intercept	96150.493	1	96150.493	130.746	.000	.678
Filltype	13365.301	2	6682.651	9.087	.000	.227
Error	45594.613	62	735.397			
Total	315548.210	65				
Corrected Total	58959.914	64				

a. R Squared = .227 (Adjusted R Squared = .202)

Directional Measures

			Value
Nominal by Interval	Eta	Fill type Dependent	.991
		Max Weight Dependent	.476

Figure 26: Eta squared test correlation 711



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Max Weight is the same across categories of Fill type.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Pairwise Comparisons of Fill type

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
3-2	17.233	9.855	1.749	.080	.482
3-1	43.413	9.305	4.666	.000	.000
2-1	26.180	6.166	4.246	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Figure 27: Kruskal Wallis Test correlation 711

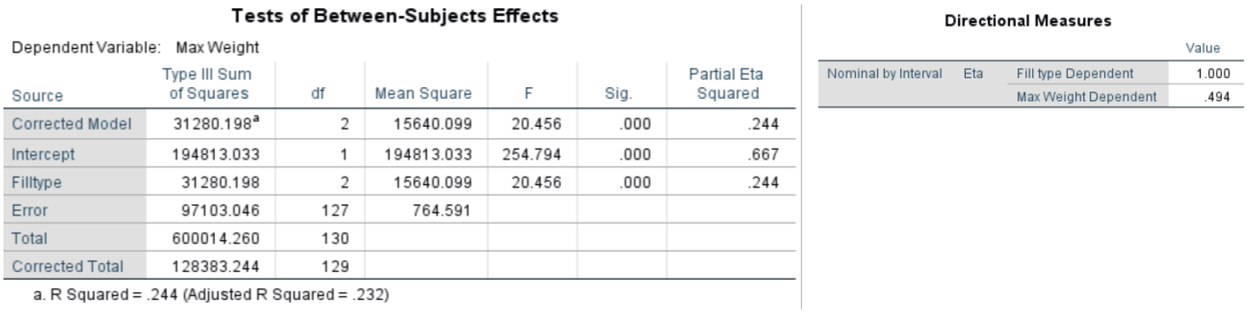
When we examine the relation between “Max weight”, and “Fill type” more in depth and perform a Kruskal Wallis test to see whether the distribution of the “Max weight” variable differs between the Filling types considered, we have to reject the null hypothesis which assumes the distribution to be the same across the fill types considered. *Figure 27* show the Kruskal Wallis test for the 711. We see that the distribution of the max weight significantly differs between fill types 2 &3 in relation to fill type 1. The distribution of the “Max weight” variable is therefore influenced by the “Fill type” variable. But which attribute is to be included within the study?

Having consulted with the technical staff, it was decided to focus on the “Max weight” attribute. According to the technical staff, the fill type should not have an influence on the production speed given that the machines are set-up correctly. The reason is found in the method of filling. The bags pass the fill stations 1,2, and 3 in series via a rotational wheel. The speed with which the wheel rotates is therefore limited by the longest stop that is required at one of the fill stations. This means that the speed of the wheel is effectively uninfluenced by the fill type since all stations are visit either way. Only product characteristics, which makes filling at one of the station take longer, could influence the speed with which the machine can operate. In the next section, the filling lines 709, 710, and 711 are analyzed in more detail.

709
First, the null hypothesis, which assumes the distribution of the considered variable to be equal across the different clusters, is tested. Thereafter, the implications of the outcomes are discussed.

1. <u>Format:</u> The formats produced on the 709 are: 1/12, 2/12, 3/30, 2/7, and 2/8. At a 95% confidence interval, we fail to reject the null hypothesis, which assumes the distribution of the format type across the different clusters to be the same. (Figure 30)
2. <u>Fill type:</u> Not examined due to correlation between "Fill type", and "Max weight". (*Figure 28,* and *Figure 29*)
3. <u>Max weight:</u> at a 95% confidence level, we have to reject the null hypothesis which assumes the distribution of the max weight to be the same across the different clusters (*Figure 31*). Between clusters 3-2, there is a significant difference as to the distribution of the "Max weight variable". On average, cluster 3 holds the articles with the lower max weight when compared to cluster 2. Analyzing the individual clusters, we can furthermore see the articles clustered in cluster 1 mostly exceed 100 grams, or do not exceed 35 grams, whereas cluster 4 holds mostly articles with a max weight ranging from 30 to 90 grams. This is similar to what we find at the 711.
4. <u>Avg. order size:</u> At a 95% confidence level, we fail to reject the null hypothesis which assumes the distribution of the average order size to be the same across the different clusters (*Figure 32*).

Considering the outcomes of the statistical tests, we see that the speed with which the 709 operates is influenced by the "Max weight" of the article produced. Especially articles with a max weight between 35-90 grams are produced with higher speeds when compared to products with a max weight outside of this range. At a 95% confidence level, we fail to reject the null hypothesis which assumes the distribution of the order size, and format to be the same amongst the different clusters.



