Improving the continuous flow

Increasing the performance at Packaging Line 51

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HEINEKEN

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Preface

After months of hard work, I am really proud to present this report which concludes my master Industrial Engineering and Management at the University of Twente. This master thesis marks the end of five years of studying, in which I developed myself and became what I am today. During my final internship at Heineken, I realized what I want in the future and what I stand for, and I owe my gratitude for this to many people.

First of all, I want to thank Heineken for giving me the opportunity for doing this research during five months at the brewery in Zoeterwoude. Everyone was really open and tried to help me out whenever they could. Soon after I started, I felt at home at the ‘five’, the packaging line at which my research took place. This is thanks to the operators, who welcomed me with their arms wide open, but special thanks goes out to Dennis Schoonveld and my day-to-day supervisor Inge Schrama. They involved me in the daily processes, which made me feel part of the team. Inge introduced me to everyone on the first day of my internship, and kept on thinking with me how to get the most out of these six months, not only for my research, but also looking at the future and my personal development. I also owe my gratitude to ‘my V-graph team’. Our work together the previous months was useful for my research, but we also really gained something for line 51. Improvements have been made, and a lot of these things would not have been possible without their input, support, contacts, and all the information about the process and Heineken.

Next to Heineken, also the University of Twente helped making this research possible. My first supervisor, Leo van der Wegen, has been involved almost from the very beginning, and his feedback helped to get this research to a higher level. My second supervisor, Ahmad Al-Hanbali gave his critical advice, mostly on the literature, which forms one of the foundations of this research. Although we decided that it was better to perform a simulation study instead of using analytical methods, Ahmad his feedback was really helpful. I am very grateful to both of my supervisors for their critical feedback, but also for the motivational words.

Next to that I want to thank the people who supported me, not only during my master thesis, but also during the rest of my study. A special thanks goes out to Freek, he listened to me every evening, came up with ideas and was not afraid to give his critical advice. Thank you for that, it really helped me to keep the goal in mind, but also find time to relax and enjoy everything.

After all these words of gratefulness, the only thing left is to wish you a pleasant time of reading this report.

Marjon Pol, Leiden, 13 September 2014

Management Summary

To stay ahead of the competition on the competitive beer market, Heineken needs to increase efficiency continuously. Mainly, this means producing more in the same time, preferably with fewer resources than currently, to save costs and remain competitive in industry. One of the packaging lines for which this holds is line 51 of the Heineken brewery in Zoeterwoude, which fills and packages bottles of the Heineken brand for the USA market. The current performance of this line is below the target stated by management, and therefore improvements are necessary. Therefore, the objective of this research is to ***determine how the operational performance of packaging line 51 can be improved.*** As safety and quality are really important, the research is bounded by some constraints. This leads to the research question:

How can the performance of packaging line 51 of the Heineken Brewery in Zoeterwoude be improved, while taking into account the quality and safety regulations?

First the current performance is analysed, as the performance is below the target, which is mainly caused by lower output than expected, due to blocking and starvation of the machines in the process. The filling machines are the bottleneck, and over the first part of 2014 we see that the fillers are quite some time of the available production time not working due to breakdowns, blocking and starvation of the machines. To increase output and avoid as many disruptions as possible, a continuous flow should be created in the process. This flow is related to the availability and speed of machines in the process.

In the main part of the process, the speed of the machine is determined by the fill rate of the buffer in front of the machine. If the buffer is almost empty, the machine works on low speed, while the machine works on high speed when the buffer is (almost) full. To ensure a continuous flow on the line, which increases the output and therefore efficiency, it is important to determine right buffer strategy for the packaging line. The buffer strategy contains the settings for the different machines speeds (low, nominal, and high) and the fill rates at which the speed changes (buffer strategy).

To determine the buffer strategy for packaging line 51 a simulation model is developed and validated with current data, and using expert-knowledge from the process. The model is used to run experiments, which represent different scenarios. In the model, the packaging process is represented from the filling machines until the box packers. Five experimental factors are used:

- Fill rate at which the labellers change to nominal speed
- Fill rate at which the labellers change to high speed
- Fill rate at which the box packers change to nominal speed
- Fill rate at which the box packers change to high speed
- High speed of the box packer 511

First of all, 16 experiments are conducted which use different combinations of the settings for the fill rates at which machine speeds are changed (first 4 experimental factors). From these experiments we conclude:

- The moment of speed change for the labellers should be kept the same.
- The moment of speed change for the box packers should be changed, change to nominal and high speed at a lower fill rate than in the current settings.
- Implementing these changes reduces blocking time of the filling machines leading to annual savings.

The experiments where the high speed of box packer 511 is increased (experimental factor 5) are only conducted with the best scenarios from the first round of experiments. From these experiments we can conclude:

- Additional annual savings can be realized by increasing the speed of the box packer, not taking into account the effect the repair works have on the number of breakdowns.
- Buffer strategies should be adapted to the new speed for the labellers and box packers.
- Implementing these changes leads to an output increase of 1% per shift.

From the research, recommendations have been formulated. The main recommendations are:

- The advised buffer strategies should be implemented to increase the continuous flow on the packaging line.
- Repair works on the box packer 511 are beneficial for the process and should therefore be executed to increase the maximum speed.
- Optimizing buffer strategies on packaging lines have high benefits, and therefore more people should be educated in the process of changing the settings, so capacity is not impeding the implementation.
- Data registration should be improved, so reliable process data is available and the simulation model can be adopted and used for further research.

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Abbreviations & Definitions

Buffer strategy	The machine settings which determine when the machine changes to another speed, and the speed it changes to.
CS&L	Customer Service & Logistics
GSC	Group Supply Chain
HNS	Heineken Netherlands Supply
KPI	Key Performance Indicator
MTBA	Mean Time Between Assists
OEE	Overall Equipment Effectiveness
OPI	Operational Performance Indicator
OPI-NONA	Operational Performance Indicator: No Orders, No Activity
Plano	Flat folded empty carton box
TPM	Total Productive Maintenance

1. Introduction

This chapter gives an overview of the research. Section 1.1 describes the research context by giving an introduction to the company and to the specific department in which the research is conducted. In the remainder of the chapter the research outline is given. This starts with the research motivation in Section 1.2, followed by the problem description (Section 1.3). In Section 1.4 the research objective is defined, after which the scope and approach of the research are described in Sections 1.5 and 1.6.

1.1. Context description

This section starts with a general introduction to Heineken, with a special focus on the location in Zoeterwoude. After the general introduction, the focus turns to the packaging department of the brewery in Zoeterwoude, where the research is conducted.

1.1.1. Introduction Heineken

Heineken is one of the leading companies in the brewery industry worldwide. They have an annual turnover of more than 18 billion euro and employ 76,191 people of which 4,053 FTE's are working in the Netherlands.

The rich history of Heineken dates back from 1864, the year the brewery was founded in Amsterdam. In 1928 Heineken started to become a truly international player, starting with export to Asia in 1929 and to the United States in 1933. In the past 15 years numerous mergers and acquisitions changed the brewery landscape significantly, resulting in an increase in market share for the 4 main global players from 22% in 2000 to 41% in 2012.The most recent major acquisition was in 2012, when Heineken acquired Asian Pacific Breweries. Today, Heineken has 165 breweries worldwide, serving customers in no less than 178 countries. Besides Heineken, the world's leading brand in the International Premium Segment IPS, the company offers an extensive range of products comprising approximately 250 brands, including various beers, cider and other beverages.

Since almost a century ago, Heineken is exporting beer and this created a solid foundation to become a strong international brand. In addition, Heineken has many global marketing campaigns that maintain its global and premium image and to outperform its competitors. This is why Heineken is by far the company with the highest export volume throughout the world, accounting for 29.1 million hectolitre.

More than 10 million hectolitres of beer is brewed within the Netherlands to be transported all over the globe. In total, this is about 7% of the Heineken beer volume worldwide. The beer is brewed and packed in three breweries (located in Zoeterwoude, Den Bosch and Wijlre) belonging to Heineken Netherlands Supply (HNS), and then transported to the customer by different means of transport. The breweries produce the Heineken brands in all kinds of packaging types and for all kinds of markets. Heineken Nederland Supply exports to more than 150 countries worldwide.

The brewery in Zoeterwoude is one of the largest beer breweries of Europe and is designed for producing large quantities of beer. The process of beer production can be split in two main parts:

brewing and packaging. This research is conducted on the packaging department, which is introduced in the next section.

1.1.2. Introduction packaging department brewery Zoeterwoude

The packaging department of the brewery in Zoeterwoude consists of nine packaging lines, of which some are split up in several sub-lines. The lines are divided based on the type of packaging used and the destination of the products. An overview of the lines can be seen in Table 1. Each of these lines can both fill and package specific types of beer in specified packages. The nine packaging lines are divided over five rayons, which have a rayon manager as responsible. An overview of the organizational structure can be found in Figure 1. As this research will be conducted at Rayon 3, the organizational structure is split up in more detail for this rayon. At Rayon 3, production runs five days a week, 24 hours a day, and therefore three teams of operators are working on the packaging line.

Rayon	Line number	Packaging	Destination
1	1	Returnable bottles	Local
	9	50L kegs	Local
2	2 (21,22)	One way bottles	Export
	3	One way bottles	Export
3	5 (51,52)	One way bottles	Export
4	6	Cans	Export
	4 (41,42)	4L kegs	Local/Export
5	7	One way bottles	Export
	8 (81,82)	One way bottles	Export

Table 1: Overview of the packaging lines Heineken brewery Zoeterwoude

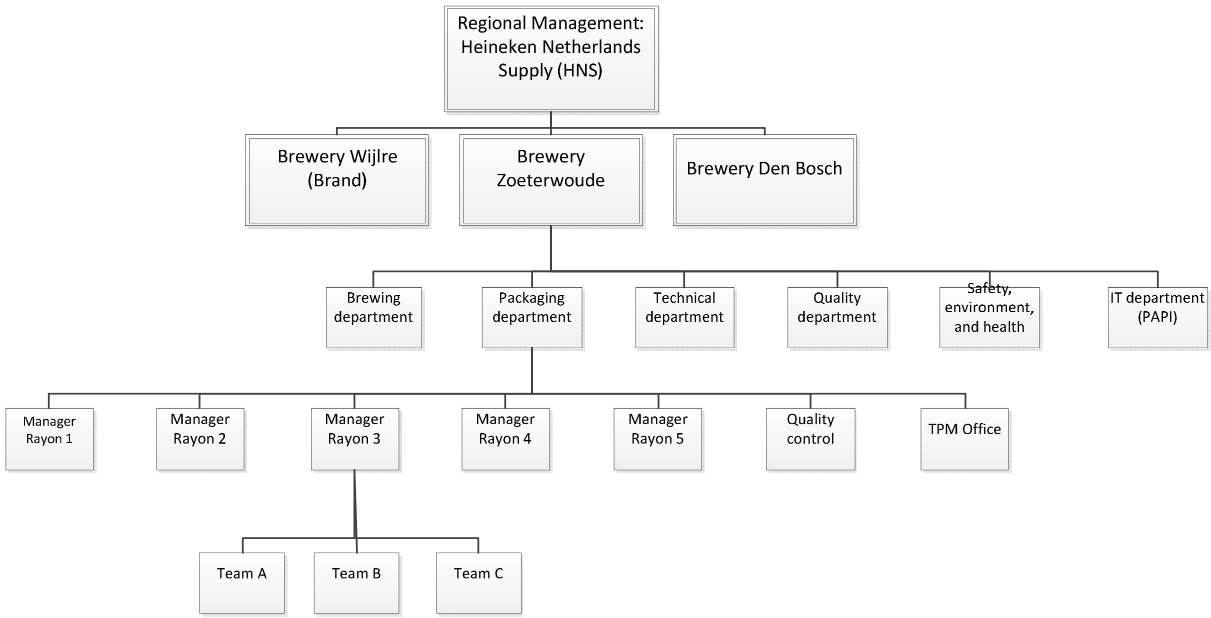

Figure 1: Organizational Structure Heineken Netherlands

Rayon 3 produces one way bottles for the export market. The line is divided into two sub-lines, which both have two filling machines.

1.2. Research motivation

The beer market is a competitive market, with a few big global players. As one of these big global players, HNS needs to continuously realize efficiency improvements to reduce costs and stay ahead of the competition. Therefore, the production process has to be improved, as more products need to be produced, preferably with fewer resources, in less time, and with lower costs.

Within Heineken, the Overall Performance Indicator (OPI) is one of the key performance indicators (KPI) used. This OPI is determined as a product of availability, performance, and quality (see Appendix A) like the overall equipment effectiveness (OEE) in Total Productive Maintenance (TPM) **Invalid source specified.**. Every shift the OPI is measured and determined. Currently, the OPI of packaging line 51 is below the target for 2014 as stated by the head office, while this is one of the brewery's priorities for 2014 (see Appendix B). To fulfil the demand from the market while keeping the costs as low as possible, efficient use of the available production hours is important for Heineken. Therefore, the OPI on packaging line 51 needs to be increased.

1.3. Problem description

Globally, Heineken is measuring the efficiency of the packaging lines using OPI. This is done based on the filling machines, which are seen as main machines and are the bottleneck in the process. The filling machines are the bottleneck machine to ensure the quality of the product. To ensure a high product quality, the filling machines should work as continuously as possible. Therefore, a packaging line is designed with the filling machine as machine with the lowest technical capacity.

For packaging line 51 of the Heineken brewery in Zoeterwoude, the availability and performance aspect of the OPI show room for improvement. As Heineken is operating in the food- and beverages industry, quality always has been focused on. Therefore, the current performance on the quality aspect of the OPI is on target. To reach the OPI target set by the head office, the availability and performance aspects need to be improved. Availability of the machines is related to breakdowns, which is a stop longer than 5 minutes as a result of mechanical, electrical/instrumentation failure on components, subassemblies or packaging line machinery and control systems (Heineken, 2011). The performance is determined by minor stops and speed losses, but also includes blocking and starvation of the machine (See Appendix A).

Both speed losses and blocking and starvation can be related to the availability and speed of machines. The speed of the machines on packaging line 51 is changed quite often by the operators on the line. These speed changes have a big influence on the efficiency of the line. Not only does changing the speed of one machine influence the speed of other machines, but this results in a non-continuous flow. Therefore, the machines often have start and stop moments, which can damage the machines and leads to more disruptions. Therefore, it is important to determine on which speed the machines should normally be working, to create a continuous flow on packaging line 51. This increases the performance-aspect of the OPI and the output of the packaging line.

Efficient use of the available production hours is important for Heineken to fulfil the demand from the market. Therefore, both the time and frequency of breakdowns, minor stops, speed losses, blocking, and starvation should be reduced.

1.4. Research objective

Based on the problem description in Section 1.3, we can define the objective of this research:

The objective of this research is to determine how the operational performance of packaging line 51 can be improved.

To reach this research objective we need to determine the right speeds for the machines on production line 51 of Heineken to assure a continuous flow on the line. This speed is dependent on different factors, which have to be identified. Probably these are the buffer size, speeds of previous/next machines, chance of disruptions in the process, and the mean time to repair. Taking all necessary factors into account, the best machine speeds for packaging line 51 at the Heineken brewery in Zoeterwoude are determined.

Also, we look how continuous flow can be secured in case of disruptions. Several sensors are placed on the buffers of the line, which determine the fill level of the buffers. Based on these fill rates, machine speeds can be automatically adjusted to secure the continuous flow. Currently, the settings for these flow regulations are not optimal, as a lot of stop/start moments can be seen in the overview of actual machine speeds. Therefore, it is important to identify at which fill level of the buffers the machines should speed up or slow down.

1.5. Scope of the research

The research focuses on packaging line 51 of the Heineken brewery in Zoeterwoude, this choice is made by the company. Only the packaging process will be analysed, which starts with empty glass bottles entering the production floor, and ends when the pallets are ready to be transported to customers. This is the part which belongs to the filling/packaging department, while the brewing of the beer and the logistics of raw material and complete order handling are the responsibility of other departments. After completion of the research for line 51, we will also determine to which extend the results can be generalized to other packaging lines in the brewery in Zoeterwoude.

The research takes the current level of breakdowns as given, as this is the wish of Heineken. They want to improve the continuous flow with the current failure rate. Also, technical improvements are not in line with the study background in which this research is conducted. This means that we take the current level of failures and breakdowns as a restriction, and not focus on this reduction.

Also, the research is bounded by two constraints stated by Heineken. First of all, as Heineken is operating in the food- and beverages industry, strict laws and regulations consist related to quality of the products. Also, Heineken is well-known for its high product quality and this is one of the main points in the vision of Heineken. Therefore, some machines and conveyer belts are bounded in speed or capacity.

The second constraint is related to safety. The working environment has to be safe for the operators, and this bounds the possibilities. Heineken follows a zero accident policy, and therefore the safety levels of operations cannot be decreased.

1.6. Research approach

The research objective and the problem description, given in previous sections, lead to the following central research question:

How can the performance of packaging line 51 of the Heineken Brewery in Zoeterwoude be improved, while taking into account the quality and safety regulations?

To answer this research question, we divide the central question into several sub-questions. The answers of these sub-questions lead to a solution for the current problem as described in Section 1.3. In the description beneath the sub-questions the research method is briefly described.

The first step to answer the central research question is to understand the current process and the way Heineken measures performance on the packaging line. Therefore, Chapter 2 answers the question:

How is packaging line 51 currently performing?

This question is answered using information supplied by Heineken, its employees, and its information systems. Also, information is gathered by walking around on the production floor and gathering information from machines and operators. Chapter 2 discusses both the outline of the packaging line and the current performance as evaluated by Heineken.

Knowing the current performance, we need to determine which factors are important to create a continuous flow on the packaging line. Also, we need to evaluate how these factors can be modelled to analyse their influence on the continuous flow in the process. Therefore, we answer the question:

Which factors influence the continuous flow on a production line according to the literature, and how can this be modelled to analyse the influence of these factors?

These factors and the possible modelling methods are discussed in Chapter 3. Based on the advantages and disadvantages of different modelling methods found in the literature, we develop a model in the first part of Chapter 4.

After the improvement areas for packaging line 51 are identified and a model is developed, we come up with changes necessary to increase the current performance and create a continuous flow on the packaging line. After identification of the possible improvements, a choice has to be made between the proposed changes. To make the right decision, evaluation of the influence on the organization and the impact on the process performance is necessary. The question answered in the second part of Chapter 4 is:

Which changes are most beneficial to increase the performance on packaging line 51?

After identifying the influence of the changes, we can answer the main research question and recommend the changes with the highest potential to Heineken. The conclusion and recommendations can be found in Chapter 5.

2. Packaging Line 51

In this chapter, an overview of the process on packaging line 51 is given. We describe the packaging process in Section 2.1, after which the methods used on the packaging line, for measurement and system changes, are described in Section 2.2. Section 2.3 deals with the organization of the packaging line. The description is followed by an analysis of the current performance of the line and individual machines in Section 2.4.

