HEINEKEN

Improving performance of the Star Bottle production line

A case study at Heineken

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“The future belongs to those who prepare for it today.”

- Malcolm X

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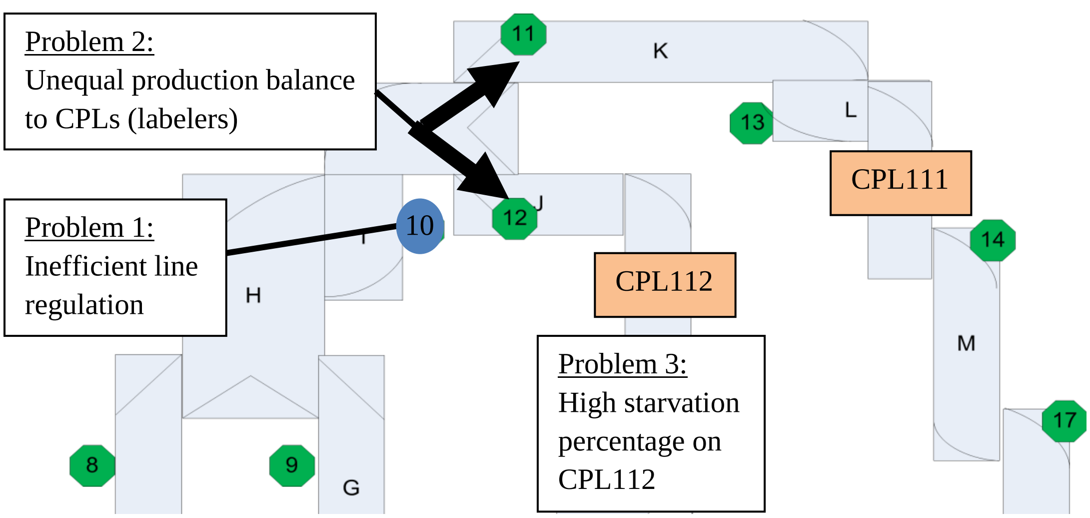
Management Summary

HEINEKEN needs to stay ahead on the competitive beer market and therefore it constantly needs to improve its performance. This report focuses on the production line of the Star Bottles, introduced at HEINEKEN in 2013. Production line 11 produces Star Bottles and differs from other production lines at HEINEKEN because it has multiple speeds on the filling machine. This line is known as a self regulated production line, where speed levels of the machines are regulated by sensors on the production line. Overall, the performance of line 11 is below target, so improvement is necessary. This leads to the following research question:

How to improve line performance on the regulated production line (line 11) at HEINEKEN Zoeterwoude?

First, to determine the focus of this research we performed a process analysis and data analysis. The focus is on the pasteurizer and the labelers (CPLs). The pasteurizer is the bottleneck machine and most inefficiencies occur on this part of the production line. These problems are formulated and displayed below:

- Problem 1: Blockage on pasteurizer due to inefficient positioning of sensors. A blockage on the pasteurizer occurs when the CPL111 (labeling machine) fails and CPL112 does not start production, simply because sensors are not triggered when they should. A minute loss on the bottleneck machine is a minute loss on the output of the total line. This problem is also known as 'inefficient line regulation'.
- Problem 2: Unequal production balance between the labelers. CPL111 produces 57% of the total output and CPL112 produces 43%. This is a problem because the maintenance schedule does not fit and extra CILT-activities (**C**leaning, **I**nspection, **L**ubrication and **T**ightening) by operators need to be performed.
- Problem 3: Labeler 112 has an extremely high starvation percentage (64% of total time).



Based on the process and data analysis it is known that problem 1 is caused by inefficient line regulation. The second problem is a lay out problem, but can also be solved with a more efficient line regulation. Problem 3 is a mistake in the software. This problem is communicated to the software department and will be solved in January 2015. In order to improve the line regulation, a conceptual model is designed that is the base for a simulation model. We use this simulation model to perform experiments of alternative solutions to problem 1 and 2. In these experiments, the position of the sensors and the number of speed levels of the machines are changed.