Tests of Between-Subjects Effects

Dependent Variable: Max Weight

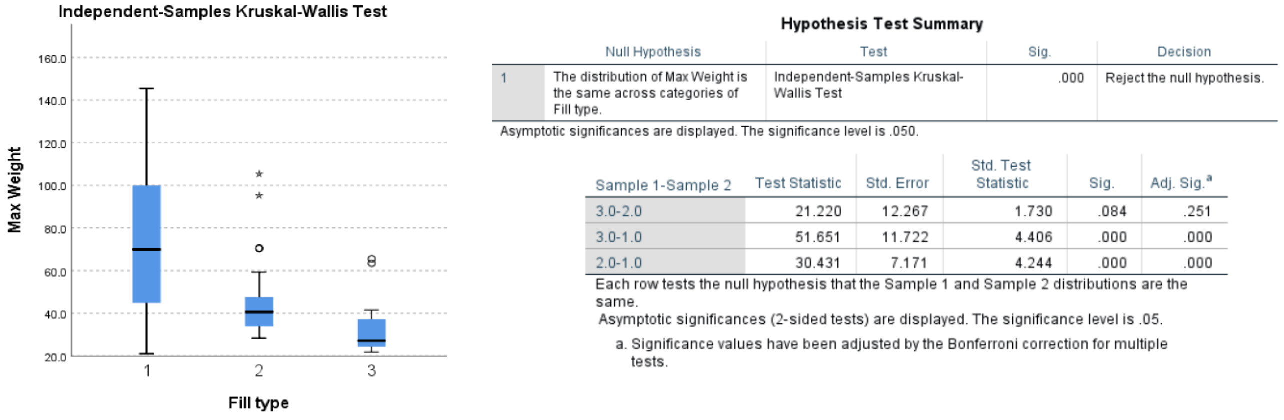
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	31280.198[a]	2	15640.099	20.456	.000	.244
Intercept	194813.033	1	194813.033	254.794	.000	.667
Filltype	31280.198	2	15640.099	20.456	.000	.244
Error	97103.046	127	764.591			
Total	600014.260	130				
Corrected Total	128383.244	129				

a. R Squared = .244 (Adjusted R Squared = .232)

Directional Measures

			Value
Nominal by Interval	Eta	Fill type Dependent	1.000
		Max Weight Dependent	.494

Figure 28: Test correlation 709



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Max Weight is the same across categories of Fill type.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

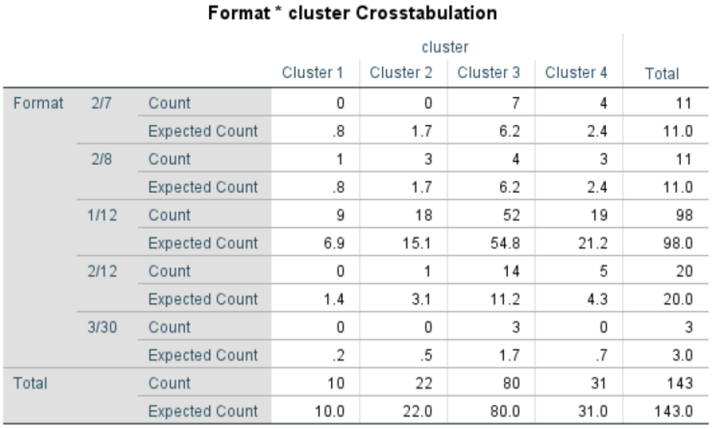
Asymptotic significances are displayed. The significance level is .050.

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
3.0-2.0	21.220	12.267	1.730	.084	.251
3.0-1.0	51.651	11.722	4.406	.000	.000
2.0-1.0	30.431	7.171	4.244	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

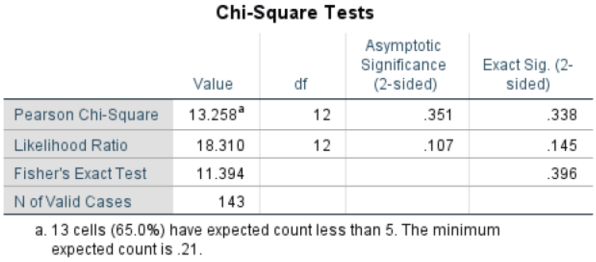
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Figure 29: Kruskal Wallis Test correlation 709



Format * cluster Crosstabulation

			cluster				
			Cluster 1	Cluster 2	Cluster 3	Cluster 4	Total
Format	2/7	Count	0	0	7	4	11
		Expected Count	.8	1.7	6.2	2.4	11.0
	2/8	Count	1	3	4	3	11
		Expected Count	.8	1.7	6.2	2.4	11.0
	1/12	Count	9	18	52	19	98
		Expected Count	6.9	15.1	54.8	21.2	98.0
	2/12	Count	0	1	14	5	20
		Expected Count	1.4	3.1	11.2	4.3	20.0
	3/30	Count	0	0	3	0	3
		Expected Count	.2	.5	1.7	.7	3.0
Total		Count	10	22	80	31	143
		Expected Count	10.0	22.0	80.0	31.0	143.0

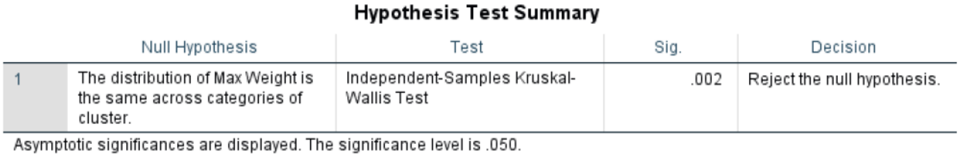


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)
Pearson Chi-Square	13.258[a]	12	.351	.338
Likelihood Ratio	18.310	12	.107	.145
Fisher's Exact Test	11.394			.396
N of Valid Cases	143			

a. 13 cells (65.0%) have expected count less than 5. The minimum expected count is .21.

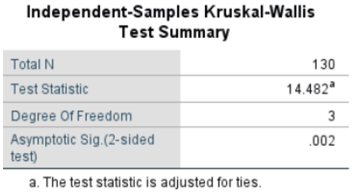
Figure 30: Test Format 709



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Max Weight is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.002	Reject the null hypothesis.

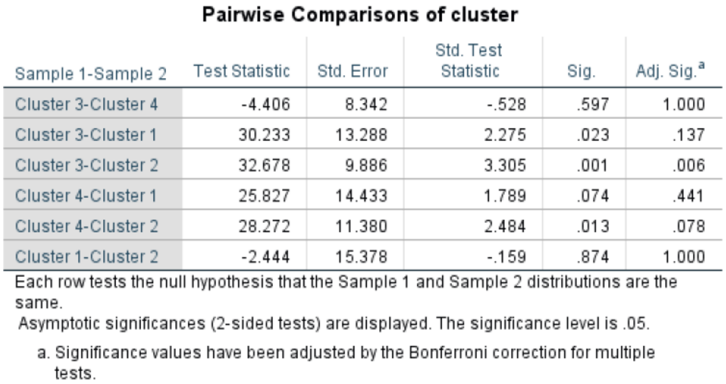
Asymptotic significances are displayed. The significance level is .050.