2.1. Packaging process

Packaging line 51 in Zoeterwoude is a one-way bottle line. This means that the bottles used are new, directly from the manufacturer and will not return in the process after use. On line 51, only one type of bottles is used, named the 355K2. This means that the content of the bottles is 355 ml. There are several packaging options: carton boxes with six-packs, with interior partition, and trays. Independent of which packaging option is used in production, all the products are meant for export and will not appear on the domestic (Dutch) market. Mainly, this line produces for the USA market.

This section describes the process on line 51. The process description is divided into two parts: machinery (Section 2.1.1) and conveyers/buffers (Section 2.1.2).

2.1.1. Machinery

This paragraph gives a short process description of these main machines. Figure 2 shows the process of packaging line 51. The machines at the upper line of this figure are together named the ‘wet area’. The bottom line of the figure shows the machines in the ‘dry area’. The carton infeed also belongs to the dry area. Appendix C gives a layout overview of packaging line 51. Appendix D gives a detailed process description and indicates the main machines.

The packaging process starts with beer entering through pipes from the brewing process and pallets with new glass bottles entering from trucks. Then the protective foil is removed from the pallets by the defoil machine, after which the bottles are removed from the pallets by the depalletiser. The depalletiser puts every layer of bottles separately on the conveyer belt, leading to the rinsing/filling machines. Here the bottles are first rinsed with water, filled with beer, and then the bottles are closed with a crown cork. Next, they are transported to the pasteuriser, which heats the filled bottles to pasteurize the beer and increases the shelf life of the product. From there, the bottles continue to the labelling machine, after which they are ready for packaging.

On line 51, there are two ways of packaging. The first one is in carton boxes; the second one is to put the bottles on trays using the multipacker. As the multipacker is currently not used, we will only describe the packaging in carton boxes and the multipacker will be outside of the scope of the research.

The packaging machine has a second infeed, next to the filled bottles, which consists of the empty boxes. The boxes are set up by a machine. Dependent on the current way of packaging, the box is either filled with an interior, a carton dividing the box into 24 compartments (each for one bottle), or four six-pack cartons (each for six bottles), which are set up by a separate machine. Having both boxes and bottles ready, the packaging machine fills the boxes, and the filled boxes are closed by the closing machine. The closed boxes are transported to the palletiser, which puts seven layers of 12 boxes on a pallet. The pallet is covered with foil on the sleeving machine and is labelled by the sticker machine. Now the pallet is ready for transport, which is handled by Customer Service & Logistics (CS&L).

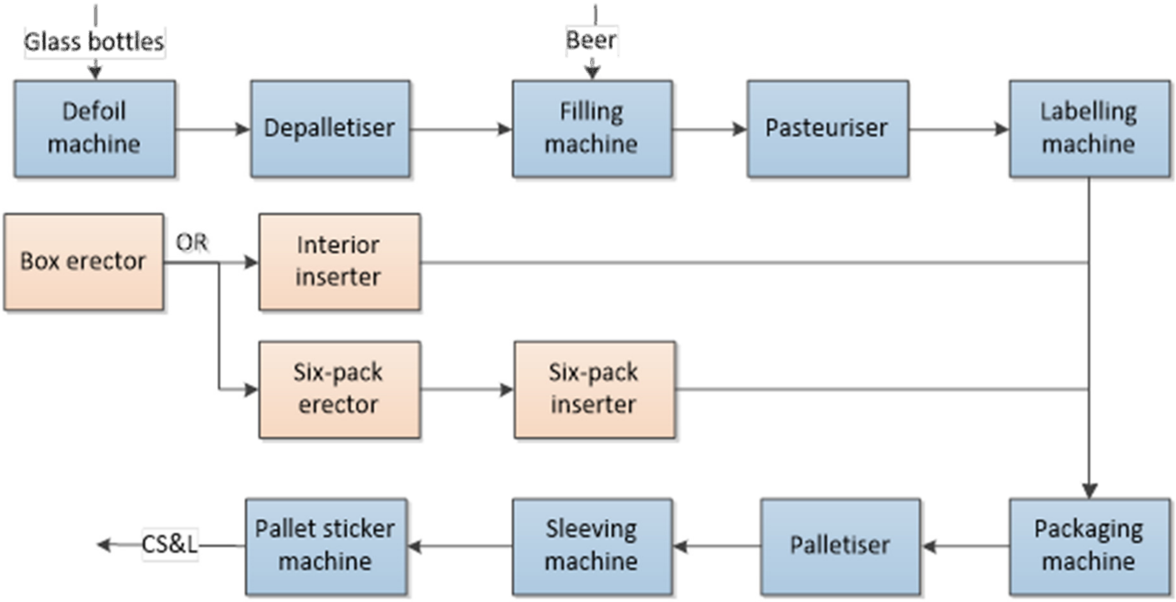

Figure 2: Process on packaging line 51, blue shows the flow of bottles, orange the infeed of carton

2.1.2. Conveyers/buffers

Between all machines in the process, conveyer belts are installed to transport the bottles or boxes to the next machine. These conveyers also function as buffers between the machines. The length and width of these conveyers determine the buffer capacity.

Some of the workstations along the line consist of single machines, but sometimes two machines are placed in parallel. To equalize the workload of parallel machines, the bottles are sometimes gathered together on one conveyer belt between the workstations, but split up again in front of the next machine. Division of workload over the machines is done based on congestion on the conveyer belt (See Figure 3 for an example).

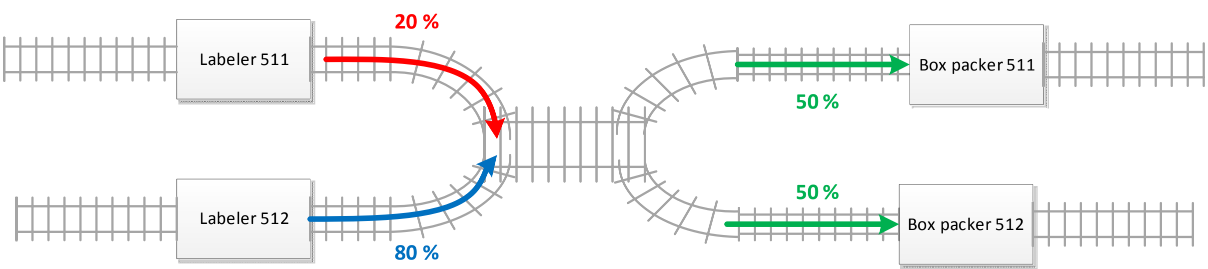

Figure 3: Example of merging and splitting of bottles for equal division of workload

Speeds of the machines are partly related to the fill level of the buffers. Along the conveyer belts, sensors are placed to determine the fill level of the buffers. They are programmed to slow down or stop upstream machines when the buffer is (almost) full, and to speed up or start these machines when space is available in the buffer. Also the speed of downstream machines is managed using these sensors, but in the opposite way. The speed of the machine depends on the settings of the machine. How these are determined and adjusted is described in the next section.

2.2. Method

In this section, we describe the methods used at the line for measurement and system changes. As quality is the number one aspect at Heineken, we start with describing where in the process measurements for quality take place (Sections 2.2.1). Also, we describe the current methods used to evaluate overall efficiency and speed (Sections 2.2.2 and 2.2.3). In Section 2.2.4 we describe how the speed of machines can be adjusted.

2.2.1. Quality checks

In the packaging process several quality checks take place. Some of the checks are done automatically with the use of sensors, but some of the checks are done by the machine operators on the packaging line. At every automatic check, products outside the allowable range are emitted from the process. Out of range manual checks require an adjustment, but can also lead to a blockage of final products.

Wet area

Before entering the filler, every bottle is automatically checked on shape and content by a sensor. After the filling, bottles are checked again, this time on the fill level and pressure on the crown cork. The operators of the filler manually perform scheduled checks on the products. During these checks, they also check the fill level of the bottles. Next to that, they also measure the oxygen level of the beer. At the pasteuriser, no automatic quality checks are performed. Manual checks are performed by the operators on the quality of the water, mainly on the levels of chemicals. These chemicals are used to clean the bottles, keep the water clean, and make sure the crown corks are not corroding. After the labelling machines, a more precise automatic check is performed on the fill level of the bottle. Here the allowable range is smaller than at the filler. Also, the labels are checked for position on the bottle. The operators perform scheduled checks on the labels as well, especially looking whether there is air present under the labels.

Dry area

Each box is checked on weight after the packaging machines. Also, there is a check whether the box is closed properly directly after closing. This is checked again between the packaging machine and the palletiser; just before the palletiser a system checks if the box is wet. A wet box means that a bottle is broken along the process and these boxes cannot enter the market. The last manual checks are performed at the packaging machine; operators check the overall sales quality (label position, fill level, etc.). All bottles of a box are placed next to each other and checked for fill level, label position and quality, laser codes, etc.

2.2.2. Efficiency measurement

At Heineken, efficiency is measured using the OPI (see Chapter 1 and Appendix A) on the production line. The OPI is determined by:

OPI = Availability * Performance * Quality

The quality is the fraction of time theoretically needed to make the 'good product' output, divided by the time needed for the total output created (including rework and rejected products). Heineken defines this as:

$$\boldsymbol{Quality} = \frac{Good\ product}{Good\ product + Reject\ \&\ Rework}$$

Performance is calculated by dividing the production time by the operating time. The production time is the time (theoretically) needed for the total number of products (good product + reject and rework). The operating time is the production time + the time for speed loss and minor stoppages (< 5 minutes), so the time the line has actually been in operation. Because these speed losses are especially hard to define, we also give the calculation starting with the total time:

$$\boldsymbol{Performance} = \frac{Production\ time}{Operating\ time}$$

$$\begin{gathered}\boldsymbol{Operating\ time}\ = \ total\ time - unused\ time - nonteam\ maintenance \\ - \ No\ Order\ No\ Activity - change\ over\ time - planned\ downtime - breakdown\ time\end{gathered}$$

Here breakdown time only includes stops longer than 5 minutes.

The last part of the OPI, the availability is calculated as follows, where manned time is the total time – unused time (e.g. weekends).

$$\boldsymbol{Availibility} = \frac{Operating\ time}{Manned\ time}$$

To make these calculations clear, we provide an example with virtual numbers. Here we calculate the OPI as goals for the packaging lines are based on this measure.

Total time: 480 minutes
Meetings: 30 minutes
Change over time: 30 minutes
Planned downtime: 60 minutes
Breakdown time: 80 minutes
Speed loss and minor stoppages: 30 minutes
Good product: 20000 boxes

Manned time: 450 minutes (480-30)
Operating time: 280 minutes (450-30-60-80)
Production time: 250 minutes (280-30)

From the numbers given we can calculate the OPI if we

The capacity of the packaging line is determined by the fillers, which can fill 120,000 bottles per hour. As a box contains 24 bottles, this means 5,000 boxes per hour. For a production of 20,000 boxes, theoretically 240 minutes are needed. This gives the following OPI:

$$OPI = availability * performance * quality = \frac{280}{450} * \frac{250}{280} * \frac{240}{250} * 100\% = 53\%$$

Because the OPI requires a lot of calculations, we will only look at the output of the packaging line. The output has the highest impact on the OPI, which is used to determine performance at Heineken. From now on, if performance is mentioned, we mean output of the packaging line. An increase in output will automatically result in an improved OPI, as long as the manned time remains the same.

2.2.3. Speed evaluation

At Heineken, a V-graph is used to determine how the speeds of different machines on the line should be balanced. The V-graph sets the capacity of the bottleneck machine as 100%, and the machines before and after the bottleneck are set on increasing percentages as further away they are from the bottleneck machine **Invalid source specified.**. A general example from the brewing industry is displayed in Figure 4. If the machines are set at the right speeds and the buffers are used in the right way, this reduces the blocking and starvation times of the bottleneck machine. Minor stops up- or downstream are covered by the buffers, so only longer stops influence other machines along the line, especially longer stops of the bottleneck machine **Invalid source specified.**.

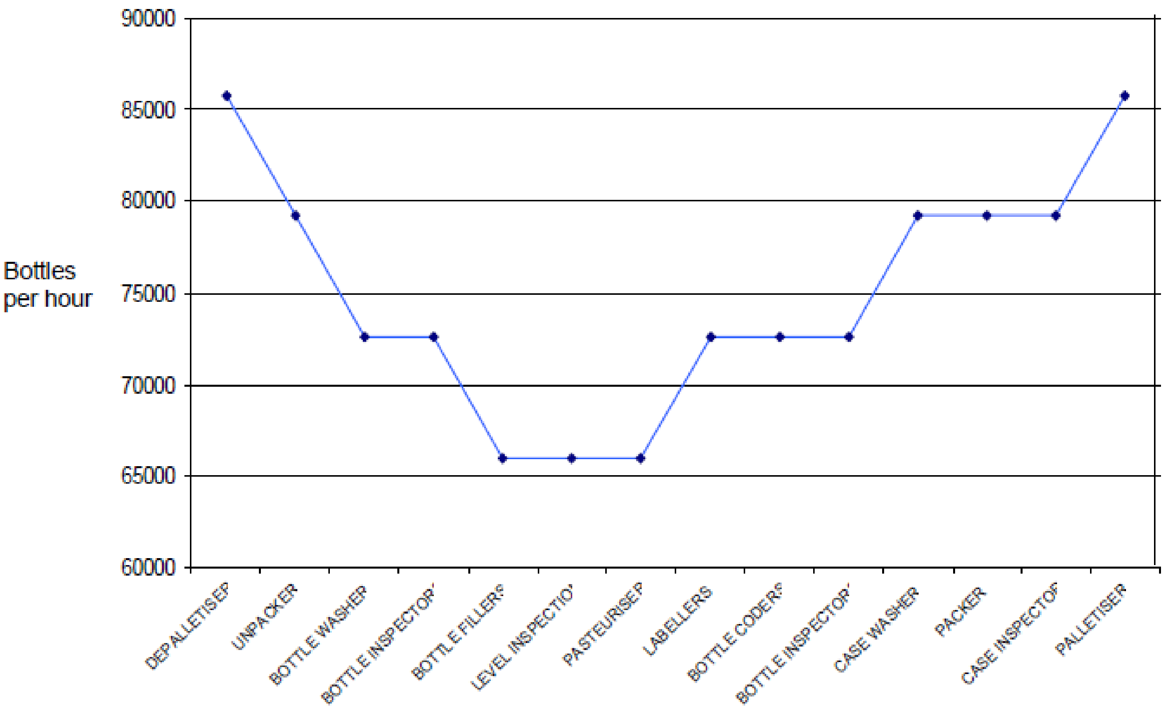

Figure 4: Example V-graph (Browne, 2005)

At the packaging lines the filling machine is the bottleneck machine, as explained in Section 1.3. This is already taken into account during design and acquisition of the line. During this phase, the group supply chain (GSC) of Heineken determines what the V-graph should look like. They use increasing percentages, which are not constant. The percentages are determined based on experiments conducted quite a while ago. Therefore, it is important to look critically at these percentages, as they are not determined especially for this line and almost independent of the available buffer capacities. Also, the V-graph is only determined for the main machines on which the bottles are processed, but the carton infeed is not taken into account.

Machine speeds are limited by several factors, of which one is the technical capacity. In general, it is not possible to set the machines on the maximum technical speed and still secure the quality. Also, working at this speed results in a lot of stops for the machine, which can increase the chance of breakdowns. Therefore, for every machine, the best processing speed should be determined. Currently, the set points of the machines at packaging line 51 are based on experience and historical results. Determining set points, operating on these speeds, and only changing this in rare cases when no other options are available, increases the efficiency of the packaging line by reducing speed loss and blocking and starvation times.

2.2.4. Speed adjustment

As already mentioned in Section 2.1.2, the speed of the machines is partly determined by the sensors along the conveyer belts, but also by the speed settings of the machine. Some of the machines have several speeds. Next to a nominal speed on which the machine normally works, they also have a low and/or high speed in case of high or low buffer fill levels.

Machine	Adjustment method	Number of different speeds
Defoil machine	Programming	1: nominal
Depalletiser	Programming	2: nominal and high
Filling machines	Operator	1: nominal
Pasteuriser	Programming	2: nominal and high
Labelling machines	Operator	2: nominal and high
Packaging machines	Programming	3: low, nominal and high
Box erector	Operator	1: nominal
Interior inserter	Operator	1: nominal
Six pack erector	Programming	3: low, nominal and high
Six pack inserter	Programming	1: nominal
Palletiser	Programming	1: nominal
Sleeving machine	Programming	1: nominal
Pallet sticker machine	Programming	1: nominal

Table 2: Speed adjustments of main machines

There are two ways to change the speed settings; either the operator changes the speed on the machine, or a programmer changes the set points as programmed in the machine software. For some machines, it is possible for an operator to change the speed, while on other machines changes are only possible by adjusting the software program. The second column of Table 2 shows which method is used for which machine.

The third column of Table 2 shows how many speeds the machine uses. Some of the machines use several different speeds while being in production. If we look for example to the packaging machines, we see that there are three speeds, which can be adjusted by programming. This means, that in the software program, three different set points exist, one for low speed, one for nominal speed, and one for high speed. When the machine is in production, it will always use one of these speeds. The current speed is determined by sensors along the conveyer belt in front of the machine. These sensors detect until which point the buffer is currently filled with bottles, and based on this fill rate, the speed is adjusted. Figure 5 displays this process, by showing two machines and the conveyer belt (buffer) in between. The speed of machine 2 is determined by sensors along this conveyer belt, represented by the vertical black lines.

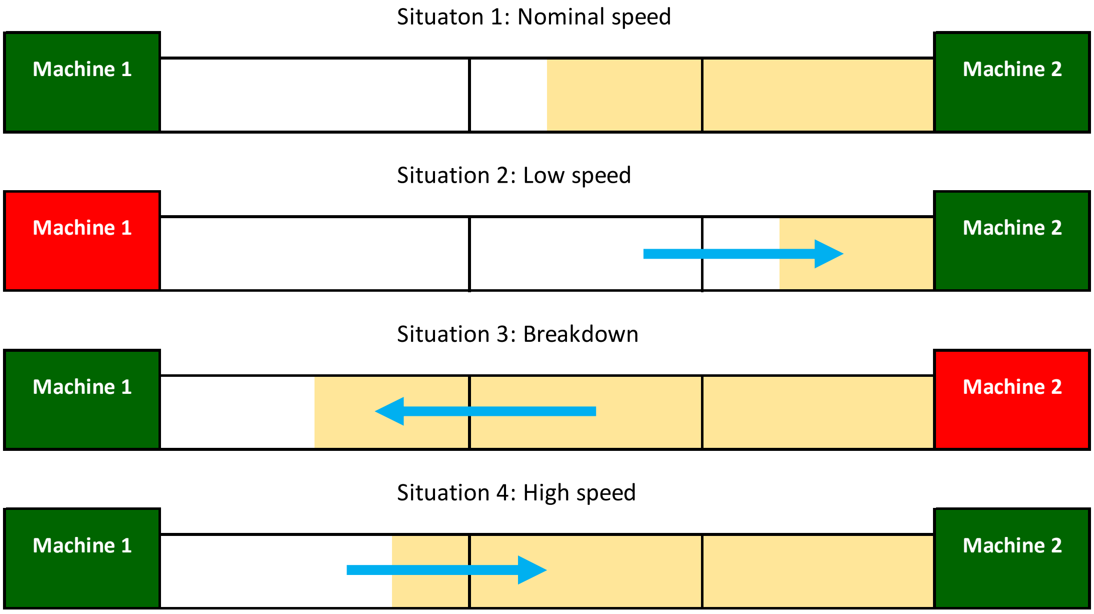

Figure 5: Example of how sensors along the conveyer belts determine machine speed

In situation 1, we see the machines both in 'normal' state. They are both working at nominal speed and the buffer is in steady state. As soon as machine 1 breaks down, we go to situation 2. There is no supply of bottles, so the buffer gets empty. The sensor closest to machine 2 is no longer detecting bottles, and changes the speed of machine 2 to low speed. If machine 1 is not restarted before the buffer becomes empty, we call this starvation of machine 2. As soon as machine 1 starts working again and there is supply of bottles, the process goes (slowly) back to 'steady-state' as in situation 1. As soon as the sensor detects bottles again, the machine goes back to nominal speed.