Independent-Samples Kruskal-Wallis Test Summary

Total N	130
Test Statistic	14.482[a]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.002

a. The test statistic is adjusted for ties.

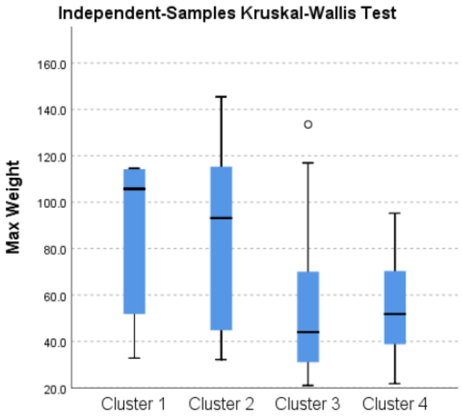


Pairwise Comparisons of cluster

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Cluster 3-Cluster 4	-4.406	8.342	-.528	.597	1.000
Cluster 3-Cluster 1	30.233	13.288	2.275	.023	.137
Cluster 3-Cluster 2	32.678	9.886	3.305	.001	.006
Cluster 4-Cluster 1	25.827	14.433	1.789	.074	.441
Cluster 4-Cluster 2	28.272	11.380	2.484	.013	.078
Cluster 1-Cluster 2	-2.444	15.378	-.159	.874	1.000

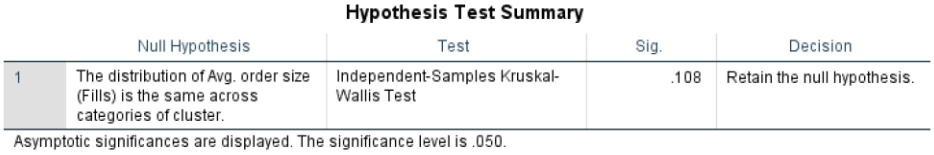
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.



Independent-Samples Kruskal-Wallis Test

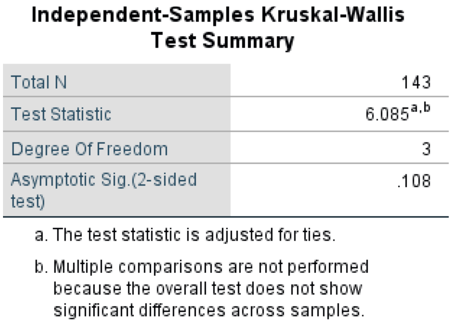
Figure 31: Test Max weight 709



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Avg. order size (Fills) is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.108	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

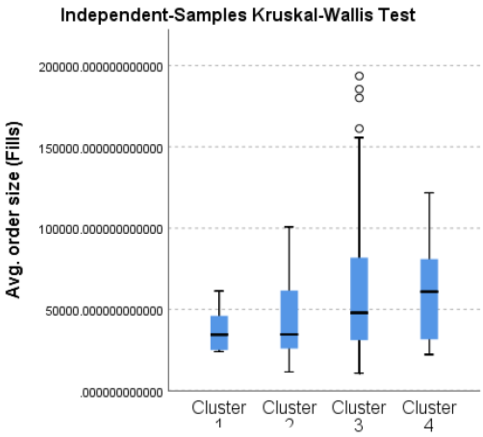


Independent-Samples Kruskal-Wallis Test Summary

Total N	143
Test Statistic	6.085[a,b]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.108

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.



Independent-Samples Kruskal-Wallis Test

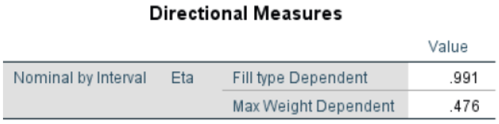
Figure 32: Test Avg order size 709

710

First, the null hypothesis, which assumes the distribution of the considered variable to be equal across the different clusters, is tested. Thereafter, the implications of the outcomes are discussed.

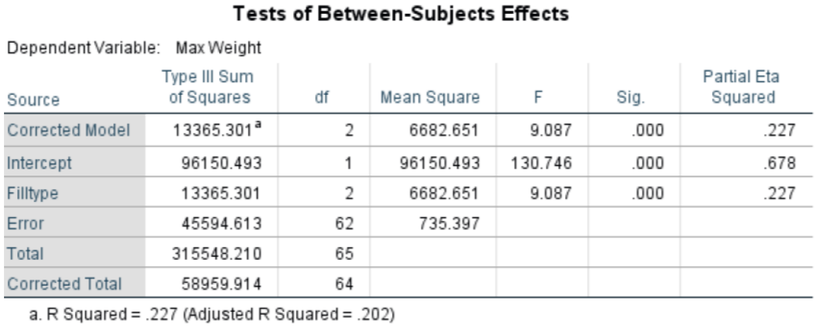
1. Format: The 1/12 is the only format produced on the 710. Therefore, the distribution of the format across the different clusters is not examined.
2. Fill type: This variable has not been examined as a correlation was found with the "Max weight" variable. (Figure 33)
3. Max weight: at a 95% confidence interval, we cannot reject the null hypothesis which assumes the distribution of the max weights to be the same across the different clusters (Figure 34)
4. Avg. order size: at a 95% confidence interval, we cannot reject the null hypothesis which assumes the distribution of the average order size to be the same across the different clusters (*Figure 35*)

There is no significant difference in the distribution of the max weight, and average order size between the different clusters. This could indicate that these variables do not influence the production speed of the 710.