Another option is a breakdown of machine 2, which is displayed in situation 3. As soon as this happens, the bottle supply continues, while there is no processing of bottles. In this situation the buffer gets fuller. If machine 2 does not start working again before the buffer is completely full, we speak of blocking of machine 1. As soon as machine 2 is restarted, we get to situation 4. If the sensor closest to machine 1 detects bottles, it changes the speed of machine 2 to high speed. This way, the buffer is emptied partly. As soon as the buffer is no longer filled until the sensor, the machine changes to normal speed and we are back in situation 1.

This way, the different speeds as displayed in Table 2 are assigned to the machines based on the fill rate of the buffer. The programmed fill rate for speed change determines the moment when the machine slows down or speeds up. The placement of the sensors along the conveyer belt determines for which fill rates this is possible.

2.3. Organization

As mentioned in Section 1.1.2, there is one rayon manager and there are three teams of operators on packaging line 51. In this section we discuss those stakeholders, but also other groups and people working on the line, that can influence, or are influenced by, the performance of the line. We start with the people directly involved in the daily operations, which are the rayon manager, the operators, but also the installation administrator. Next to that, we describe the interests of the company management, (in which we include all hierarchical levels above the rayon manager), the technology/quality department, the maintenance department, and the logistics department (CS&L).

The rayon manager is responsible for the performance of packaging line 51. She determines the strategy for the packaging line based on the line set by the management of Zoeterwoude and the global management of Heineken. Also, she manages the operators and the installation administrator. The installation administrator is responsible for all the machines and installations of the packaging lines. He is the first contact point for the operators when something is wrong with an installation and communicates this to the maintenance department. He collects and processes labels for repairs, modifications, and safety written by the operators.

On packaging line 51, there are three teams of operators, working in shifts of 8 hours, during 5 days, 24 hours a day. During the weekend, the line is normally not in use. The main task of the operators is to make sure the machines are running and high-quality products are produced. This means they have to make sure materials are available, clean the machines, check the quality, detect problems, and, when necessary and possible, troubleshoot failures. When they cannot fix a problem, they contact the installation administrator or someone from the maintenance department. The operators are important in the process of changes, as they are the ones taking care of the production, and they can influence the performance and output of the process. Therefore, support of the operators is needed when implementing changes.

The maintenance department consists of several sub-departments. On the line, mainly the all-round maintenance engineers and the electricians are needed to solve problems. These are the employees assisting the operators when problems occur on the line during production. When programs of the machines or conveyers need to be adjusted this is done by the programmers. Changes on the line often need to be done by the maintenance department, so they are important for the implementation.

Next to the people working on the line, either in daily operations or when needed, the technology/quality department is also important. They evaluate the quality of the product, look at safety issues, and reflect on the influences of changes to product quality when needed. Every week the quality is evaluated with the rayon manager, and actions are taken if necessary. When changes are made, it is important that the quality/technology department is informed to ensure the quality.

CS&L is also a stakeholder that needs to be taken into account. They are responsible for the supply of materials (empty bottles, carton, etc.) and the transport of completed products. When big changes occur, they need to be informed and their opinion should be taken into account. If materials are not supplied, or final products are not transported, this results in stops in the process.

At last, also the management is important. The management consist of several layers in the hierarchy, starting by the packaging manager. He should be involved to get his support for changes. Also, he is the final responsible to the local brewery manager concerning everything happening in the packaging department.

2.4. Current performance

This section describes the current performance of the process. We start with a description of the overall process performance. Several aspects will be discussed, based on how Heineken evaluates performance and speed as discussed in Section 2.2. As mentioned in Chapter 1, quality is not taken into account as a lot of focus is already on quality performance, and next to that, there is a separate quality department within Heineken to evaluate and improve this aspect of the OPI.

2.4.1. Availability

In this section we evaluate the current performance and take a closer look at the losses in the availability and performance aspect of the OPI. Looking at Figure 6, we see an overview of the categories of unplanned downtime as percentage of effective working time (time the machine is theoretically available for processing, so not in stop for cleaning, unmanned time, etc.). The unplanned downtime has a direct influence on the performance, and should therefore be minimized.

This figure is confidential

[redacted]

Figure 6: Total unplanned downtime main machines as percentage of effective working time

The category “other” includes the time where the machine status is unknown, due to no or incomplete status registration. The remainder of the effective working time, the machine is in production. Internal stops include both breakdowns (> 5 minutes) and minor stops (< 5 minutes). Starvation is mostly due to bottles, but for the box packers there is a separate registration for starvation due to lack of boxes. Therefore, “starvation other” is added for this machine.

Figure 7 focuses on the filling machines and shows the development over the weeks. We see a decline in the total unplanned downtime, which means that there is already an increase in performance. This is due to the fact that after the weeks of revision (weeks 2 till 4), always some start-up problems occur, but after a while, the process stabilizes. As the fillers are the bottleneck in the process, most of the analysis is done on these machines. We see that these breakdowns and minor stops form only a really small part of the downtime on the filling machines (on average x% of the effective working time). Especially blocking forms a main part of the downtime on the filling machines. Together, blocking and starvation account for a big part of the effective working time. The same accounts for Figure 6, for almost all machines blocking and starvation form the main part of the unplanned down time. This is generally unnecessary loss of efficiency, and therefore important to improve.

This figure is confidential

Figure 7: Unplanned downtime filling machines as percentage of effective working time

2.4.2. V-graph

To determine the current speed performance, the V-graph is designed for the current situation. Appendix E shows how the calculations for the machines are made. We calculate the theoretical capacity for each machine, taken into account the current settings of the machines. So if a machine has several speed levels, the highest level is chosen and plotted in the V-graph. For the box packer, the whole carton infeed is taken into account, as the packer can never work faster than it gets the materials for packaging. The V-graph of the current process is shown in Figure 8. The red line shows the current line capacity, while the dotted grey line shows the line determined by the GSC. The graph shows a gap between the current performance and the ideal performance according to Heineken.

The flat V-graph in week 11 results in blocking and starvation, as described in the previous section. Even minor stops influence the machines up- and downstream, as there is almost no extra capacity to empty or fill buffers after a stop. In Chapter 3 we search in the literature for the related research to be able to determine the best speeds for the machines.

The biggest gap between the line of the GSC and the current performance can be seen at the palletiser. In 2013, Heineken introduced a new bottle, named the K2. This bottle is made of thinner glass, and also more light-weight carton is used for the packaging. As a result, transport costs decreased significantly, but the chance on broken bottles increased. The palletiser uses moving beams to move the boxes to the right place, and the impact of these beams on a box is high. Therefore, the machine is currently working at lower speed than should be possible according to the technical specifications. The technical specifications would be 120% of the filling machines capacity, so for this machine, the line of the GSC (135%) is not reachable without placing another or extra machine. Therefore, a technical team is currently looking at the possibilities to increase the capacity.

The second pair of machines showing quite a gap between current and desired state, are the box packers. First of all, this is due to the fact that the machine can simply not work at the speed stated in the technical specifications. These specifications are quite general, and with the current boxes and bottles this speed cannot be reached. The distance between the machine and the box is too big, due to the relatively high K2 bottle. Therefore, the maximum reachable percentage compared to the bottleneck rate would be 122%. Also this percentage is currently not reached due to wear and tear of the machine.

This figure is confidential

Figure 8: V-graph of line 51, GSC line and the current line in week 11

2.4.3. Speed changes

In Section 2.2.4 we described the speed adjustments that can be made by the operators. Evaluating the data over the last seven weeks (the weeks after the last revision period) of the speeds that can be adjusted manually, we see that the speeds on the box erector and interior inserter are almost never changed. The speed of the interior inserters is changed twice on each machine, because of a test with another type of insert, and the speed of the box erector has not been changed at all.

The speeds of the fillers and labellers are changed quite regularly. Therefore, a trigger has been designed where the operators fill out the reason for increasing or decreasing the speed from the agreed set point. This trigger is used to see reasons why the speed is changed. On the fillers, we can see that the speed is (almost) always changed after a (long) period of no production. This is related to the temperature of the beer in the pipes from the brewery to the packaging department. The temperature influences the process, and therefore the operators need more control which is created by lowering the speed. For the labellers, it turns out that the placement of the sensors along the conveyers before the machines is not optimal, and therefore the speed is often increased manually to empty the buffers. This manual change has a positive effect on the continuity at the filling machines. This is an important observation in designing the new set points and buffer workings.

2.5. Conclusion

In this chapter we evaluated the current process and performance, from which we can conclude that most improvement can be obtained by reducing the amount of blocking and starvation of the filling machine. Blocking and starvation currently make up a big part of the total effective working time, while internal stops (breakdowns and minor stops) only account for a small percentage. As the filling machine is the bottleneck in the process, and therefore the lowest point on the V-graph, the blocking and starvation times should be minimal when the speed and buffer settings are according to the V-graph philosophy. This philosophy leads to a continuous flow on the packaging line, where disruptions only occur when machines up- or downstream from the fillers have breakdowns. For minor stops, the buffers should be able to prevent other machines from stoppages.

The focus of this research is on reducing blocking and starvation, by looking at the speed settings of machines and the use of buffers in the process. The research uses the current failure level as a given fact, and reducing the frequency and time of stops is outside the scope of this research. By reducing the time of blocking and starvation of machines, the continuity of the flow on the line will increase. In the research, we look at packaging line 51 of Heineken in Zoeterwoude. We focus on the part from the depalletiser to the palletiser, so we exclude the defoil machine, the sleeving machine and the pallet labeller.

To be able to give an advice for a more continuous flow on the line, Chapter 3 discusses the factors for continuous flow according to the literature. In Chapter 4, a more extensive analysis of the gaps between the current state and the desired state (which is based on the literature) is conducted to come up with alternatives and solutions to minimize the blocking and starvation time of the filling machines.

3. Literature

This chapter provides theory which can be used for analysing and improving the current performance at Heineken. First we classify the packaging process according to the literature in Section 3.1. This is necessary to determine which methods from the literature are applicable to the packaging line. After this classification, we study variability in Section 3.2, as this is the main source for the difference between effective throughput and theoretical throughput. Section 3.3 deals with how we can model variability and the effects of variability. Section 3.4 and 3.5 respectively discuss analytical models and simulation models. Section 3.6 describes a method to determine buffer sizes. The process has finite buffers, and therefore buffer sizes need to be known. The last section (Section 3.7) concludes, based on the literature, on which method we use in the remainder of the research.

3.1. Classification of the packaging process

This section describes the process from a theoretical view. We review the process based on existing classifications of manufacturing processes, to be able to use the literature which is applicable to the process at packaging line 51. Manufacturing processes can be divided into several categories. This section discusses some of the categories used for classification.

First of all, we can distinguish between discrete or continuous processes. In discrete manufacturing separate units are produced, where continuous manufacturing entails production in bulk quantities **Invalid source specified.**. But, as stated by Cooke, Bosma, and Härte **Invalid source specified.**, the error introduced by modelling the production as a continuous variable is small, due to the high production rate of hundreds of bottles per minute. Therefore, models for continuous production can also be taken into account.

The second classification can be made looking at the machines in the process. The machines can either be reliable or unreliable, as well as form a synchronous or asynchronous line. Reliable machines are always up and ready for processing, whereas unreliable machines have downtime. In a synchronous process all workstation have the same production rate/capacity, whereas this is not the case for an asynchronous process **Invalid source specified.**.

Another way to classify a system is whether it is open or closed. In closed systems, there is a constant number of 'jobs' present, while in an open system this number is an independent random variable **Invalid source specified.**.

The packaging process at Heineken is a discrete manufacturing process, as the bottles are filled per piece. Also, it is an unreliable and asynchronous process. We can classify the packaging process as an open system, and mass production with asynchronous part transfer, which is very common for production lines.

The last classification is based on the saturation of the process. A saturated process always has raw materials available as input of the process, and at the output inventory space is always available. A non-saturated process has either a buffer at the begin and/or at the end of the production line. Although there are buffers at both sides of the line, we assume the packaging process at Heineken to be saturated. This has big advantages for the analysis of the process, and is very close to reality, as the buffers at the beginning and the end of the process almost never cause blocking or starvation on any of the machines.

3.2. Variability

There is no manufacturing process without variability, which makes it important to know how to cope with variability and to determine the influence of the variability on the process. Variability can be either good (e.g. product variety) or bad for the company, but as stated in the variability law: 'increasing variability always degrades the performance of a production system' **Invalid source specified.**. Therefore, variability reduction is necessary to increase performance.

To measure the variability of a random variable we use the coefficient of variation (CV, represented by c), which is the standard deviation (σ) divided by the mean (t). We can identify three classes, low variability ($c < 0.75$), moderate variability ($0.75 \leq c < 1.33$), and high variability ($c > 1.33$). Sometimes, it is more convenient to use the squared coefficient of variation (SCV, represented by c^2). The formulas are:

$$c = \frac{\sigma}{t} \qquad c^2 = \frac{\sigma^2}{t^2}$$

Even if variability is not decreased, we can influence how it affects performance by using buffers. There are three options to buffer variability, which can be used in combination. These are: inventory (stock), capacity (overcapacity), and time (waiting time). Which buffering strategy is best, depends on the business environment **Invalid source specified.**.

Variability is a result of several causes. In a manufacturing environment, the most common sources of variability are: natural variability, random variability, outages, setups, operator (un)availability, and rework **Invalid source specified.**. Random failures can be classified as pre-emptive outages (occur whether we want them or not), while setups and rework can be classified as non-pre-emptive outages (we can control when they happen).

Another type of variability in production processes is flow variability. This is the effect of variability at one station on another station in a line. The departures at one workstation are the arrivals at the next workstation, and therefore variability is transferred downstream the production line.

All the above mentioned sources of variability can cause time losses in the production, as they result in queues somewhere along the production line. As the effects of variability are related to arrivals and departures at the workstations, they are also related to machines speeds.

3.2.1. Bottleneck machine

The bottleneck rate used to calculate throughput is the effective rate of the bottleneck machine, which is determined by the nominal rate times the availability. As availability we use the probability that the machine is not down, where blockage and starvation are also seen as if the machine is available **Invalid source specified.**. Increasing the bottleneck rate is related to technical changes, reducing breakdowns, improving operator skills, and increasing manned time, which are outside the scope of this research. Therefore, we look at increasing the bottleneck utilization to increase the throughput. This means reduction of blocking and starving of the bottleneck, for which Hopp and Spearman **Invalid source specified.** give two ways to do this. The first is increasing the buffer size in the system, which is most effective immediately in front of the bottleneck or after the bottleneck. The second method is buffering the bottleneck with capacity by increasing the effective rates of non-bottleneck stations, in which extra capacity at the highest-utilization non-bottleneck stations will generally have the largest impact **Invalid source specified.**.

3.2.2. Controlling variability

At packaging line 51, the ultimate goal is to increase throughput without reducing quality or increasing costs. To increase throughput, either the bottleneck utilization or bottleneck workstation processing rate (from now on bottleneck rate) should be increased, as throughput = bottleneck utilization * bottleneck rate (all for the workstation) **Invalid source specified.**. Both the bottleneck utilization and the bottleneck rate are lower than theoretically possible due to variability. Therefore, it is important to deal in the right way with variability.

3.2.3. Variability Pooling

One way of dealing with the consequences of variability is by variability pooling, in which multiple sources of variability are combined. There are several methods for this, of which one applicable at the packaging lines at Heineken is queue sharing. If one of the workstation experiences a long processing time, due to either process variability or a breakdown, jobs can go to another machine which reduces waiting time and decreases the effect of variability **Invalid source specified.**. This method can be used when parallel machines are available.

3.3. Modelling variability and the effects

To analyse variability and the effects of variability, we can use a modelling approach. We consider two types of models: analytical models and simulation models. Both have their own advantages and disadvantages, and based on the requirements of the model we can determine which method is the best. Therefore, we discuss the basic modelling approach in this section, together with the considerations when developing a model.

The basic modelling approach consists of 8 steps **Invalid source specified.**:

1. **Identify the issues to be addressed**: ascertain the needs of the user: what is the problem? How will the model be used? When is it needed?
2. **Learn about the system:** identify the performance measures of interest to the user, characterize the relevant aspects of the components and key parameters of the system.
3. **Choose a modelling approach:** use simulation or analytical models, do models already exist?
4. **Develop and test the model:** obtain data on the parameters of the model, make 'reasonable' assumptions.
5. **Verify and validate the model:** check the model for internal consistency (verification), and assess the accuracy of the results (validation).
6. **Develop a model interface for the user:** ensure that the user can actually use the model and convince the user of the value of the model.

7. **Experiment with the model:** develop an understanding of factors influencing the performance of the system.
8. **Present the results:** give recommendations based on the model results, explain the possibilities and limitations of the model, promote the model.

When applying these steps consecutively, a good choice for the type of modelling is made and the model is developed, evaluated, and used in the right way. When developing a model, several considerations should be made **Invalid source specified.**. These considerations are also important in step 3 of the basic modelling approach, when choosing which type of model is used. We mention the factors for considerations and how they behave in analytical and simulation models.

- **Complexity versus simplicity**: A complex model often represents reality better, while it also takes a lot of time and is harder to verify and validate. Analytical models are limited in complexity they can handle, while simulation models can often be made as complex as necessary;
- **Flexibility**: Both analytical and simulation models can be flexible, parameter values can be changed easily;
- **Data requirements**: In general simulation models need more data than analytical models. Most important is the data format available in reality and whether this corresponds with the data requirements the model;
- **Transparency:** For user acceptance, the model must be understood. For analytical models mathematical skills are needed to understand the model, while simulation models often can be easily explained.
- **Efficiency:** both in development and use models can consume a lot of time. The time needed for development depends on model complexity and skills of the modeller. In use, analytical models are often quite efficient, while simulation models can require substantial time.
- **User interface:** For the use of the model, a good user interface is essential. Simulation models have more options for the user interface, due to the visual representation used. Analytical models are often restricted to input and output screens as interface.