Directional Measures

			Value
Nominal by Interval	Eta	Fill type Dependent	.991
		Max Weight Dependent	.476



Tests of Between-Subjects Effects

Dependent Variable: Max Weight

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13365.301[a]	2	6682.651	9.087	.000	.227
Intercept	96150.493	1	96150.493	130.746	.000	.678
Filltype	13365.301	2	6682.651	9.087	.000	.227
Error	45594.613	62	735.397			
Total	315548.210	65				
Corrected Total	58959.914	64				

a. R Squared = .227 (Adjusted R Squared = .202)

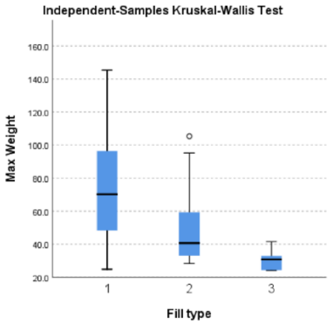
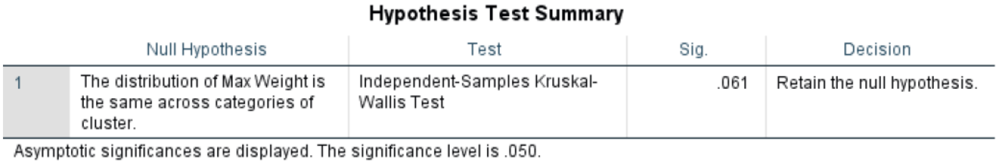


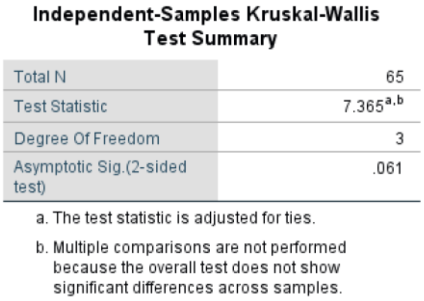
Figure 33: Correlation test 710



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Max Weight is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.061	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.



Independent-Samples Kruskal-Wallis Test Summary

Total N	65
Test Statistic	7.365[a,b]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.061

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

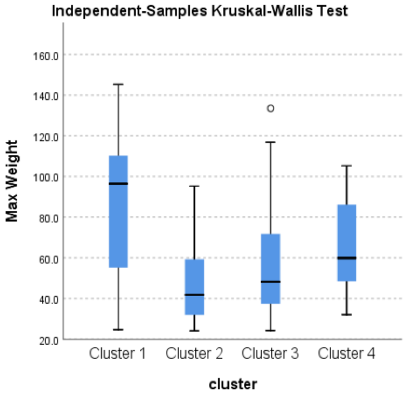
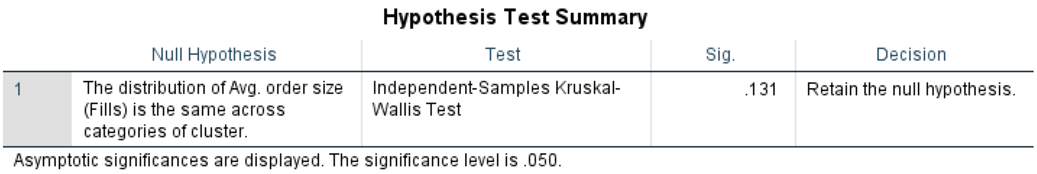


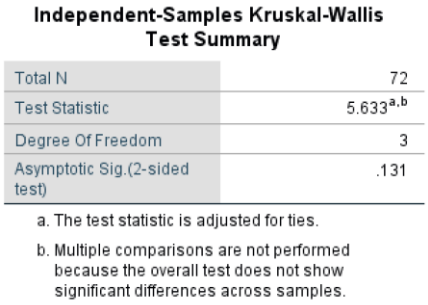
Figure 34: Test Max weight 710



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Avg. order size (Fills) is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.131	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.



Independent-Samples Kruskal-Wallis Test Summary

Total N	72
Test Statistic	5.633^a,b^
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.131

a. The test statistic is adjusted for ties.

b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

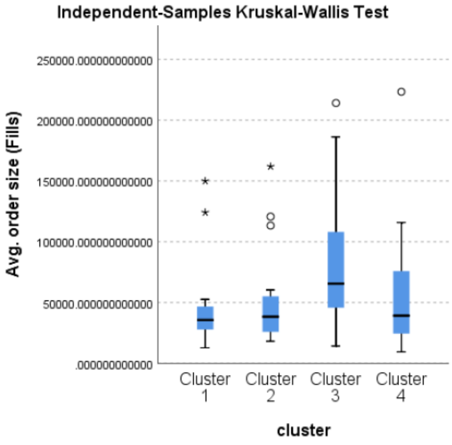


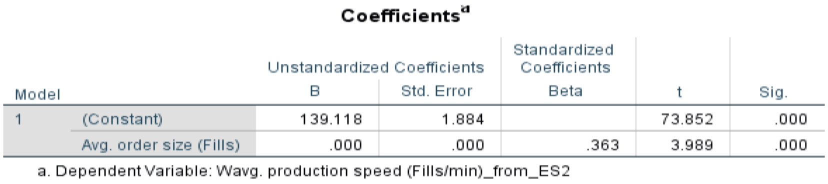
Figure 35: Test Avg order size 710

711

First, the null hypothesis, which assumes the distribution of the considered variable to be equal across the different clusters, is tested. Thereafter, the implications of the outcomes are discussed.

1. Format: Only the 1/12 format is produced on the 711 which, by definition, makes the distribution of the "format" variable the same amongst the clusters.
2. Fill type: The distribution of the fill type amongst the clusters has not been examined because of the correlation found between fill type and max weight (Figure 26, and Figure 27*)*
3. Max weight: at a 95% confidence level we have to reject the null hypothesis which assumes the distribution of Max weight to be the same across the different clusters. Figure 38 shows that there is a significant difference between clusters 1-3, and 1-4. Clusters 3, and 4 hold, on average, more light-weight products when compared to the first cluster. To be precise: clusters 3, and 4 hold mostly products a weight ranging between 30-90 grams, whereas the first cluster mainly holds products which are either lighter than 30 grams, or heavier than 90 grams.
4. Avg. Order size: at a 95% confidence level we have to reject the null hypothesis which assumes the distribution of the average order size to be the same across the different clusters. *Figure 37* shows that there is a significant difference between clusters 1-2, 1-3, and 1-4. This is interesting to see, as the first cluster holds the smallest orders. Considering cluster 2,3,and 4, we see that the average order size increases as we move along the clusters.