To be able to make a choice between analytical and simulation models, we need to explorer both options further. Therefore, in the following sections (3.4 and 3.5) we go into more detail on both model types.

3.4. Analytical models

Analytical models describe a system in mathematical relationship. When looking at variability in production lines, these relationships are generally described using queuing theory. In the literature we can find exact models for rather simple processes, for example flow lines with two machines. For more complex systems, mathematical relationships are often hard to determine, and therefore analytical models require assumptions, resulting in only approximations of reality. Still, it is often possible to simplify systems by integrating machines or looking only at parts of the system, on which analytical model can be applied **Invalid source specified.**. Therefore, we look into more detail in useful analytical models from queuing theory. In this section, we give an overview of the formulas which are used when analysing a system analytically. We start with process time variability, and then continue with flow variability (3.4.2) and the queuing effect of variability (3.4.3).

3.4.1. Effective process time variability

Applying the formulas for each of these variability sources gives us the parameters for the effective process times. These formulas are summarized in Table 3. An explanation of the used variables can be found in Table 4. If both pre-emptive and non-pre-emptive outages are involved, we apply the formulas consecutively.

Situation	Natural	Pre-emptive	Non-pre-emptive
Examples	**Reliable Machine**	**Random Failures**	**Setups; rework**
Parameters	t_0, c_0^2 (basic)	Basic plus m_f, m_r, c_r^2	Basic plus N_s, t_s, c_s^2
t_e	t_0	$\frac{t_0}{A}, A = \frac{m_f}{m_f + m_r}$	$t_0 + \frac{t_s}{N_s}$
σ_e^2	$t_0^2 c_0^2$	$\frac{\sigma_0^2}{A^2} + \frac{(m_r^2 + \sigma_r^2)(1-A)t_0}{A m_r}$	$\sigma_0^2 + \frac{\sigma_s^2}{N_s} + \frac{N_s - 1}{N_s^2} t_s^2$
c_e^2	c_0^2	$c_0^2 + (1 + c_r^2)A(1-A)\frac{m_r}{t_0}$	$\frac{\sigma_e^2}{t_e^2}$

Table 3: Summary of formulas for computing effective process time parameters (Hopp and Spearman, 2008)

3.4.2. Flow variability

To calculate the flow variability, we need the arrival rate at a station, denoted by r_a. This is the inverse of the mean time between arrivals, t_a. If we assume a production line without yield loss or rework, the arrival rate to station i, equals the departure rate of station i-1. Therefore, we need to calculate the inter-departure times CV (coefficient of variation) of each station. This can also be seen in Figure 9. We can do this with the following estimation formula **Invalid source specified.**:

$$c_d{}^2 = 1 + (1 - u^2)(c_a^2 - 1) + \frac{u^2}{\sqrt{m}}(c_e^2 - 1)$$

Where

$u = \frac{r_a t_e}{m}$ utilization

$c_a = \frac{\sigma_a}{t_a}$ coefficient of variation of the interarrival times

$c_e^2 = \frac{\sigma_e^2}{t_e^2}$ coefficient of variation of the effective process times

m number of parallel machines at the workstation

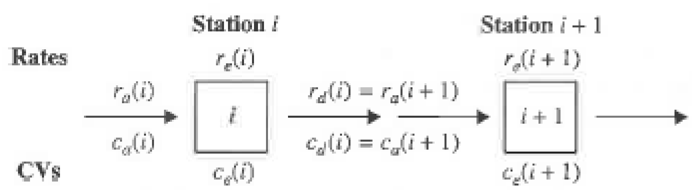

Figure 9: Propagation of variability between workstations in series Invalid source specified.

3.4.3. Effects of variability - Queuing

In this section, we briefly give some equations which can be used to determine time losses in the production. We use Kendall's notation to classify the queuing stations. This notation uses four parameters to characterize a queuing station: A/B/m/b, where A describes the distribution of arrival times, B describes the distribution of process times, m is the number of machines at the station, and b is the maximum number of jobs that can be in the system. For A and B, the following three values are mostly used **Invalid source specified.**:

- D: constant (Deterministic) distribution
- M: exponential (Markovian) distribution
- G: completely general distribution (e.g., normal, uniform)

Symbol	Explanation
c	Coefficient of variation
σ	Standard deviation
t	Mean
σ^2	Variance
t_0	Mean of natural process time
c_0	Coefficient of natural process time
t_e	Mean of effective process time
σ_e^2	Variance of effective process time
c_e	Coefficient of variation of effective process time
A	Availability
m_f	Mean time to failure
m_r	Mean time to repair
c_r	Coefficient of variation of repair times
N_s	Mean number of jobs between setups
t_s	Mean of setup duration
c_s	Coefficient of variation of setup duration
t_a	Mean time between arrivals
σ_a	Standard deviation of inter-arrival times
c_a	Coefficient of variation of inter-arrival times
r_a	Average arrival rate ($1/t_a$)
c_d	Coefficient of variation of inter-departure times
u	Utilization
m	Number of parallel machines at workstation
b	Buffer size
ρ	"corrected utilization"

Table 4: Explanation of the used variables

3.4.3.1. Fundamental queuing relationships

Hopp and Spearman **Invalid source specified.** give several fundamental relationships in queuing theory. First of all, the utilization, already given in Section 3.4.2. They also give relations for the mean time spent at the station and in the queue. This is done using Little's law **Invalid source specified.**, which is applicable to the total workstation and the queue of a workstation. Also, they give the relation between the time in the queue and the total time at the station. The WIP is the work-in-process, TH represents the throughput, CT the cycle time, and CT_q the cycle time in the queue:

$$WIP = TH * CT$$
$$CT = CT_q + t_e$$

Another useful and well-known equation is Kingman's equation, which is also known at the VUT equation. This formula is an expression of the waiting time for queuing models with general process and inter-arrival times by a variability term (V), a utilization term (U), and a time term (T). This approximation is based on the formula for the M/M/1 queue. The approximation for CT_q for single machines is given by **Invalid source specified.**:

$$CT_q(G/G/1) = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{1-u}\right) t_e$$

3.4.3.2. Blocking models

The above mentioned models do not take into account the effect of blocking. Therefore, this section describes the models used by Hopp and Spearman **Invalid source specified.** for systems with limited buffers, in which blocking can occur. We only look at the general blocking models, as the distribution of the processing and inter-arrival times are not yet determined. All equations given, lead to approximations of the throughput. Hopp and Spearman only discuss situations with one machine, so to apply the models to the packaging process at Heineken this has to be taken into account.

Hopp and Spearman **Invalid source specified.** give approximations for the WIP and cycle times using the WIP without blocking (WIP_{nb}), and buffer size (b). To get these approximations, we need to determine the throughput of the production line. For blocking models, we identify three different situations: arrival rate less than production rate, arrival rate greater than production rate, and arrival rate equal to production rate. For two of these three situations we need estimates for the buffer size, which we discuss in Section 3.6. In the remainder of this section we determine the throughput for these situations. For all situations, we can determine WIP and cycle times using Little's Law. For the WIP we obtain an upper bound and for the cycle time a lower bound by using the following formulas:

$$WIP < \min\{WIP_{nb}, b\}$$

$$CT > \frac{\min\{WIP_{nb}, b\}}{TH}$$

Situation 1: Arrival rate less than production rate

If the arrival rate is less than the production rate, u is smaller than 1. Therefore, we can use Kingman's equation and Little's law to determine the WIP without any blocking, and from there we can determine the throughput for a system with blocking, using the formulas for M/M/1 systems.

$$TH \approx \frac{1-u\rho^{b-1}}{1-u^2\rho^{b-1}} r_a$$

in which

$$\rho = \frac{WIP_{nb} - u}{WIP_{nb}}$$

$$WIP_{nb} \approx \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u^2}{1-u}\right) + u$$

Situation 2: Arrival rate greater than production rate

In this situation, we approximate the throughput and the work-in-progress by analysing the line in reverse order. By doing this, the arrival process becomes the production process and vice versa, resulting in a utilization less than 1, as the utilization is now determined by 1/u. Our system can now be evaluated as in situation 1, using the following formulas:

$$TH \approx \frac{1-u\rho^{b-1}}{1-u^2\rho^{b-1}} r_a$$

in which

$$\rho = {}^{1}/_{\rho_R}$$

$$\rho_R = \frac{WIP_{nb} - {}^{1}/_{u}}{WIP_{nb}}$$

$$WIP_{nb} \approx \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{1}{u(u-1)}\right) + \frac{1}{u}$$

Situation 3: Arrival rate equal to production rate

In the situation where u=1, we can approximate the throughput using the following formula according to **Invalid source specified.**. The theory behind the formula is very extensive, and therefore we only give the approximation for the throughput:

$$TH \approx \frac{c_a^2 + c_e^2 + 2(b-1)}{2(c_a^2 + c_e^2 + b - 1)}$$

3.4.3.3. *Variability pooling with parallel machines*

As mentioned in Section 3.2.1.2 one way of dealing with the queuing effect of variability is by using variability pooling on parallel machines. Therefore, we present the adjusted VUT-equation by Hopp and Spearman **Invalid source specified.**, which is an extension of Kingman's equation (for explanation of the variables, see Table 4):

$$CT_q(G/G/m) = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u^{\sqrt{2(m+1)}-1}}{m(1-u)}\right)t_e$$

3.5. Simulation models

Sometimes, real-world systems are so complex, that they cannot be described analytically. In this case, simulation models can be very useful. *"Simulation is the process of designing a model of a system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system"* ***Invalid source specified.***. We evaluate a model numerically, which provides us we data for estimation of the true characteristics of the model **Invalid source specified.**.

Simulation models give the possibility to estimate performance while conditions are regulated by the programming of the model. This makes it possible to do several experiments, of which the results can be compared to analyse proposed systems or come up with improvements for the current system. In reality conditions cannot be controlled and it takes a lot of time and investments to compare several system configurations. By making use of the visualization options provided by a simulation model, it is often easier to convince people about a proposed solution.

In this section, we describe the theory about simulation studies, starting with how to conduct a simulation study in Section 3.5.1. In the next section (3.5.2.) we discuss the different types of simulation models.

3.5.1. Conducting a simulation study

For conducting a simulation study we can identify three main steps: problem definition, model construction, and experimental design. In this section, we describe these steps and their sub steps as displayed in Figure 10. In Section 3.3 we discussed the basic modelling approach, and we see that the steps of both models show similarities. The model in this section assumes that the decision to conduct a simulation study is already made, while in the basic modelling approach this decision is made in step 3.

Step 1: Problem definition

The first step in a simulation study is the problem definition. In this step the problem is formulated and a plan is made for the study. This step corresponds to step 1 and 2 of the basic modelling approach. The result of this first step is generally a project specification, which includes the following points:

- *Introduction problem and project goals*: introduce the problem, and determine goals, restrictions and timing, visualization and run times.
- *Expected contribution and results*
- *Concise model description*: scope and detail, assumptions, experimental factors and reports
- *Data requirements and collection*
- *Time planning*
- *Cost estimate*

Step 2: Model construction

Step 2 of conducting a simulation study consists of the construction of the model. Therefore, data needs to be collected and the model is defined and programmed. The result of this second step is a working, valid model, which can be used to reach the goals stated in the first step. Important is that the model is verified and validated. This step corresponds to the steps 5 and 6 of the basic modelling approach.

Step 3: Experimental design

The third and last step of a simulation study determines the experimental design, executes the experiments and analyses the output of the experiments. In this step, we try to answer the following question: Which of possibly many parameters and structural assumptions have the greatest impact on a performance measure? Therefore, we need to determine the factors, their levels, and the combination of levels that will be used. This step corresponds to step 7 and 8 of the basic modelling approach.

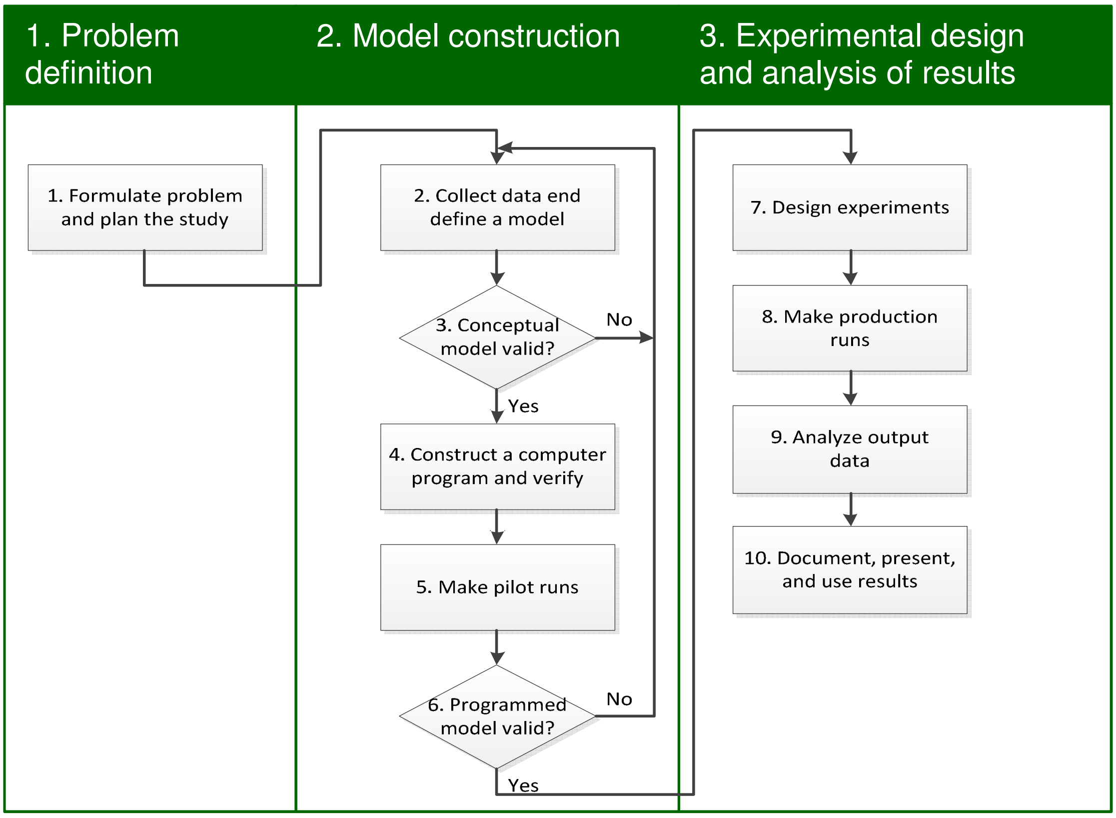

Figure 10: Steps in conducting a simulation study Invalid source specified.

3.5.2. Types of simulation models

There are several types of simulation models, which can be classified using three dimensions **Invalid source specified.**. These dimensions are:

- Static vs. Dynamic Simulation Models: static simulation models represent the system at a certain time, while dynamic simulation models show how the system evolves over time.
- Deterministic vs. Stochastic Simulation Model: a deterministic simulation model does not contain any probabilistic components, while in a stochastic simulation model random input components do exist.
- Continuous vs. Discrete Simulation Models: a discrete simulation model has state variables which change at separate points in time, while a continuous model has continuous state changes.

Law **Invalid source specified.** discusses several types of simulation, which are related to the dimensions above. Below we mention these simulation types and briefly explain the ones that are not directly related to the dimensions.

- Discrete-event simulation
- Continuous simulation
- Combined discrete-continuous simulation
- Monte Carlo Simulation: Monte Carlo simulation is a static discrete simulation model, which can be either stochastic or deterministic.
- Spreadsheet simulation: For discrete problems which are not too complex, a simulation can be conducted using a spreadsheet program.

Next to these simulation types, we can also differentiate between terminating simulations and non-terminating simulations. In terminating simulations, there is a natural event specifying the end of a simulation run, e.g. the end of the day or end of the week. In non-termination simulations, there is no such event. Due to this, terminating simulations are dependent on initial conditions, while in non-terminating simulation we generally look at steady state measures. At the start of a simulation the system is in transient system behaviour, as the performance depends on initial conditions, while after some time the system can go to steady state behaviour. This is not always the case, as parameters can also change over time, resulting in continued transient system behaviour. When looking at steady-state parameters, we need to determine the time it takes until the system is in steady state.

3.6. Conclusion

There are two main options to analyse variability in production processes. It can be done analytically, using the models presented in this chapter, or using a simulation model and the corresponding methods for analysis. Both options have their advantages and disadvantages, as displayed in Table 5.

If we look at the basic modelling approach by Buzacott and Shanthikumar **Invalid source specified.**, we can now execute the first three steps. In Chapters 1 and 2 the problem is introduced, which is that the current output level is below the goal stated by Heineken. This is due to blocking and starvation of the main machines, which is related to variability in the system. We want to model this variability, so we can determine on which speed each machine should work based on a certain fill rate of the buffer in front of the machine. The model must be understood by people of Heineken, and fulfil the requirements of this research. The main performance measure is the output of the system, together with the percentage of time the filling machines are blocked, as these measures are used to determine the OPI. The main decision variables in the system are the machine speeds and the fill rates of the buffers.

	Advantages	Disadvantages
Analytical models	• Low effort in application • Fast in executing phase • Relatively easy to validate	• Only applicable for relatively simple systems • Hard to deal with dynamic situations
Simulation	• User friendly • Useful in convincing people due to visualization • Possible to experiment without risks • Cheap compared to experimenting in reality	• Takes a lot of time in both development and execution phase • Hard to validate • Lot of data needed

Table 5: Comparison advantages and disadvantages analytical and simulation models

Both analytical models and simulation models are not used within Heineken at the moment. In the literature we found examples of both models, which can be useful for the development and execution. Based on the requirements stated above and the advantages and disadvantages from Table 5, we can choose a modelling approach. The packaging process at Heineken is a complex, very dynamic system. As these are mentioned as main disadvantages of analytical models, the use of a simulation model is preferred. The disadvantages of simulation models are the time development and execution take, the validation, and the amount of data needed. Within Heineken a lot of data is available, so this is not a problem. Time can be a problem, but if the study is scoped properly, this can be limited as well.

Because the advantages of a simulation study outweigh the disadvantages, we use a simulation study to answer the research question. A simulation study will help to identify which settings for the buffer strategies and speed of the machines should be used to get an optimal output. Also, the visual representation of the process can help to convince people of the impact of changes. In Chapter 4 we discuss the next steps of the basic modelling approach, which correspond to the steps of conducting a simulation study. From now on, we follow the steps of the last method as presented in Section 3.5.1.