The production speed of the 711 is influenced by both the max weight of the product processed, and the order size. Larger orders are produced at higher speeds. Applying a linear regression reveals that the coefficient of the influence of the average production size on the production speed is significant, even at a 99% confidence level (*Figure 36*) The coefficient equals 0.000105. The max weight is also of influence on the production speed. This relation does however not appear to be linear. Especially products lighter than 35 gram, or heavier than 90 grams, are produced at lower speeds. 72% of these products are found in cluster 1, or 2, and 94% in cluster 1,2,or 3. Products with a max weight between these values are produced at higher speeds and primarily found in clusters 3, and 4.

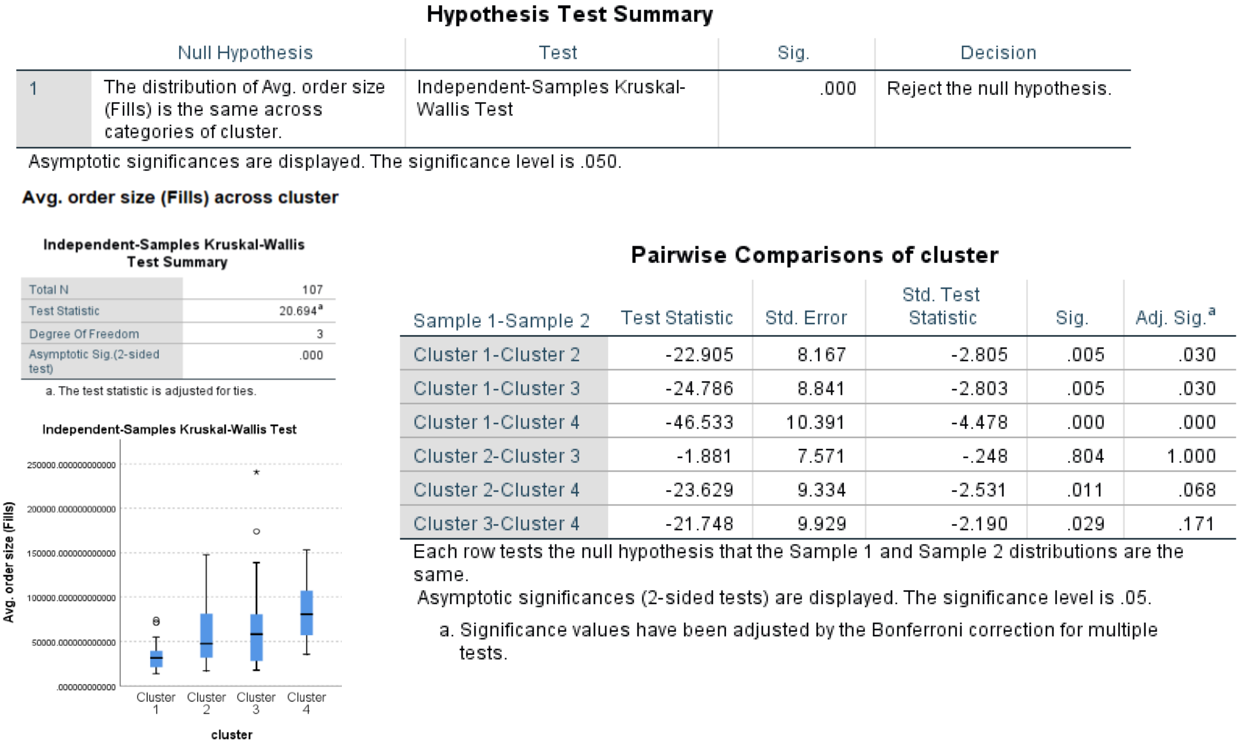


Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	139.118	1.884		73.852	.000
	Avg. order size (Fills)	.000	.000	.363	3.989	.000

a. Dependent Variable: Wavg. production speed (Fills/min)_from_ES2

Figure 36: Linear regression 711



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Avg. order size (Fills) is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Avg. order size (Fills) across cluster

Independent-Samples Kruskal-Wallis Test Summary

Total N	107
Test Statistic	20.694[a]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.000

a. The test statistic is adjusted for ties.