4. Simulation study

Based on the problem of our case study and the advantages and disadvantages of different models to analyse the problem, we decided to use a simulation study to analyse the situation. This chapter describes the execution of the simulation study of packaging line 51 at Heineken Zoeterwoude. The sections are based on the model presented in Figure 10 (see Page 29). Section 4.1 gives the project specification, Section 4.2 explains the data used for the model, while Section 4.3 describes the model and the process of model validation. Section 4.4 continues with a description of the experiments, followed by the results in Section 4.5.

4.1. Project specification

We start with giving the project specification for this simulation study. Time planning and cost estimate are not discussed, as these are not relevant for our study. The data requirements and collection are discussed extensively in the next section, and therefore not discussed in this project specification.

Problem and project goals

To minimize blocking and starvation on the filling machines of packaging line 51 the right buffer strategy need to be determined. These machines are the bottleneck on the packaging line, so a more continuous flow through these machines will increase the output of the line. Therefore, the goal of this project is to determine the machine speeds and buffer strategy for the line in such a way that the filling machines can produce as continuously as possible, without causing too many start-stop moments at other machines. The buffer strategy is defined as "the machine settings which determine when the machine changes to another speed, and the speed it changes to". The moment of speed change is based on the fill level of the buffer. This strategy differs per machine.

Expected contribution and results

The simulation study will show possible improvements regarding buffer strategies on packaging line 51. A user-friendly model will be delivered, together with a report containing a description, the results, and the conclusions from the experiments.

Scoping

In Chapter 2, we already stated that only the part of the process between the filling machines and the box packaging machines is interesting to evaluate. Therefore, we only take these machines into account in the simulation model. Next to that, we also scope on the type of packaging, to save time in modelling and analysis. Currently, a test is running on the whole packaging department dealing with the number of assists an operator has to execute. This test is only executed on the 'loose' products, so only when the interior partition is used. By choosing the same packaging type, the effects of both projects can be combined and result in better performance. Also, interior partition is used on all packaging lines, while this is not the case for six-packs. This means that horizontal expansion is possible when the 'loose' setting is chosen. Therefore, only the machines used during production of loose are taken into account in the simulation.

4.2. Model and input data

This section starts with a description of the type of model and simulation program we use to execute our simulation study. Then we define the input data needed for this model, together with the values and distribution of this data in Section 4.2.2.

4.2.1. Simulation model

In Chapter 3 several types of simulation models were described and discussed. In this section we classify our simulation model and explain which simulation type is chosen, together with the program used for modelling.

First we classify the system based on the three dimensions mentioned in Section 3.5.2. Our model is a discrete simulation model, as the state of the system only changes when an event occurs, namely finishing a part on one of the machines, a breakdown or stop of a machine, etc. The processing times of the parts are stochastic, as breakdowns can occur, and therefore the whole system can be seen as stochastic. We look at the evolution of the system over time, which makes the system dynamic. With this classification, we can determine which simulation type we will use. Two options remain; the discrete-event simulation and spreadsheet simulation. The last one is only applicable for simple systems, which is not the case at packaging line 51. Therefore, we use discrete event simulation.

Several programs offer the possibility to make a discrete event simulation model of a packaging line. The level of a simulation study is partly determined by the experience of the programmer. Therefore, we choose a simulation program used at the University of Twente, which is Plant Simulation. This is an object oriented simulation language, offering standard building blocks especially designed to model manufacturing processes. Using the method building blocks, the programmer can program according to his own wishes and the wishes of the client.

4.2.2 Input data

For our discrete event simulation model, we need several types of input data. In this section, we discuss the input data needed, and determine how this data can be modelled. Experimental factors are not discussed in this section, as this is not pre-determined input data, but can be specified by the user. The experimental factors are the set points for machine speeds and the fill rates of the buffer at which the machine changes its speed.

All the data about states of the system can be retrieved from the databases at Heineken. An example of the retrieved data can be found in Appendix F. For every machine status we can see the start time, end time, and duration in seconds. From this data we should be able to determine the input we need for the simulation model.

To have a valid model, which represents reality as close as possible, the input data has to be representative. We want to analyse and improve the current situation, and therefore it is important to use recent data. Therefore, we decided only to use data from the process in 2014. In the first weeks of January, two weeks of revision took place on packaging line 51. This means that no production took place, but machines have been checked, adjusted, and repaired. The first few weeks after the revision period, small adjustments were needed to improve the process. Therefore, we decided not to use data of January and February, leaving us with data from March and April. This data gives us a huge number of data values, which gives a good base to determine the input for the simulation model. By using a lot of data values the impact of incidental occurrences is limited.

4.2.2.1 Determining input data

There are three ways to use collected data to model random input: (1) use of a theoretical probability distribution function fitted to the data, (2) use of an empirical distribution function based on the data, or (3) direct use of the data in the simulation. All options have their advantages and drawbacks, which we discuss briefly.

For a simulation, it is generally preferred to use a theoretical distribution function, as irregularities are smoothed out, and it is easily possible to work with different scenarios. When a theoretical distribution is hard to find, an empirical distribution can be useful. The disadvantages of using an empirical distribution compared to a theoretical distribution are smoothed out when a large number of data values are available. The direct approach is useful for model validation and complex data structures.

The values used in the model, depend on how the input is modelled. Using a theoretical distribution makes it possible to use input data outside of the observed values. The observed values determine the shape of the data, but leave all values open as possibilities. When an empirical distribution function is applied to the data, the used values are limited to the boundaries set by the observed data. Values between the minimum and above the maximum will never be used. Between those boundaries, every value can be taken as input. Direct data use limits the input to the observed values. This means that the data only describes history, and it can occur that there is insufficient data to make all simulation runs.

There are three important types of input data we have to define: (1) processing times, (2) machine times to failure (interval between failures), and (3) machine repair times (duration of failure). Plant simulation offers several options to give data input for these variables. To get the simulation as close as reality as possible, we first try to fit a theoretical distribution function for those variables. If this doesn't work, we continue with the empirical distribution function. As we want to simulate different settings, direct data use is not preferable. The distribution functions and their parameters need to be tested and evaluated for every machine in the process.

For the input data for which we need to define a distribution, we used the program EasyFit to check the fit of several distributions. Easyfit provides three goodness-of-fit measures for each distribution, namely Kolmogorov-Smirnov (KS), Anderson-Darlin (AD), and Chi-Squared (CS). For each of these tests, the confidence degree of the fit is given. For the analysis we only look at the KS and CS test, as these tests are most commonly applied. The following distributions are checked, based on the possibility to enter them in Plant Simulation:

- Beta
- Uniform
- Normal
- Erlang
- Exponential
- Gamma
- Log-normal
- Weibull

4.2.2.2 Processing times

For the processing times, we will not use an empirical or probability distribution, as the processing times are not registered and therefore not available. Also, the processing times are only dependent on the machine speed, so we can determine processing times with a simple formula creating a dependency on machine speed.

4.2.2.3 Interval between failures

To determine machine times between failures, we have several options. First of all, there are two types of failures we can use: time-dependent and operation-dependent failures. With time-dependent failures, machine breakdowns happen after a certain time, independent of whether the machine is operating or not. Using operation-dependent failures, the machine only breaks down when it is in operation. We will use the latter, as this is closest to reality for packaging line 51.

To determine a distribution (either a theoretical probability or empirical distribution), we look at the time that the machine had the status production between the failure statuses. This way, we exclude all times the machine is unavailable due to blocking and starvation. From this data, we try to fit a distribution. For the intervals between failures, we use all the data available, as both small and large intervals can have a big influence on the throughput of the process. A small interval has a big influence because the buffers are not restored to their steady state position yet, while a long time between two failures gives the possibility to restore buffers.

Appendix G gives the results from the Easyfit analysis. From this analysis we conclude that for almost all machines, there is no theoretical distribution which fits to the data from the process (p-value is zero, or very close to zero). Therefore, an empirical distribution is used in the simulation model, which is further explained in Appendix G.

4.2.2.4 Time to repair

As said before, Heineken divides disruptions into two categories: (long) breakdowns and (short) stops. The boundary between short and long stops is placed at 5 minutes (300 seconds). In theory, short stops should not influence any machines down- or upstream, as the buffer should be able to cope with these stops. Long breakdowns do influence the remainder of the process, as the buffers are not able to deal with this. As our goal is to reduce 'unnecessary downtime', due to causes up- or downstream, the long breakdowns are not interesting for the simulation. These are incidents, and are not part of a pattern in the failure duration. Therefore, we decided only to take failures up to 300 seconds into account.

Appendix G shows the results of the Easyfit analysis. From the results, we see that the distribution which fits the data differs per machine. Also, the p-values differ a lot. As we cannot say theoretically that one of the tests is better than the other, we try to take into account both p-values in our conclusion. Table 6 shows the chosen distributions and their parameters per machine. A discussion of these conclusions can be found in Appendix G.

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Table 6: Distributions and parameters for time to repair

4.3 Model description

In this section, we briefly describe the simulation model used for the experiments. In this section we give a general overview of the model and state the assumptions and the limitations. The main frame of the model contains several areas (see Figure 11). In the remainder of this section we discuss the different areas of this main frame. Also, the model is validated in Section 4.3.2.

4.3.2 Model of the packaging line

In this section we describe the model of the packaging line, which forms the main part of the frame displayed in Figure 11. Represented are the machines, the buffers, and the path followed by the bottles (grey shaded area). Most machines are connected with arrows, but for some of the machines the transport of the bottles is programmed in the model to reflect reality as good as possible, because splitting and merging of bottles is based on congestion. Therefore, we need to take bottles from the buffers with the highest content. The carton infeed is modelled in a separate frame, and therefore only represented by one symbol in Figure 11. Figure 12 shows how the infeed is modelled. In both figures buffers are displayed starting with “B_”, while material input is also clearly marked.

4.3.2.1 Model of the packaging line

At the start (left side of the model), we see the empty bottles entering the system. Here we assume that empty bottles are always available. From here on we see the process from the filling machines until the box packers. In the model, the palletiser (end of the model) functions as a drain, this means that it deletes the objects from the system.

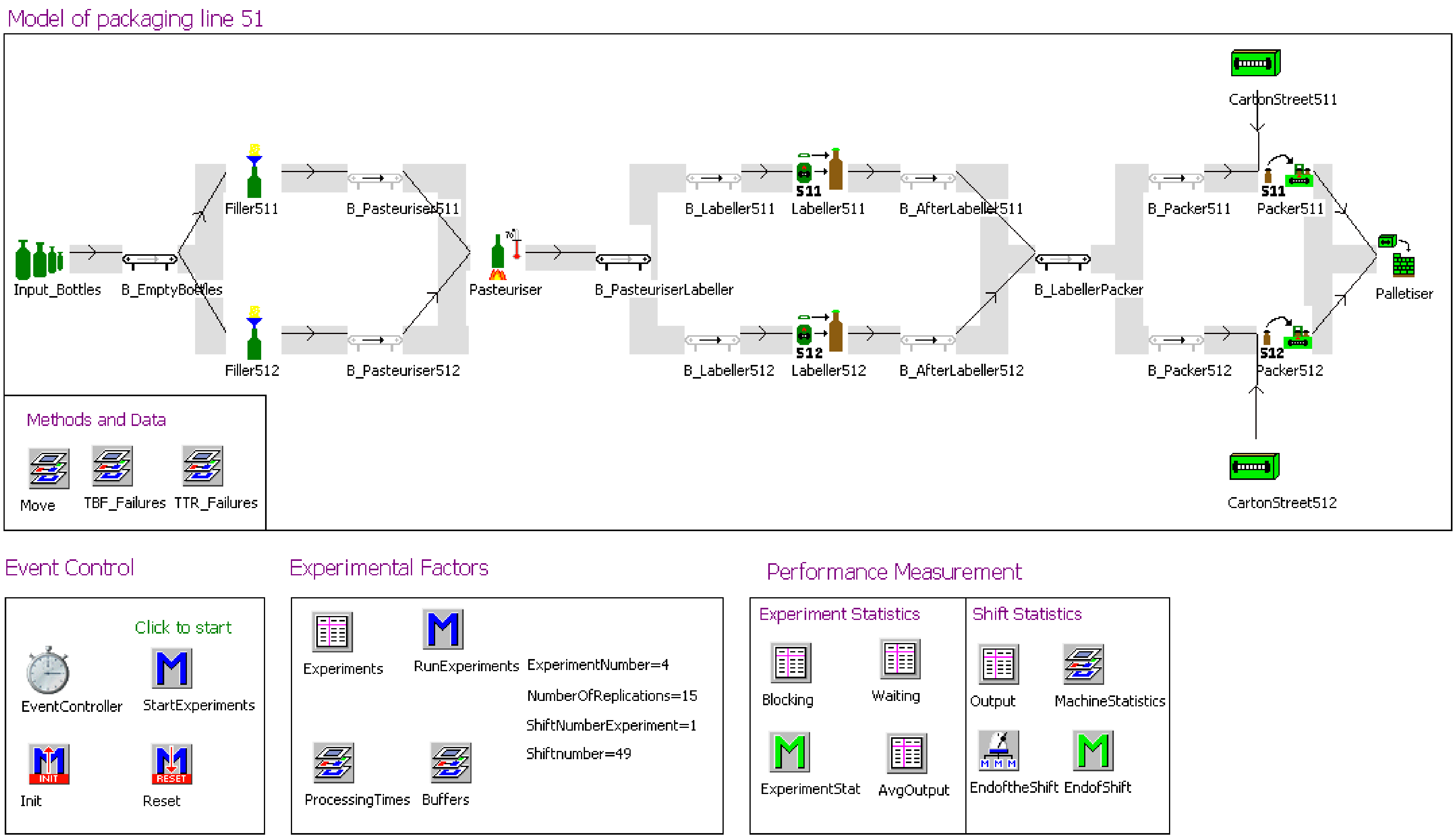

Figure 11: Main frame of simulation model

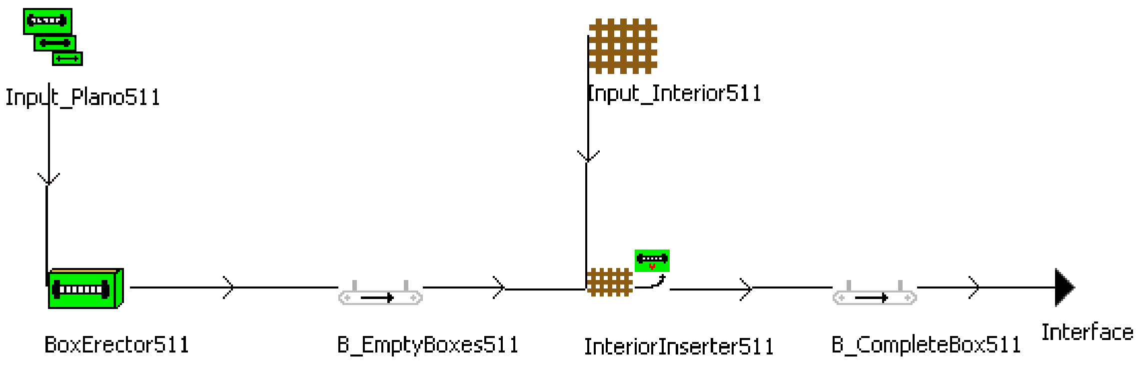

Figure 12: Carton infeed 511 in the simulation model

In reality the buffers are conveyer belts, so they also have a transport function. To simulate the transport time of the bottles on the conveyer belts, a processing time is assigned to each object representing a buffer. This means the bottles spend a minimum time in a certain buffer before they are allowed to move on.

Different from reality is the modelling of the pasteuriser. In practice, the pasteuriser has two separate lanes, each one directly connected to a filling machine. As soon as one of the lanes is blocked, the whole pasteuriser stops working (so both lanes). In the model the separation of the lanes is not represented, to model this effect of blocking of the pasteuriser. Using two lanes results in a lot of extra checks which have to be programmed in the model, which has a very negative effect on the runtime of the model. Also, the pasteuriser is modelled with only one speed, which equals the capacity of the filling machines. In reality the pasteuriser has two speeds, but the effective capacity cannot be determined exactly as this is related to the density of bottles within the pasteuriser. Another research is conducted on this within Heineken, but the results are not applicable in the model. Therefore, the pasteuriser is modelled with only one speed.

The box packers need batch processing for the bottles, which is modelled by an assembly station. The assembly station takes one box and 24 bottles, before completing the packing.

Assumptions

Next, we summarize all assumptions made to model the packaging line as close to reality as possible, without making it too complex. We start with the general assumptions which account for the whole system, and continue with assumptions per machine in the process.

- Processing times are based on the speed of the machines in bottles/hour.
- The influence of rejected products on the total output is very low, and therefore not taken into account.
- Breakdowns longer than 300 seconds are incidental, and therefore not taken into account in the simulation model, as we simulate the steady state behaviour of the process.
- When bottles split over several buffers or machines, this happens based on the availability of space after the point of split. The bottles move to the machine/buffer with the most unused capacity.

- When bottles merge from several buffers or machines, this happens based on the supply of bottles before the merging point. Bottles are moved from the machine/buffer with the least unused capacity.
- As soon as the buffer after a machine has a place available, the machine starts processing again.
- There is no starvation due to lack of supply of bottles, beer and carton as input of the process.
- The influence of the pasteuriser on the process is negligible, as the number of breakdowns is very low and the processing time is always the same. Therefore, the pasteuriser is modelled as a completely reliable machine.
- The pasteuriser only uses one speed, which equals the speed of the filling machines. Also, the separation of upper and lower deck of the pasteuriser is not modelled.
- The availability of the palletiser is based on the historical data of blocking of the box packers. This means it is not necessary to model the buffer between the box packers and the palletiser.

For the model we need to determine buffer sizes. For the buffers containing bottles the method used is explained in Appendix H. Table 7 displays the buffers sizes for bottles as used in the model. The *EmptyBottles* buffer is not displayed, as this buffer only ensures unlimited supply of bottles, but does not influence the system. Table 8 displays the buffer sizes for boxes, which are determined by counting the boxes on packaging line 51.

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Table 7: Buffer sizes for bottle buffers

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Table 8: Buffer sizes for box buffers

4.3.2.2 Event control

The event control field contains all elements that are used to reset, initialize, and start the experiments. The *EventController* makes it possible to stop, continue, accelerate, or delay the simulation.

4.3.2.3 Experimental factors

The third field in the main frame is the field with *Experimental Factors*. This field contains all information concerning the experiments. The table file *Experiments* contains the experiment settings, which are assigned to the right objects at the right time using the other methods, variables, and the generator.

Every time a bottle enters the machine, the fill rate of the buffer is checked, and if necessary the speed is adjusted. There are two factors that can be changed, both on three levels; low, nominal, and high speed for the labeller, and low, nominal, and high speed for the box packers. The value for low speed means the machine changes to low speed, as soon as the fill rate is below this level. The value for nominal speed means the machine switches to nominal speed if the fill rate is higher than the stated level and for high speed counts the same as for nominal speed.

4.3.2.4 Performance measurement

Performance Measurement is the last field in the main frame. Performance is measured based on periods of eight hours, which is one shift. This time frame is chosen, because this is the period always used at Heineken for performance measurement and therefore data is available over periods of eight hours. By choosing the same period, extensive validation of the model is possible. Also, eight hours is a good period when looking at run time. When using a longer period the run time increases, while shorter periods give a risk on high variance.

By triggering the methods on certain times, statistics of one shift or a total experiment are stored in corresponding table files. The shift statistics are deleted as soon as a new experiment starts, while the experiment statistics are saved and will be used for analysis of different system configurations.

4.3.3 Model validation

To make sure the simulation model represents reality, we need to validate the model. For the first step expert knowledge is used. The model is examined by the rayon manager, installation administrator and two operators. They confirmed that reality is represented properly, despite the assumptions made.

The second step consists of comparison of the results from the simulation with historical results. If the model represents reality perfectly, the results from the model should equal the historical results. Some differences are observed, due to assumptions made. These are:

- Output in boxes per shift is in the model approximately x% higher than the output of a shift without major disruptions in reality. This is due to the assumption of unlimited supply of bottles and boxes as input of the process. This corresponds with the starvation measured on the filling machines (see Chapter 2), which equals x-1%.
- Failure percentages of each machine are lower than in reality, due to the assumption of only taking into account failures shorter than 300 seconds. The difference is for each machine approximately y% of production time.

- Blocking of each machine is lower in the model than in reality, due to two factors. First of all, blocking is significantly lower because failures longer than 300 seconds are not taken into account. These failures always result in blocking of machines earlier in the process. Next to that, total accumulation is assumed. This means, that in the model we assume that all bottles move directly forward to the next machine. In reality this is not the case, and therefore the machines switch earlier to higher speed in the model, than they do in reality. This prevents blocking of machines upstream in the process.

As these differences are the result of modelling assumptions and can be explained, the model can be seen as valid after performing these two steps of model validation.

4.4 Experimental design

To give an answer to the research question, we need to conduct several experiments. In this section we describe the configuration for these experiments and how we conduct the experiments. This also includes the number of replications for every experiment and how the statistics are determined.

4.4.2 Experiment configuration

As stated before in Sections 4.1 and 4.3.1.3, we have two main factors which we can change for the experiment configurations, which are the speeds of the machines and the fill rates of buffers at which those speeds change. For each of these settings, we can choose multiple values. If we take into account every speed for each machine and a corresponding moment for changing, too many factors would be taken into account. Therefore, decisions about which factors to include in the experiments should be made, which are discussed with the rayon manager, installation administrator, and operators.

First of all, we decide not to change anything at the carton infeed. The machines at the carton infeed only have one speed, and the current speeds give almost no starvation (of boxes) on the box packers. Therefore, nothing is changed on these machines.

Also, nothing is changed on the nominal speed of all machines in the process. The current speed of the filling machines is determined based on quality constraints. Increasing or decreasing this speed would negatively influence the quality performance, and therefore the only speed used for each of the filling machines is z bottles per hour. On a line without disruptions every machine should be working on the same speed to ensure a continuous flow. Therefore, the nominal speed of every machine processing bottles should equal the speed of the filling machines, which is z bottles per hour (labelling machines) and equals x boxes per hour (box packers). As these settings are used in the current situation, the nominal speed of these machines is not changed.

The analysis of the current process in Chapter 2 shows that there is currently too much blocking of the labellers and filling machines, while the percentage of time the machines are starved is low. From this, we conclude that changing the low speed for both the labellers and box packers is not necessary. From the same analysis, we can conclude that the high speed of the labellers does not have to be changed. In general, the filling machines are only blocked when the labellers are, and this shows that the labelling machines are able to handle input coming from the filling machines. For the box packers, the maximum speed is currently limited by technical constrains of the machines. In the end of 2014 changes will be made on box packer 511, making it possible to increase the maximum speed from y to y+2 boxes per minute. Therefore, it is useful to run experiments with both speeds.

Having decided that we only change the maximum speed of box packer 511 and do not change the speed of the other machines, only the moment of speed change is left to discuss. This is only interesting for machines with more than one possible speed, as the start/stop moments of the machines do not show any problems. This also means that we only look at the labellers and box packers. The low speed of these machines also determines when the machine starts again, and is therefore not taken into account, resulting in the following five experimental factors:

- Fill rate at which the labellers change to nominal speed
- Fill rate at which the labellers change to high speed
- Fill rate at which the box packers change to nominal speed
- Fill rate at which the box packers change to high speed
- High speed of the box packer 511

The moment of changing to another speed is determined by sensors along the conveyer belt before the machine. Changing the position of these sensors and programming them accordingly is a very time-consuming task and the availability of man-hours for this is very limited. Therefore, we restrict the possibilities based on the current placement of sensors. The current placement of the sensors along the buffers before the labellers and box packers are displayed in respectively Figures 13 and 14. The sensor points are marked, and the corresponding fill rates are displayed. We also see the current settings, where the red colour shows when the machine is stopped, the orange colour shows when the machine is working on low speed, while yellow corresponds to nominal speed, and green to high speed.

This figure is confidential

Figure 13: Sensors along conveyer belt between pasteuriser and labellers

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Figure 14: Sensors along conveyer belt between labellers and box packers

Increasing the machine speed too late results in blocking, and therefore we look at possibilities to change to higher speed earlier than the current configurations. As can be seen in Figure 13, this only leaves one alternative option for both the nominal and high speed of the labellers. The same accounts for the nominal speed of the box packers, as can be seen in Figure 14. For the high speed of the box packers, we have three options we can choose for the sensors. Based on the fill rate at which the labeller changes and the amount of blocking, we decided to use the sensor closest to the machine. It is preferable that the machine does not change to nominal and high speed at the same sensor, so we choose a% to leave multiple combinations open. The current settings and the alternative settings for the moment of speed change used in the experiments are displayed in Table 9.

This table is confidential

Table 9: Settings per experiment factor

As we can see in Table 9, we have 5 factors which all can use two levels. Using all combinations we would have 2^5=32 experiments. As this takes a long time to run, we first simulate the 16 (2^4) experiments dealing with the different fill rates, and then we execute the last change (increased speed box packer 511) only for the current situation and the best alternative. We see that the current setting of 'labeller to nominal speed' and the alternative setting for 'labeller to high speed' are the same. We want the machine to be able to use all speeds, which means we can leave out the combination of these factors, reducing the number of experiments with 4. This leaves us with 14 experiments to execute, as displayed in Table 10. When the results still show room for improvement, it is possible to use one of the other alternatives for the moment of changing the box packers to high speed.

4.4.3 Warm-up period

We want to evaluate the steady-state performance of the system. This means we should disregard the measurements taken in the system before it enters its steady state. To enter the steady state in this system, the first bottles need to exit the system, while the buffers also reach their 'normal' fill level. This takes approximately two hours, and therefore we take a warm-up period of one shift. This means we delete the first shift for every experiment. Appendix I describes how this warm-up period is determined.

4.4.4 Weekend

During the weekends, the packaging line is normally not producing. We can choose to put this into the simulation model, but this would mean we need to delete the 'finishing' shift as well. As we look at the steady state, there is no influence on the results if we do not take the weekend into account. Therefore, the weekend is not included in the simulation.

This table is confidential

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Table 10: Experiment Configurations

4.4.5 Number of replications

To ensure that the relative error for the experiment meets the requirements, we determine the number of replications using the theory as described by Law **Invalid source specified.**. The calculations are displayed in Appendix J. With a confidence level of α=0.05 and a maximum relative error of 0.05, we need to execute each experiment at least 5 times. As this number is very low, we decided to perform 15 replications for each of the experiments.

4.5 Analysis of results

The results of experiment 1, which displays the current situation, are displayed in Table 11. In the first column, we see the output in number of boxes per shift (8 hours). The second column shows the average percentage of production time the filling machines are blocked, while in the third and fourth column we see the same for the pasteuriser and the labellers. The fifth and sixth columns show this percentage for starvation of respectively the labellers and box packers.

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[redacted]

Table 11: Results of experiment 1

To compare the alternative settings with the current setting, Table 12 displays the results as a percentage of the current situation. Experiment 1 is taken as 100%, and every number under 100% means a decrease of the total time a machine is blocked or starved, while a percentage above 100% shows an increase in these times.

	Output	Blocking fillers	Blocking Labellers	Starvation labellers	Starvation box packers
1	100.00 %	100 %	100 %	100 %	100 %
2	100.79 %	31 %	71 %	148 %	300 %
3	100.35 %	71 %	98 %	124 %	136 %
4	100.67 %	42 %	66 %	185 %	319 %
5	99.56 %	110 %	112 %	99 %	150 %
6	99.99 %	97 %	91 %	142 %	304 %
7	99.53 %	101 %	116 %	164 %	139 %
8	100.76 %	55 %	76 %	161 %	302 %
9	100.88 %	47 %	76 %	301 %	108 %
10	100.50 %	75 %	93 %	235 %	226 %
11	100.36 %	67 %	94 %	285 %	142 %
12	100.87 %	49 %	69 %	352 %	297 %

Table 12: Results experiments 1 till 12 (index compared to exp. 1)

The perception exists that the output and percentage of time the filling machines are blocked are correlated, and if this is the case, we want to minimize the blocking of the fillers. If the fillers are the real bottleneck of the process, this would be the case. To check this hypothesis we determine the correlation coefficient of the variables output and blocking fillers. This is done using the following formula, in which ρ represents the correlation coefficient of X and Y, cov the covariance between X and Y, and σ the standard deviation of X or Y:

$$\rho(X,Y) = \frac{cov(X,Y)}{\sigma(X)\sigma(Y)}$$

Using this formula, we get:

$$\rho(output, blocking\ fillers) = \frac{-47.872}{0.44 * 125.733} = -0.85$$

A correlation coefficient of 1 or -1 shows an expected linear correlation between the variables X and Y, while this coefficient is 0 if there is no correlation. From the correlation found, we can conclude that the output and the blocking percentage of the fillers seem negatively linearly correlated. Knowing this correlation, we do not longer need to take into account both the output and the blocking percentages of the fillers.

In this analysis, several aspects are taken into account. The main aspect is the output, as in the end we strive for a higher output from the process. Next to that, we also look at the percentage of time machines are starved, as high starvation percentages mean a lot of start-stop moments. In the model, ramp down and ramp up times (time it takes to stop or go from stop to a certain speed) are not taken into account. Also, the influence of start-stop moments on the failures is not modelled, as this influence is not known. The perception is, and this is supported by literature, that having a lot of start-stop moments has a negative influence on machine failures, so influences the process negatively. Because of this perception, we try to minimize the starvation percentages, while the output is maximized. The waiting percentages from the model are higher than they will turn out in practice, as we assume that all bottles gather directly in front of the next machine (complete accumulation). In reality, this is not the case, which means that more bottles are present in the buffers at the moment of changing speed.

For experiment 9 till 12 we see a big increase in starvation percentages for the labelling machines. Although these turn out lower in practice, we cannot accept starvation percentages of this level. For these experiments, the labeller changes earlier to nominal speed and earlier to high speed than in the current situation. This combination can be left out in the remainder of this research, as these percentages of time the machine is starved are not acceptable.

When looking at the output, we see that the even numbered experiments score the best, together with experiment 9. In all even numbered experiments, the box packers change to high speed at a fill rate of 35%, compared to 80% in the current situation. This seems to have a positive influence on the output, but we also see that the percentage of time the box packers are starved increases significantly.

As the current experiments do not give a really satisfying result, we conduct some extra experiments. From the first results we concluded that changing earlier to a high speed than in the current situation for the box packers is useful, but setting this at a fill rate of 35% gives a lot of starvation on the labeller. Therefore, we conduct extra experiments in which the box packers change to high speed earlier (the only other option available due to the restriction on using the sensors currently placed along the conveyer belts). This leaves us with four new experiments, for which the settings are displayed in Table 13.

This table is confidential

Table 13: Configurations for extra experiments

	Output	Blocking fillers	Blocking Labellers	Starvation labellers	Starvation box packers
1	100.00 %	100 %	100 %	100 %	100 %
2	100.79 %	31 %	71 %	148 %	300 %
2.1	100.18 %	89 %	91 %	110 %	111 %
4	100.67 %	42 %	66 %	185 %	319 %
4.1	100.72 %	37 %	75 %	116 %	140 %
6	99.99 %	97 %	91 %	142 %	304 %
6.1	100.26 %	79 %	90 %	184 %	146 %
8	100.76 %	55 %	76 %	161 %	302 %
8.1	100.55 %	47 %	68 %	185 %	109 %

Table 14: Results of extra experiments (indexed compared to exp 1)

From Table 14, we can conclude that both experiment 4.1 and 8.1 show a significant increase in output, which is clearly higher than in the first round of experiments. Also, in both cases there is an increase in starvation of the labellers and box packers, but this increase is limited compared to the results of the first experiments. It depends on the requirements of Heineken which of these experiment settings are best. Experiment 4.1 shows a better output, with lower waiting percentages, and therefore we would recommend these settings. This means that compared to the current situation, the box packers go earlier to nominal speed and also go earlier to high speed.

As said in Section 4.4, we also conduct extra experiments in which the high speed of the box packer 511 is x+2 boxes per minute. In October construction is planned on this machine, and the expectation is that the maximum possible speed increases afterwards. Therefore, it is important to know the effect of this change. As the results of the previous experiments showed two acceptable sets of settings, we conduct three more experiments. First of all we simulate the current situation with increased speed of the box packer, and then both alternative situations. The settings for the experiments are displayed in Table 15, while Table 16 shows the results.

This table is confidential

[redacted]

Table 15: Settings extra experiments with adjusted high speed box packer 511 and their corresponding experiments

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[redacted]

Table 16: Results experiments with adjusted high speed box packer 511

From Table 16 we conclude that the expected increase in maximum speed of box packer 511 has quite some impact on the output. Without any other changes, the speed increase results in an increase in output of 0.55%. If we assume that the advised changes for the buffer strategies are already made, the increase will be around 0.4%. With this new maximum speed, the waiting time on the labellers decreases. This decreased starvation makes it more beneficial to change the buffer strategy around these machines. When the labellers change earlier to nominal speed, a positive effect on the output is created. Therefore, we advise to make this adjustment as soon as the construction work on box packer 511 reaches the expected speed increase.

4.6 Conclusion

To determine the right machine speeds and buffer strategy to minimize blocking and starvation on the filling machine on packaging line 51, a simulation model has been developed. The model simulates the packaging process from filling to packing in boxes as closely to reality as possible. The input of materials to the process is assumed to be continuous. Historical data has been analysed to determine the input distribution for the times to repair and times to failure. Extensive validation of the model has shown that it represents reality as closely as possible, given some assumptions made for modelling purposes. The main assumptions are:

- The influence of rejected products on the total output is not taken into account.
- Breakdowns longer than 300 seconds are not taken into account.
- Bottles move *to* the machine/buffer with the most unused capacity.
- Bottles move *from* the machine/buffer with the least unused capacity.
- There is no starvation due to lack of supply of bottles, beer and carton as input of the process.
- The pasteuriser is modelled as a completely reliable machine with one speed.
- Separation of upper and lower deck of the pasteuriser is not modelled.
- The availability of the palletiser

To come up with the right machine speeds and buffer strategies, 14 experiments were designed. The experimental factors taken into account are:

- Fill rate at which the labellers change to nominal speed
- Fill rate at which the labellers change to high speed
- Fill rate at which the box packers change to nominal speed
- Fill rate at which the box packers change to high speed
- High speed of the box packer 511

The factors concerning the fill rate are combined into 12 experiments, which are conducted to determine which of these settings gives the best results. From this first set of experiments, we learn that changing earlier to both nominal and high speed on the labellers has a highly negative influence on the percentage of time the labeller is starved. Therefore, this combination of factors is excluded from the remainder of the research. Also, we learned from the first experiments that changing to high speed on the box packer at a very low fill rate is too early, as this results in a high percentage of starvation of the box packers, which does not represent a continuous flow.

Still, it seems useful to change earlier to high speed on the box packers than is done in the current configuration. Therefore, four extra experiments are conducted, in which the switch to high speed is made at a medium fill rate. From these experiments we can conclude that, with the current speed settings, the box packers should change earlier to nominal speed, as well as to high speed, while no changes have to be made on the buffer strategy around the labelling machines. This could reduce the blocking of the filling machines compared to the current situation, which results in yearly savings.

In addition to these experiments, a future situation is also taken into account, in which the maximum speed of box packer 511 will increase. Without any further changes to the packaging line, this would increase output with more than 0.5%. When also looking at the buffer strategy around the labellers and box packers, we conclude that in this case the labellers should also change earlier to nominal speed, resulting in an additional output increase of 0.5% could be realized, increasing the savings even further.

5 Conclusion and recommendations

This chapter concludes this report which describes the research conducted at packaging line 51 of the Heineken Brewery in Zoeterwoude. Also, it gives recommendations divided into two categories, recommendations coming directly from the research (5.2.1), and further recommendations (5.2.2)

5.2 Conclusions

By answering several sub questions, dealing with the current situation, the existing literature, and possible improvements and their benefits, we can now give an answer to the following research question:

How can the performance of packaging line 51 of the Heineken Brewery in Zoeterwoude be improved, while taking into account the quality and safety regulations?

This research question is answered by means of answering three sub-questions. In this conclusion we discuss the answers to the sub-questions, followed by the answer to the main research question.

The first sub-question is: "***How is packaging line 51 currently performing?".*** At line 51, the current performance is below the target, especially if we look at the output of the packaging line. The target set by the head office for the OPI is not reached in 2013 and very challenging. This is mainly due to blocking and starvation on machines in the process, which are related to the availability and speed of the machines.

As the filling machines are the bottleneck in the process, and therefore the lowest point on the V-graph, the blocking and starvation times should be minimal when the speed and buffer settings are according to the V-graph philosophy. This philosophy leads to a continuous flow on the packaging line, where disruptions only occur when machines up- or downstream from the fillers have breakdowns. For minor stops, the buffers should be able to prevent other machines from stoppages.

Looking at the unplanned downtime of each machine, we see that the fillers are on average x% of the total production time not working. y% of this is due to breakdowns, but the other z% is due to blocking and starvation of the machines. This has a negative influence on the continuous flow on the packaging line and therefore the output is below target.

The second sub-question is: "***Which factors influence the continuous flow on a production line according to the literature, and how can this be modelled to analyse the influence of these factors?".*** From the literature, we can conclude that the blocking and starvation are due to variability in the process. Variability always degrades the performance of a production system, and therefore it is important to reduce this variability as much as possible. Possible strategies to deal with variability are the use of buffers within the process, or buffering the bottleneck machine with capacity, increasing the effective rates at non-bottleneck stations. This last option is also the theory behind the V-graph. Variability pooling, e.g. by using queue sharing can also help to reduce variability.