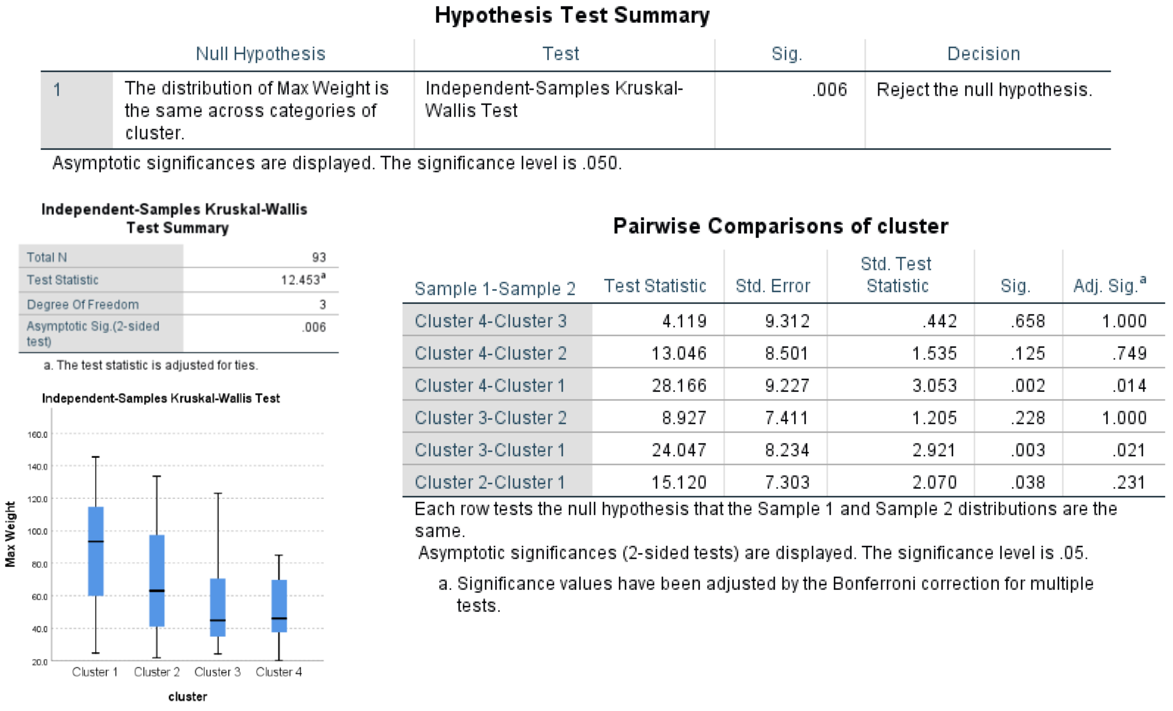
Pairwise Comparisons of cluster

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Cluster 1-Cluster 2	-22.905	8.167	-2.805	.005	.030
Cluster 1-Cluster 3	-24.786	8.841	-2.803	.005	.030
Cluster 1-Cluster 4	-46.533	10.391	-4.478	.000	.000
Cluster 2-Cluster 3	-1.881	7.571	-.248	.804	1.000
Cluster 2-Cluster 4	-23.629	9.334	-2.531	.011	.068
Cluster 3-Cluster 4	-21.748	9.929	-2.190	.029	.171

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Figure 37: Test Avg order size 711



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Max Weight is the same across categories of cluster.	Independent-Samples Kruskal-Wallis Test	.006	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Independent-Samples Kruskal-Wallis Test Summary

Total N	93
Test Statistic	12.453[a]
Degree Of Freedom	3
Asymptotic Sig.(2-sided test)	.006

a. The test statistic is adjusted for ties.

Pairwise Comparisons of cluster

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Cluster 4-Cluster 3	4.119	9.312	.442	.658	1.000
Cluster 4-Cluster 2	13.046	8.501	1.535	.125	.749
Cluster 4-Cluster 1	28.166	9.227	3.053	.002	.014
Cluster 3-Cluster 2	8.927	7.411	1.205	.228	1.000
Cluster 3-Cluster 1	24.047	8.234	2.921	.003	.021
Cluster 2-Cluster 1	15.120	7.303	2.070	.038	.231

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Figure 38: 711 test Max Weight

Conclusion
The speed of the 709, and 711 is influenced by the max weight of the article being processed. Products with a max weight between 35, and 90 grams are more dominantly present in the 3rd and 4th clusters which entail the higher production speeds. Based on the clustering performed, we cannot assume that this influence is also experienced at the 710. Reexamining the individual clusters of the 710, we do see that cluster 1 holds the articles with the highest average max weight. However, this significance might be harder to proof as the orders upon which the average production speeds are based, show a low variance in production speed when compared to the 709, and 711 (208 in comparison to 333, and 290 respectively). This means that speeds are more clustered together which makes influences on this speed stand out less. These more clustered production speeds might be explained by the technical capacity of the filling line, which is lower when compared to the 709, and 711 (170, when compared to 180, and 190). In addition, in an interview, the team leader explained that in planning the orders, they try to only plan orders between 20-70 gram on the 710. Therefore, the influence of weight might already be minimized within the data.

Something similar happens at the 709 when we consider the average order sizes. As this is the only of the three filling lines that can handle formats other than the 1/12, all other formats, which are usually produced in smaller batches, are produced on this line. We do see that the average order size is of influence on the production speed for the 711. The significant difference was found between cluster 1, and the other clusters. Examining cluster 1, would say that a good "border" value equals 40.000 fills.

Based on the clustering we would distinguish categories of products between 35-90 gram for the 709, not distinguish any categories for the 710, and distinguish a category of orders between 0-40.000 fills, and >40.000 fills for the 711 with an additional sub-division of products ranging between 35-90 gram, and products outside of this range. However, there are inconsistencies within the date which might have influenced the results of the clustering performed. These inconsistencies are listed in Section 6.3.3.

How do the findings withhold to the experience of operators?
Experienced operators of the 709, 710, and 711 have been asked to identify products which, in their experience, are difficult to run at high speeds. They were presented with a list with al products produced on the filling line 709, 710, or 711, respectively, and asked to encircle these products. Several operators declared that "White" powders were difficult to process. In analyzing the results, we found that for all three lines, the operators encircled products with a Max weight over 100 grams, or under 40 grams. In hindsight, almost all "white" powders adhere to these weight criteria. This seems in line with the results of the clustering, be it that the influence of the max weight attribute was also identified at the 710. There were even operators which explained that the 710 began to experience problems with weights over 90, and even 70 grams. This influence ought to be caused by the setup of the machine. Whereas the "bags" are held by two clamps at the 709, and 711, the 710 only holds the bag with one clamp. When the weight of the bag increases, the bag starts to "hang". This causes trouble sealing the bag, and/ or depositing additional raw material (2,and 3 point fills). The relationship between the total weight of the first, first two, or all three fills and production speed was not examined in the clustering performed. Within this study these influences will not be included. When additional research were to be performed, this would be an interesting field to explore. Within this study, the categories identified by the analyses of the clustering are used. Therefore, we can distinguish the following categories:

709
1. Orders with: 35 < Product max weight < 90
2. Orders with: Product Max weight <= 35, or Product Max weight >=90

710
3. All orders

711

4. Orders With an order size <= 40.000 fills, with Max Weight: 35< Max Weight < 90
5. Orders With an order size <= 40.000 fills, with Max Weight <= 35, or Max >= 90
6. Orders With an order size > 40.000 fills, with Max Weight: 35< Max Weight < 90
7. Orders With an order size > 40.000 fills, with Max Weight <= 35, or Max >= 90

Section 3A.3: Method selection

This section is focused on the following research question:

"How can we determine the new, product-dependent workloads?"