In the literature two methods were found which analyse the influence of variability on continuous flow. First of all, analytical models can be used, which describe a system in mathematical relationship. From existing queueing theory we can use the formulas to analyse the different types of variability and describe the system in mathematical formulas. Analytical models can give a very good approximation of reality, but therefore detailed input is required. Therefore, analytical models are best applicable to simple systems and are not able to deal with dynamic situation easily.

Another option is the use of simulation models, in which a model is designed which reflects the system as closely as possible. Simulation models give the possibility to design and test alternatives to the current situation. Model development takes a lot of time, and a lot of data is needed to simulate reality precisely. Simulation model are able to deal with complex, dynamic systems, and give a visual back-up for conclusions.

Both modelling methods have their advantages and disadvantages, but as we need to model a very complex system, we chose to use a simulation model. This model is used to determine the optimal buffer strategy, which determines at which fill rate of the buffer the machine changes speed, and to which speed to machine changes.

A simulation model is developed and validated with current data, and using expert-knowledge from the process. The model is used to run experiments. Different scenarios are developed, and translated to 12 experiments, of which the first one corresponds with the current situation. In these experiments, the fill rates at which the labelling machines and box packers change to a different speed are the experimental factors. From these first 12 experiments 4 more experiments are developed, which use a slightly different buffer rate. Afterwards, 3 more experiments are conducted to analyse the influence of increasing the high speed of one of the box packing machines, as an increase in the maximum speed of box packer 511 is expected on short notice do to repair activities.

From the simulation study, we can determine changes which are most beneficial to the performance measurements of packaging line 51. This is related to the last sub-questions, which is: "***Which changes are most beneficial to increase the performance on packaging line 51?".***

From the results of the experiment, we see that a balance has to be found between chance on blocking of machines and the time the machine is starved. When blocking is reduced to a minimum, the chance on starvation increases, which also disturbs the continuous flow. This can be seen at the labellers when they change both earlier to nominal speed and to high speed compared to the current situation. Also, we can conclude that changing too early to high speed on the box packers has a very big influence on the percentage of time the machines are starved.

For the labellers, the model shows that the moment of changing to nominal speed should be kept the same, and the same account for the moment of changing to high speed. Around the box packers the buffer strategy should be changed, the change to nominal speed should take place at a lower fill rate of and the fill rate at which the machine changes to high speed should be placed earlier as well. Implementing these changes would lead to a reduction of blocking on the filling machines of x% of the production time, which equals yearly savings.

In addition, even more savings could be realized when the high speed of box packer 511 changes to more boxes per minute. Without any other changes compared to the current situation, this would already increase the output with 0.5%. When also implementing a revised buffer strategy, another additional output increased of 0.5% can be realized. In this buffer strategy the speed changes of the labellers should take place at earliers for both nominal and high speed. The same accounts for the box packers.

Having answered the sub questions, we can now answer the main research question. The performance of packaging line 51 can be improved significantly by changing the buffer strategies around the labelling machines and the box packers. By changing the moments at which the machine changes to another speed, the time the fillers are blocked can be reduced. As the filling machines are the bottleneck in the process, this would directly lead to an increase in output. For packaging line 51, each hour that the filling machines are not working costs money. This means that with implementing the new buffer strategies only, a lot of money can be saved on yearly basis. A scenario that also have been investigated is increasing the high speed of box packer 511, as this will happen when repair works have taken place, which leads to an additional reduction of blocking of the filling machines. The output increase will be more than 1%, which equals even higher annual savings.

5.3 Discussion

There are some limitations to the research, which we discuss in this section. Most of the limitations are related to modelling assumptions, while some are due to other factors in the process of conducting this research.

First of all, there are limitations in the simulation model. These exist because it is never possible to model reality precisely, and therefore assumptions have been made. One of the assumptions is that there is always supply of bottles, carton, and beer. The scope of the research focuses on machine speeds and changeover moments, and to model this, a saturated system is preferred. This is also related to the next assumption that we only model short stops, which means failures with a duration (time to repair) of at most 300 seconds. These short stops will not disturb the supply at the input of the process. The variability in the process caused by short stops can be reduced by making good use of the buffers, while stops longer than 300 seconds always affect machines upstream or downstream in the process. Also, taking into account the long stops makes is hard to model a steady-state process, as a very long warm-up period is then required. Another important assumption is made around the pasteuriser, which is not modelled with two separate lanes, but as one. This is necessary in the model to represent reality as closely as possible, as the lanes are directly connected in speed and start-and-stop moments.

Secondly, we can discuss about the data used. The data is taken from the system, but it is known that the registration is not always totally correct. This means that the data does not represent the reality perfectly, which can influence the simulation study. How big the influence of blurred data on the results is cannot be estimated, but it urges the need to improve data registration. For this research, it was not possible to update data registration completely beforehand. Therefore the choice was made to work with the available data.

Third of all, the buffers are a simplification of reality, as they are not modelled as conveyer belt. We tried to minimize the influence of this by adding a processing time to each part of the buffer, but this is not a perfect way to display the conveyer belts. Plant simulation does have an option for using transport belts, but these require too much running time with the amounts of bottles we model. Therefore, the choice is made to use static buffers with dwell times. The effect of this simplification is that we take the direct fill rate of the buffer, which does not take into account where the bottles are placed on the conveyer belt. This leads to earlier changing to a higher speed than in reality, which leads to higher starvation percentages.

Related to the previous limitation, the dwell times of the buffers are only estimations, based on the buffer length and the information of the supplier about the maximum speed of the conveyer belts. This could influence the results, but the deviation from reality will be the same for each part of the buffer. This way, we were able to limit the influence of this estimation.

5.4 Recommendations

From the research, it follows that it is beneficial for Heineken to change the current buffer strategies. With the current failure behaviour and machine speeds, it shows clearly that the box packers should change earlier to both the nominal and the high speed. As soon as the box packer 511 has an increased high speed this strategy could be improved even further. By implementing these changes, the output can increase with approximately 0.7% compared to the current situation, but most importantly, the blocking percentage on the filling machines decreases significantly which increases the OPI.

To implement these buffer strategies, a programmer is needed. Currently, there is only one person within Heineken Zoeterwoude who has the knowledge needed to make the necessary adjustments. Currently it only leads to a lack of capacity sometimes, but this is a big risk, as illness, holidays, or retirement of this man can cause a lot of knowledge to get lost, while a lot can be gained with optimizing buffer strategies. Therefore, it is important to educate someone in this process of buffer strategies and document the knowledge. The current dependency on one person within the organization can lead to big problems in the future.

Also, data registration of the machines at the packaging lines should be updated. Currently, not all machine statuses are registered in the right way, due to several causes. This makes the data unreliable, and makes it hard to find the main reason of machine failures. The first cause is mistakes in the programming of the status registrations. Sometimes, an error is recorded as a stop, while it only reflects a warning. Next to that, data registration differs for every packaging line. Failures are named differently between lines, and it even occurs that two machines on the same line use different descriptions for the same failure. A third cause is that during a production stop, some machines get the status failure, blocking, or starvation. It is not totally clear why this happens, it is partly due to operators not logging out the machines correctly, but it also seems to be caused by the machines itself. This should be checked, and simple methods for logging out can help to prevent this wrong status registration.

Next to that, improvements can be made in the communication within and between the departments. Within the departments, there are two main communication organs, every morning an update at 8:00, and a weekly meeting of the operators. Currently, both types of meetings are regarded as an obligation by the operators, while it should be a possibility for them to come up with ideas, solve problems, and have the chance to discuss with the rayon manager and the installation administrator. A team already started on making these meetings more effective, but they should especially take the communication to operators into account, as they should see the usefulness of the meetings, and not regard it any longer as an obligation coming from the management. The rayon managers and team leaders should take the lead in this.

All ‘rayons’ within the packaging department have their own technical problems and their own teams working on it. Sometimes this results in the same work being done twice, as different people are trying to solve the same problem on their own packaging line. A clear overview of which problems people are working on and their solutions does not seem to exist. This should be created, and the role of the TPM office can be very important in this. There are TPM teams, of which a clear overview exists, but if operators are working together on a technical problem without clear guidance, documentation lacks sometimes. Putting everything in a ‘TPM format’ gives resistance from the operators as it is extra work to keep up documentation, but it can save a lot of unnecessary work. Therefore, it is important to increase horizontal expansion and find a way to improve communication between rayons.

Furthermore, improvements are also possible in the information available to the operators. Once in a while, operators need to complete exams on the machines they are working on. For this exam instruction books exists, but these are very extensive and not always up-to-date, as technical changes as well as agreements on procedures and settings change sometimes. It is important that up-to-date information is available, and that this information is easy to find. Therefore, it would be good to assign someone responsible for updating the information for every machine. This person can also create a summarized version of the instruction book, which can be placed close to the machine. This way, information can be found easily, helping the operators to solve technical problems.

During this research, the buffer strategy for line 51 has been visualized. This visualization can help the operators to understand the process better. Also, awareness of the need of continuous flow on the packaging line is created. Although it takes some time to get all information together, it is important that this overview of the buffer strategies is created for all packaging lines, and kept up to date. Also here it accounts that the information should be easy to find, as the current system for this information, EQS, is regarded as messy and overfull. Therefore, it is important to find a place to save this information carefully, and agree on who is responsible to update the drawings when changes take place.

5.5 Further research

In this research, only a limited amount of experiments have been executed. To analyse the possibilities and effects more precisely, a more extensive research on the influence of changes in machine speed on the output should be conducted. Now the simulation model is developed, this can be done quite easily. As we saw from increasing the speed of one box packer, speed changes have a big influence on the output, and are therefore interesting to run further tests with.

The simulation model represents reality, but assumptions have been made to model this. Improvements for the model can help to represent reality even better, and get even more reliable results. Especially the input data should be reviewed, as the data collection is not totally reliable, but changes have already been made since the data analysis. This could help to improve the process even more.

The simulation model developed can also be used on other packaging lines. The model is now specified for line 51, but the lines are similar in operation. This means that with simple adjustments, the model is also applicable at other lines. Therefore, an instruction is made available, in which the basics about adjusting the model are described. For all lines, a review of the buffer strategies could be useful. It would be very useful to have a model applicable for all packaging lines, just by entering some main variables. This way, Heineken can use the model, without the need to have programming knowledge available.

In this research, one of the restrictions was the current placement of sensors along the conveyer belts. Even with this restriction significant improvements can be made, which correspond with yearly savings. The simulation model can also be used to determine whether the sensors are currently placed at the right positions along the buffers. This could even lead to further improvements of the flow in the process.

The model can also be used for other purposes than review of the buffer strategy. Here we can think about simulating the effect of reducing failures (by adjusting the failure settings), the effects of placing a new machine (adjusting speed and failure settings), and many more. Therefore it is important that awareness about the existence of the model is created, so future interns can work with the model to support their research.

5.6 Practical implications for Heineken

The conclusions and recommendations from this research are not yet implemented, and therefore the practical implications are not known yet. But before the simulation model was developed, several actions have been taken to make the first steps in the improvement process to create a more continuous flow.

From the data analysis, it became clear that the box packers were the real bottleneck in the process, not only due to the high frequency of failures, but especially due to starvation from the 'carton street'. Therefore, before even starting the simulation study, the machines speeds in this part of the process have been increased. The main result from this action is displayed that starvation from the carton street has decreased from 8 to 3.5%, which has a high impact on the amount of blocking on the labellers and filling machines. Also some actions have been taken on the palletiser to increase availability, which also helps to reduce blocking on the production line.

6 Bibliography

Appendix A: Definition OPI

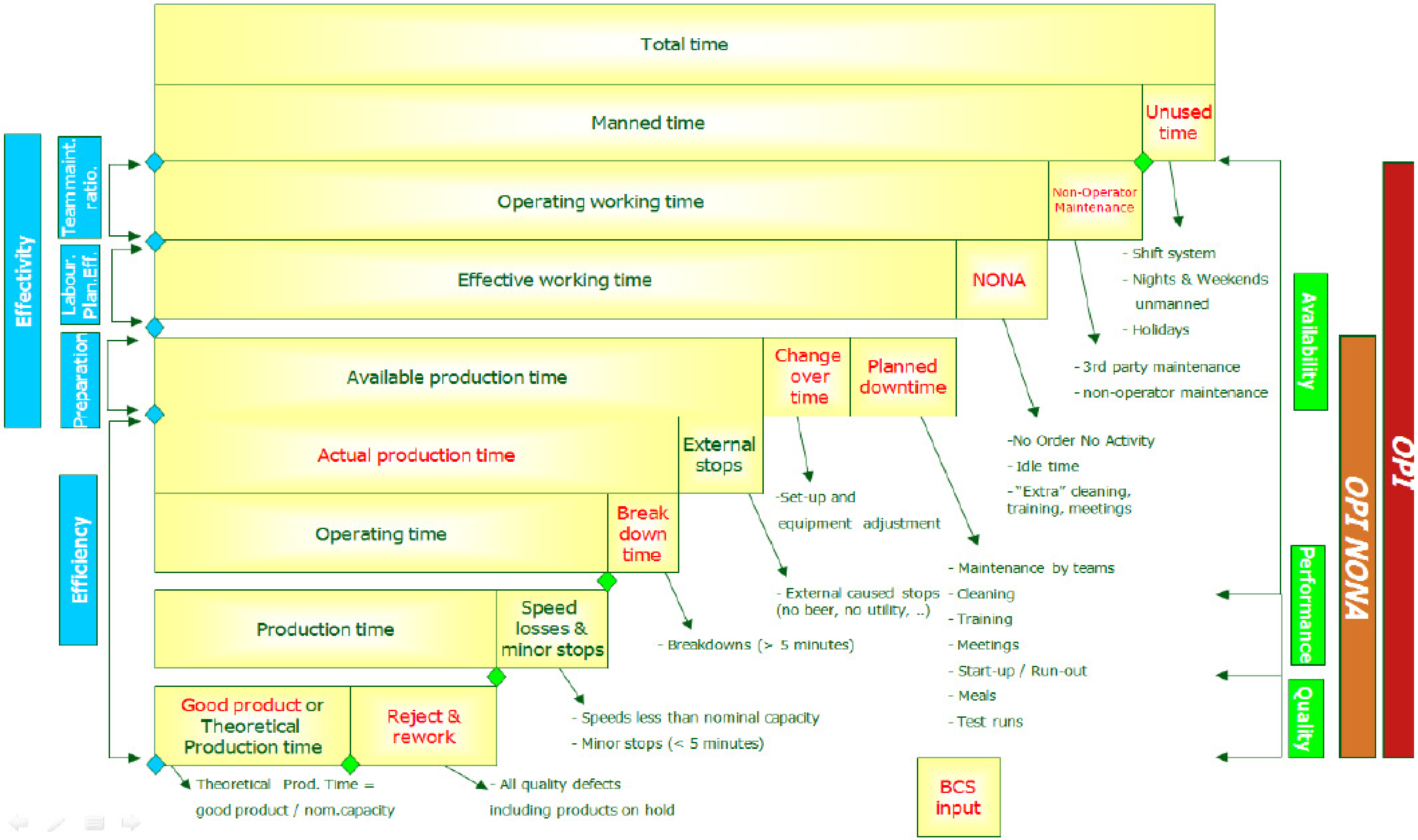

Figure 15: OPI Definition Invalid source specified.

Appendix B: Priority Chart 2014

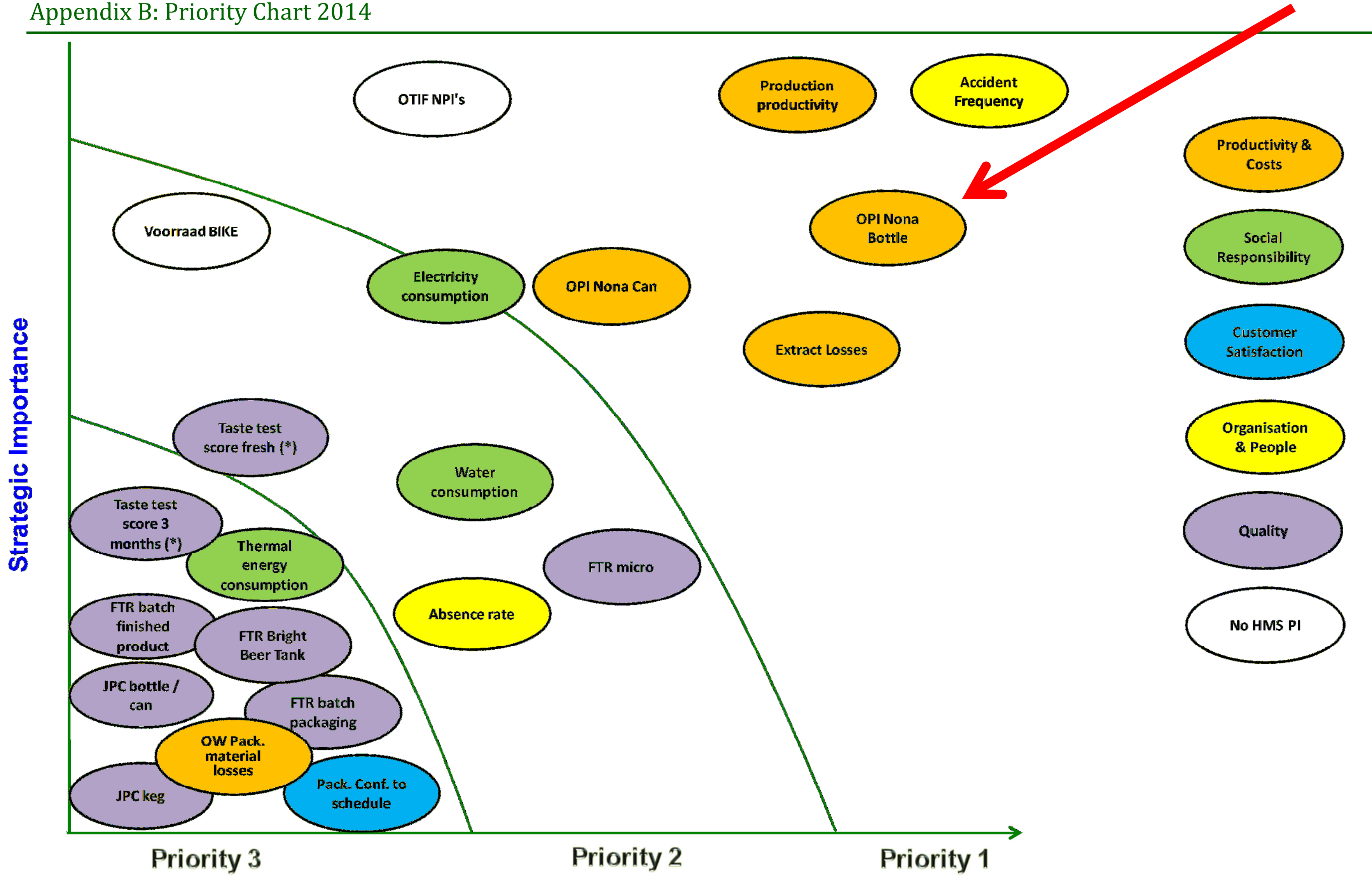

Figure 16: Priority chart 2014 Brewery Zoeterwoude. Indicated is the high priority OPI NONA bottle Invalid source specified.

Appendix C: Layout of packaging line 51

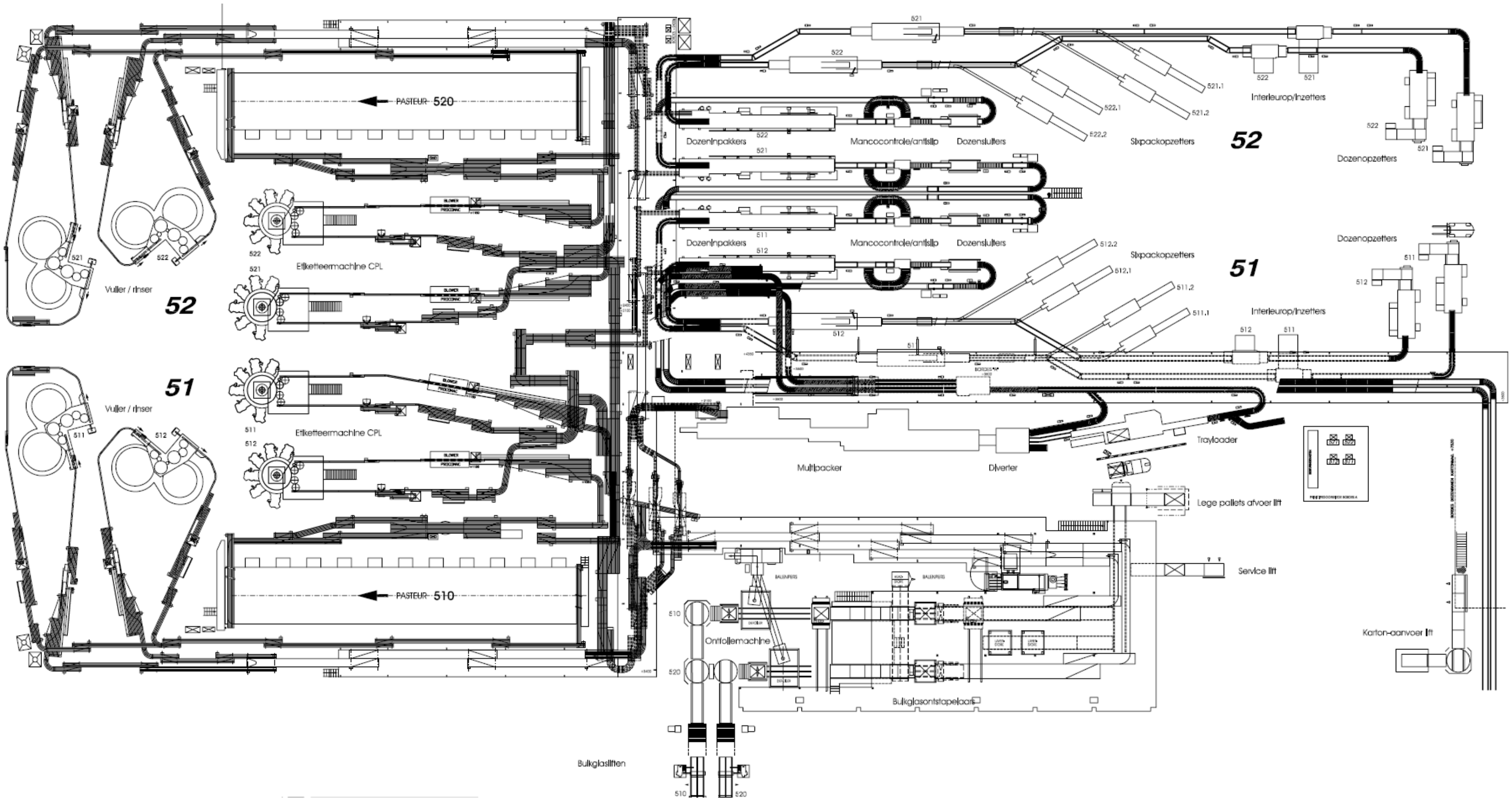

Figure 17: Layout of packaging line 51 and 52, without palletiser

Appendix D: Detailed machinery description

Based on Figure 2, this appendix gives a detailed description of the different machines in the process. First the machines processing the bottles are described. Afterwards, the machines at the carton infeed are discussed. This appendix also explains why some machines are not taken into account in the main process.

Bottle processing machinery

The logistics department is responsible for the supply of pallets with empty bottles at the entry buffer of the packaging line. The glass bottles enter the process with 3610 empty bottles on a pallet. These bottles are divided over 10 layers, each separated by piece of carton covering the layer. The top layer is covered by a carton hood. The whole pallet is covered with a plastic sleeve.

The glass bottles are delivered by a truck and unloaded in the glass unloading dock. Because line 51 is positioned on a higher floor, they are transported up with an elevator, after which they are transported further by conveyer belts.

Defoil machine

After entering the packaging floor of line 51, the pallet is transported to the defoil machine. The defoil machine takes the foil of the pallet with bottles. First it lifts the pallet slightly off the ground. Then it makes a cut in the foil using a heated thread, which is used as started point to wrap the foil of the pallet. The foil is drawn into the machine, which compresses the foil together before putting it on a pallet. As soon as all foil is removed, the pallet is put back on the ground and transported on the next conveyer belt.

Depalletiser

After the foil is taken of, the empty glass bottles are ready to be taken of the pallet. They enter the elevator, which lifts the pallet on the level of the empty glass conveyer belts. First the carton hood is taken off, and then the first layer of bottles is pushed off the pallet on the conveyer belt. When enough space is available, the next layer is pushed off. After pushing off the layer, the carton plate is taken off, which is thrown in a container. This continues until the last layer of the pallet. Then the elevator takes the empty pallet down again.

Rinsing, filling, and crowning

The empty bottle conveyers transport the bottles to the rising/filling machine. Before entering the machine, the empty bottles are automatically checked on quality. Bottles deviating from the standard are expelled from the process. There are two rinsing/filling machines (Filler 511 and Filler 512), so the stream of bottles in split in two. Both fillers work the same. When the bottles enter the machine, they are first rinsed with water. To keep the gas into the beer solution, the beer has to be filled under pressure. Also, it is important that no oxygen is left in the bottle, to assure the quality of the beer. Therefore, a vacuum is created in the bottle, after which the filling starts. When the bottle is filled, it is closed with a crown cork which is distributed along a vertical chute. After the crown cork is put on, the fill level is checked. This is done by measuring the pressure on the crown cork. If the fill level is not too high or low, the bottle continues on the conveyer belt to the next machine.

Pasteuriser

The filled bottles continue to the pasteuriser, where the bottles are heated to inactivate all micro-organisms and enzymes that can influence the quality of the beer. By pasteurising the beer, the shelf life of the product is extended. On packaging line 51, a double deck pasteuriser is installed. This means that two conveyers are transporting the beer through the pasteuriser, one upper deck (processing bottles of filler 511) and one lower deck (for the bottles of filler 512). The speed of these conveyers can be changed separately. The pasteuriser on packaging line 51 is an in-line pasteuriser, which means that it consists of a series of linked water tanks. The beer is conveyed through a tunnel-like structure, in which it is heated up in several zones, receives the heat-treatment, and then cools down in several zones.

Blower

After the pasteuriser, all bottles get together on the conveyer belt, but also split again before entering the next machine, as two blowers are installed. The filled bottles coming out of the pasteuriser are wet, which makes it hard to stick the labels on to them. Therefore, the bottles are dried by a blowing machine, which blows air on the bottles. The blower is not taken into account in the main process. There is no data available about this machine, as measurement is not taking place. Disruptions at the blower do not interrupt the process, as they only affect the quality of the labelling.

Labelling machines

Both of the blowers are put in line with a labelling machine (Labeller 511 and Labeller 512), so this time, the streams of bottles continue separated. Based on the position of the juncture in the glass, the bottles are placed in the right position. Then they are transported along several labelling positions, and the labelling machine puts three labels on the bottle; one on the neck of the bottle, one on the front, and one on the back. In the end of the machine, a laser puts the last necessary information on the bottle, as batch number, machine number, etc. When the bottles are labelled, an automated quality check is done on the position of the labels. Also, the fill level is checked again. Bottles not passing one of the tests are expelled from the process.

Box packaging machines

After receiving the label, the bottles are ready to be packed in boxes. From the labelling machine they are transported to the box packaging machine. Also here, the bottles first get together again, after which they split to two equal machines (Packer 511 and Packer 512). This machine has two types of material entering: the filled and labelled bottles from the main process, but also a box with either an interior partition or four six-packs (see section about carton in-feed). The boxes enter the machine from a lower level, while the bottles enter on high level. The machine has eight pack-arms, which grab 24 bottles from the bottle in-liner, and put them down in the box placed underneath.

Box closing machines

After the bottles are placed in the box, the weight and height of the box are checked. If bottles are missing or extra bottles have been put in the box, the weight deviates from the target and the box is transported to a separate lane. If a bottle drops from the pack-arm, it can be placed on the carton of the insert, and these boxes are also separated. When both the weight and height are according to the standards, the box can be closed. This is done by a closing machine, one of which is placed behind each packer. The machine puts glue on the box and closes it. The box closing machine is not taken into account in the main process, because the number of disruptions is very low. The machine status is registered, but the machine is only working if the packer is as well. Therefore, taking this machine into account does not lead to extra insights in the process.

Palletiser

The closed boxes are ready for transport, but they first need to be put on a pallet. Therefore, they continue to the palletiser. Entering the palletiser centrum (which is placed 5 floors below packaging line 51), the boxes are first checked for broken bottles by a 'wet boxes' detection. If the boxes are not wet, they are put on a pallet in the determined pattern. Empty pallets enter from below, and are lifted to the box-entrance level by an elevator. As soon as one layer is completed, the pallets move down a bit, so the second layer can enter. After seven layers of 12 boxes the pallet continues on a conveyer to the sleeving machine.

Sleeving machine

The sleeving machine puts a plastic sleeve over the pallet, to prevent the boxes from falling. A piece of plastic is grabbed on four corners, and put over the pallet. With the use of heat the plastic sleeve shrinks around the boxes.

Pallet sticker machine

After being covered by a plastic sleeve, one step is left before the pallets are ready for transport. Each pallet receives two labels for identification and tracking. As soon as the label is scanned, the boxes are counted as completed products and the pallet is transferred to CS&L. They put the pallets in containers to be transported by truck and/or ship.

Carton in-feed

Next to the main process where bottles are transported, there is a separate in-feed of all carton packaging material. As explained in Chapter 2, the bottles are currently packed in two different types of boxes: boxes with interior partition or boxes with four six-packs. The interior partition is a carton insert, dividing the box into 24 compartments.

Material for the carton in-feed comes from CS&L and is transported to the packaging line using an elevator. All carton is placed on pallets, which are transported next to the related machines when necessary.

Box erector

In both ways of packaging, the process starts with the two box erecting machines. The machine is fed with ‘plano’s’, which are empty, folded flat boxes. These boxes are put into the machine, which erects the boxes using suction mounts. The bottom of the box is closed with glue. The erected boxes are placed on a conveyer belt.

Interior inserter

Independent of the current type of packaging, the box continues along the interior erector. If the box needs an interior partition, the interior erector places this in the box. Also the interior partition is folded flat, and erected by suction mounts. The arms of the machine place the erected insert in the box. There are two interior erectors, both in line with one box erector.

Six-pack erector and inserter

When six-pack packaging is used, the four six-pack erectors are erecting the folded, flat six-packs and put them on a conveyer belt. Two erectors are linked to one six-pack insert, which picks up four six-packs and places them in the box passing beneath the insert machine.

Boxes filled with either an interior or four six-packs are ready to continue to the packers. The process from the packers till transport is described earlier in this appendix.

Appendix E: Speed calculations V-graph (confidential)

The number stated as capacity for each machine is the theoretical capacity with the current machine settings. So, e.g. the box packers have three possible speed settings: low, nominal and high speed. The speed displayed here is the high speed that is currently programmed in the machine. For the fillers, pasteuriser, labelling machines, box packers, and palletiser these set points are known. For the defoil machine, the depalletiser, the sleeving machine, and the pallet labelling machine several measurements have been conducted about the time needed to process one pallet. For each machine 30 measurement results have been compared, outliers have been deleted, and then the average has been taken. To make sure the machines was running at maximum speed, measurements have taken place with excessive input, while at the output side excessive capacity was available.

Appendix F: States registration machines (confidential)

Table 17: Example data retrieved from system

Appendix G: Fitting distributions: Failure duration (confidential)

Appendix H: Estimating buffer size

For the simulation model, we need to estimate the buffer size of the buffers in the process. This is done using two sources. First of all, we use the theory of Fejes Toth **Invalid source specified.**, who gives formulas to estimate buffer sizes when using hexagonal packing. Next to that, we use the isometric drawings of the line 51 to determine the sizes of the conveyer belts. These are checked by performing measurements on the packaging line.

Toth **Invalid source specified.** provides prove that the maximal density of equally sized bottles is when hexagonal packing is used (see Figure 17). There are two ways of hexagonal packing, one with rows of equal length, and one with alternating rows, as can be seen in the figure. For both, formulas have been developed to estimate the packing area. As we know the sizes of the area, we can estimate the number of rows and the length of the rows and from there calculate the density.

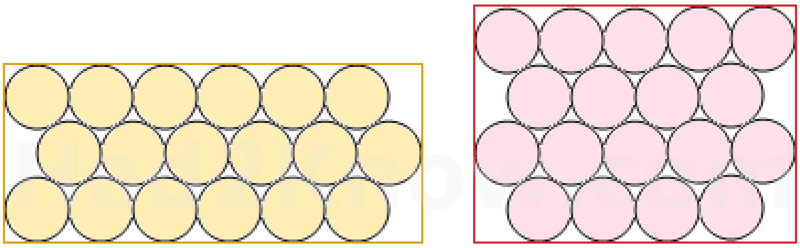

Figure 18: Hexagonal packing, left equal rows, right alternating rows

If we have k rows of alternating length, in which the length of the longest row is n, and the diameter of the bottles is d:

$$area = d^2 * n\left(\sqrt{3/2} * k + 1 - \sqrt{3/2}\right)$$

If we have k rows of equal length, in which the length of a row is n, and the diameter of the bottles is d:

$$area = d^2 * (n + 1/2)\left(\sqrt{3/2} * k + 1 - \sqrt{3/2}\right)$$

With these formulas and the dimensions of the different parts of the buffers, we can calculate the capacity of each buffer part. To determine whether to apply equal or alternating row length, we look at the width of the buffer and divide it by the diameter of the bottle. If the decimal numbers are less than 0.5 we use alternating row length, if it is more we use equal row lengths.

For each buffer part we determine n using the width/bottle diameter. Then we have all variables for the formula except for k, for which we can use a solver. This gives the buffer sizes as displayed in Table 7 (page 40).

Appendix I: Warm-up period

To determine which shifts need to be taken into account in the experiment results, the warm-up period needs to be calculated. From reality we know that this period is short, as it is close to the time the first boxes arrive at the palletiser. This is mainly determined by the processing time of the pasteuriser, which equals around 50 minutes.

To check if the process is stable after one shift, we run a simulation in which we measure the output, in number of boxes, per hour. Figure 17 shows this development of the output. Here we see that the output already stabilizes after 2 hours, so using a warm-up period of one shift (8 hours) ensures that the system is in steady state in the shifts we take into account in the results.

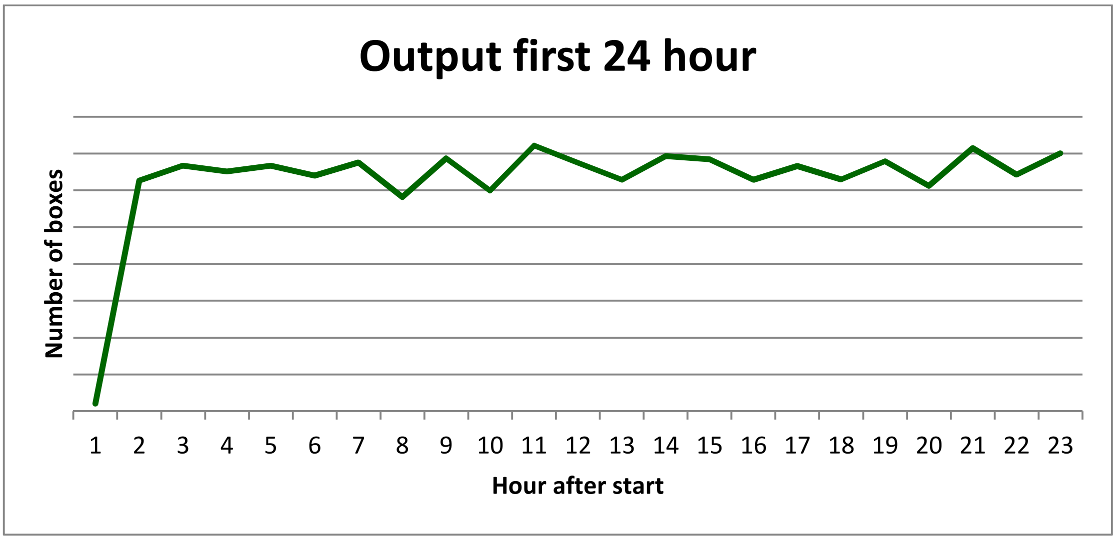

Figure 19: Output in the first 24 hour

Appendix J: Number of replications

For reliable results of a simulation study, it is important to perform enough replications for each experiment. On the other hand, more replications always result in a longer running time, which has a negative influence on the duration of the simulation project. Therefore, it is important to determine how many replications are needed.

The most well-known and commonly used method to determine the number of replications is based on the idea that replications need to be performed until the width of the confidence interval, relative to the average, is sufficiently small. So the following applies for a given relative error γ (Law, 2008):

$$\frac{t_{n-1,1-\alpha/2}\sqrt{S_n^2/i}}{|\bar{X}_n|} \leq \frac{\gamma}{1+\gamma}$$

Here, we need the student-t distribution to determine $t_{n-1,1-\alpha/2}$, where we take α=0.05. The relative error we allow is 0.05. X_n and S_n are determined by executing n replications and taking the average and variance. The needed number of replications is the minimum n for which the formula above applies. We can determine this n using a sequential procedure; we calculate the values for every n, until we reach a value which is smaller than the relative error. We determine this value based on the output measure, as this is our main performance measure.

This method is executed for every experiment setting. The results are shown in Table 22. To make sure we have enough replications to meet the relative error requirement, we take the maximum number found. This means we need to execute at least 5 replications for each experiment.

Experiment	1	2	3	4	5	6	7	8	9	10	11	12
Replications	3	3	3	3	3	4	4	3	3	5	3	3

Table 18: Number of replications per experiment