For each of the clusters of articles determined in Section 3A.2, we will evaluate the orders run. This differs from the analysis in Section 3A.2, as the performance is now examined on an order-level instead of an article level. The performance, in terms of production speed, at an article level is the "average" speed across the different orders in which the article considered is produced. In determining workloads, we have to consider the absolute "order-level" values. Within the analysis, focus is put on the top 10% scoring orders in terms of production speed. Based on the spread and absolute values, in combination with the insights gathered with relation to the technical limit of the filling lines, a maximum achievable speed will be determined. This "ideal speed" is then used to determine the accompanying workloads.

Appendix C: Reported Microstops

709			
Date: 05-07-2022 Line: 709 Order: M00012025 Format: 2/8 Fill type: 1 Max weight: 85 gram Order size: 4032 trays Order size: 64512 fills Observed: 14:00 – 15:45	MICROSTOP	Occurrence	SPEEDLOSS
	Sensor fill station 630	-	Designed speed: 180 Operating speed: 150
	Carton twisted on conveyor belt	4	
	Cartoner misfeed bag	3	
	Reset after misfeed bag	3	
	Improper sealing carton cartoner	1	
Total MES	00:09:49	15	
Total Observed		12	
Date: 04-07-2022 Line: 709 Order: M00012033 Format: 2/8 Fill type: 2 Max weight: 50.6 gram Order size: 3500 trays Order size: 56000 fills Observed: 15:00 – 19:52	MICROSTOP	Occurrence	SPEEDLOSS
	Valve fill station	4	Designed speed: 180 Operating speed: 159
	Cartoner misfeed bag	4	
	Reset after misfeed bag	4	
	Cartoner carton closing mechanism	3	
	Sensor valve station	1	
	Carton twisted on conveyor belt	2	
	Sensor fill station 630	1	
	Sensor check bags cartons cartoner	1	
	Material shortage	1	
Total MES	00:24:48	31	
Total observed		21	
Date: 11-07-2022 Line: 709 Order: M00012034 Format: 3/30 Fill type: 2 Max weight: 36.1 gram Order size: 3499 trays Order size: 104970 fills Observed: 06:00 – 07:21	MICROSTOP	Occurrence	SPEEDLOSS: Designed speed: 180 Operating speed: Unknown
	Misfeed bag cartoner	6	
	Restart misfeed	6	
	Carton twisted on conveyor belt	2	
	Bag twisted in valve station	2	
	Set valve station	2	
Total MES	00:19:11	27	
Total observed		18	

710			
Date: 07-07-2022 Line: 710 Order: M00011939 Format: 1/12 Fill type: 2 Max weight: 40.6 gram Order size: 16216 trays Order size: 194592 fills Observed: 14:00 – 18:46:23	MICROSTOP	Occurrence	SPEEDLOSS
	Sensor fill station restart	2	Designed speed: 170 Operating speed: 160
	Solas foil change	2	
	Solas loss of count	1	
	Solas adjustment conveyor setup	1	
Total MES	00:13:12	13	
Total Observed		6	
Date: 05-07-2022 Line: 710 Order: M00011797 Format: 1/12 Fill type: 3 Max weight: 41.5 gram	MICROSTOP	Occurrence	SPEEDLOSS

Order size: 4300 trays Order size: 51600 fills Observed: 16:00 – 22:00	Carton twisted on conveyor belt Solas fallen carton Solas foil problems	1 1 -	Designed speed: 170 Operating speed: 159
Total MES	00:48:24	35	
Total observed		Unknown	
Date: 12-07-2022 Line: 710 Order: M00012142 Format: 1/12 Fill type: 2 Max weight: 44.5 gram Order size: trays Order size: fills Observed: 07:00 – 07:45	MICROSTOP	Occurrence	SPEEDLOSS: Designed speed: 180 Operating speed: Unknown
	Valve station jammed + reset jam valve station Changeover foil fill station + reset	7 2	
Total MES	00:07:49	9	
Total observed		9	

711			
Date: 11-07-2022 Line: 711 Order: M00012212 Format: 1/12 Fill type: 1 Max weight: 133.5 gram Order size: 8400 trays Order size: 100800 fills Observed: 09:40 – 11:27	MICROSTOP	Occurrence	SPEEDLOSS
	Fill machine reset after disruption suction sachets MAS disruption Muerer Ventilation filling station Rotated bag checkweigher jam Clean seal fill station Open carton cartoner	11 1 1 8 1 1	Designed speed: 190 Operating speed: 149
Total MES	00:24:46	28	
Total Observed	Unknown	23	
Date: 12-07-2022 Line: 711 Order: M00012213 Format: 1/12 Fill type: 2 Max weight: 70.4 gram Order size: 5916 trays Order size: 70992 fills Observed: 08:59 – 14:00	MICROSTOP	Occurrence	SPEEDLOSS
	Jam bag cartoner Restart after jam cartoner Jam bag valve station Adjust setting glue gun cartoner Palletizer disruption tray fall + reset Fill station crumbles bag Error feed cartons cartoner Lose bag fill station Carton twisted on conveyor belt Muerer conveyer full sensor clean Palletizer overflow	4 4 1 1 3 8 1 2 2 2 2	Designed speed: 190 Operating speed: Unknown
Total MES	00:39:37	47	
Total observed		29	

Appendix D: Details limitations of the research

The shortcomings of the research, as briefly described in Section 6.3.3, are now discussed in greater detail:

1. **Achieved production speed**

The achieved production speed is calculated by means of the total produced quantity, the operating time, and the microstops (see *Equation 18*).

$$Speed = \frac{Total\ number\ of\ fills\ produced}{Operating\ time - Minor\ stops}$$

Equation 18: Data inconsistency production speed

In performing the field study several elements which influence the reliability and accuracy of these calculated achieved production speeds were discovered.

a. *Total number of fills produced*: This number is based on the palletizers counter. The palletizer marks the end station of production. This means that prior to this point there are several checkpoint at which products can be rejected. In addition, products can be discarded by operators after jams, malfunctions, or other disruptions. This means that the actual produced quantity is larger than the registered "Total number of fills".

b. *Operating time:* this time should capture the total time during which a line is available for production, and production has been ran. However, it is possible to produce units in the "SETUP" phase of production. This falls under the OEE2a category which is excluded from the operating time.

c. *Microstops:* (micro)stops, and disruptions, are registered via the last checkweigher whenever there is a disruption in product flow. However, in order to register a stop, product flow has to be interrupted for a period of 30 seconds. This means that interruptions smaller than 30 seconds do not get registered, and that all disruptions actually take 30 seconds longer. This influence is quite large, especially considering that the average order experiences over 75 microstops.

d. Several filling lines, such as the 709, make use of two separate filling machines. Whenever there is a problem, a quick clean, or material changeover at one of these machines, this stop is not detected by the MES system. Only when the two machines malfunction simultaneously, and output of both machines is interrupted, does the checkweigher sense a disruption in product flow. Therefore, some of the disruptions and/or minor stops that find their origin at these machines, are now captured in the speed loss that is experienced due to only running on one machine. This is also the reason why the sensor problem detected at the 709, which only affected the 630 filling machine, cannot be found within the MES system.

2. **Quality**

The Quality score within the OEE calculation is determined by means of *Equation 19.*

$$Quality = \frac{GoodCount}{TotalCount}$$

Equation 19: Data inconsistency, quality score

Originally, the *Goodcount*, and *Totalcount* were to be based on the information gathered by the last checkweigher. This checkweigher is positioned next to the cartoner machine and checks all cartons on their weight. It is questionable whether this setup is ideal. Prior to the carton checkweigher, the individual bags are already checked, and accepted or rejected, based on their weight. This means that not all rejects are counted. This influences both the Totalcount, and the *Goodcount*. In practice, the number of rejects is way higher than the figures in MES portray. This does not only influence the quality scores, but also effects the productivity scores via the *Totalcount*.

Within the field test, we created several bins in which we threw the products that were rejected. A bin was created for the products rejected prior to the checkweigher linked to MES, the products rejected by this checkweigher, and the products which were taken of the conveyor belt after this point. At the end, the total amount within these containers was counted. Whereas the MES system registered 16 rejects, the total amount of rejects came down to 940 units containing raw material, and 326 “empty” bags. In order to see whether this was an isolated event or something reoccurring, another test was performed. Within this test, the count on all checkweighers was reset to 0. The rejects, and total counts were collected of the checkweighers after 4 hours of production. Two calculations were performed:

1. OEE calculation with the quality aspect as calculated by the Goodcount, and Totalcount gathered from the last checkweigher.
2. OEE calculation with;
- The number of rejects calculated by the difference between the produced quantity of the first, and Goodcount of the last checkweigher.
- The Totalcount as the sum of the produced quantity of the first checkweighers.

Table 32 depicts the availability, productivity, quality, and overall OEE scores based on these two calculations.

Calculation	OEE score	Availability	Performance	Quality
1	45.18%	82.28%	55.40%	99.11%
2	45.42%	82.28%	57.55%	96.11%

Table 32: Quality score discrepancy

We see that the quality score is lower in the second calculation, whereas the productivity is higher. The decrease within the quality score is explained by the sharper increment of the total number of rejects when compared to the enlarged total produced quantity. The increase of the productivity is explained by the additional products captured within the Totalcount within the same operational period.

When the quality aspect was examined in more detail, we found that the MES system did not seem to correctly calculate the quality score on the information provided by the last checkweigher. The Application manager explained that something must have gone wrong in the setup of the system. Contact has been made with Objective, the supplier of the MES application. We discovered that not all checkweigher were online, that the different filling lines have different checkweighers communicating with MES, and that the checkweigher structurally fail to upload their statistics. As a result, the produced quantities within the MES system did not match the produced quantities linked to PowerBI. The latter is linked to the counter on the palletizer. This is the most reliable indicator as these products have actually been palletized. Within this study, these quantities have been used. Upon examination, the discrepancy between this total number of produced units registered by the palletizer in comparison to the total produced quantity registered by the checkweighers was in the order of magnitude of + 20.000 units on a 110.000 unit order. The checkweighers therefore omit to upload/ sent all data to the MES system. This is not only of influence on the quality, and performance scores, but could also influence the ability to meet the legal obligations linked to the distribution within the weights of the products produced (“e-weighing”).

If Euroma wants the quality scores to be aligned with reality, the company needs to:

- Base the *Goodcount* on the actual number of products palletized, whereas the *Totalcount* should be based on the produced quantity as registered by the first checkweigher
- Ensure that all checkweighers are online, and upload full and sound reports.
- Ensure that all pallets, or products, which are rejected after the production phase are manually booked within MES by the team leaders.

If Euroma wants the productivity score to be more aligned with reality, the company needs to:

- Base the *Totalcount* on the total number of products produced as registered on the first checkweigher.

The used “produced quantity” within this study is aligned with the most accurate count, being the palletizer. As the actual production quantity is likely to be higher, the study somewhat underestimates the productivity, and achieved production speeds of the filling lines. The quality score within MES is furthermore registered as a time. However, within this study the quality score is explained as a quantity oriented score. This is still the most accurate representation as the time within MES is solely based on the production time of the rejected quantity. In addition, no actual “time loss” ,such as a stop related to quality inspections, can be booked under the quality score, making it quantity oriented.