To find an alternative solution, we performed twelve different experiments. The results of the experiments were ranged by two indicators, output quantity and production balance. Looking at both indicators, the results of the experiments show that the current situation can be improved. In the table below, the current situation is compared with the alternative solution.

Situation	**Output In bottles**	**Production balance**		**Difference on CPLs**
	Average	CPL111	CPL112	
Current	441,313	57%	43%	14%
Alternative	453,103	53%	47%	6%
Difference	11,790	4%	4%	8%

The new situation increased the output with 11790 bottles and improved the production balance with 8%. This improvement results in a yearly saving of **€X** (*confidential*).
We can conclude that the line performance at the regulated production line (line 11) at HEINEKEN Zoeterwoude can be improved by:

- Adjusting the position of sensors and the amount of speed levels. These adjustments have a positive influence on the output and production balance of the line. Thus, 'efficient line regulation' improves the line performance.
- Reducing the amount of speed levels of CPL111 from four to three, where CPL112 remains the same with three speed levels.
- Changing all three sensor positions regarding the speed levels of CPL111, and by changing only one position of CPL112.

The alternative situation is *implemented* at the Star Bottle production line. The first results in real life support our findings and conclusions from our simulation model. The first results show that the production balance is improved (52%/48%) and that the throughput is increased. Nevertheless, we should analyze our modification in real life more frequently to ensure that our modification is an improvement in any situation on the Star Bottle production line.

In addition, we provide the following recommendations:

- *Focus more on conveyors/lines.* On all packaging lines the focus is on the machines, but the focus should be on conveyors between the machines. The implementation of the modification is relatively small, but the results are relatively large.
- *Determine the functioning of all sensors on the production line.* In order to improve the efficiency **between** machines, it is necessary to have a clear understanding of the function of the sensors.
- *Improve data registration at MES (information system).* The data registration at MES should be improved, especially for the Star Bottle production line. Due to the regulated production line, MES is not capable to measure all parameters (e.g., speed levels).
- *Hire an extra PA-/PI engineer.* When inefficiencies are noted by employees, they have to fill in a label. Different aspects on these labels are possible, and might vary from safety issues till

machines issues. When such an aspect consists of technical issues, these arrive on the desk of a PA-/PI engineer. Some filled in labels are on stack for six months. This slow response by management discourages the operators to help improve the line performance.

- *Improving the administration of inventory management of small objects.* The exchange of small objects (e.g., Teflon cylinders, glue sprayers) and their location is not registered by the maintenance department.
- *Visualization of inefficiencies for operators.* Operators should be aware of all possible states and errors of the production line.

The optimization of the line regulation of line 11 is now only performed between the pasteurizer and CPLs. Therefore we suggest further research to improve the whole line regulation of line 11.

Preface

This report presents the research I conducted in order to improve the line performance at the packaging department of HEINEKEN Nederland B.V. This research is performed in order to graduate at the University of Twente. Managing this research project was a real challenge and opportunity to develop my personal and educational skills.

Conducting and finishing this report would have never been possible without the help of others. Therefore I am using this opportunity to thank everybody directly and indirectly involved in the realization of this research.

First, I would like to thank Jojanneke Bron for realizing my graduation internship at the packaging department at the HEINEKEN Zoeterwoude brewery, for all the effort, enthusiasm, and contributing to make it a fantastic experience. Furthermore I would like to thank Dennis van Strater, Toine van den Berg, Ed van Dorp, Ernst Hageman and Peter Zandvliet for their effort, support and insights. During my 6 months internship, I believe to have developed myself at a professional and personal level due to their constructive feedback and guidance.

A second word of thanks goes to Peter Schuur and Martijn Mes, for their valuable feedback and sparring sessions. Their extensive input was indispensable in defining and executing this research, writing this report and finishing the (simulation) model.

Finally, special thanks go to my parents, brother, sister and girlfriend for their support and inspiration, which eventually is the key to my success.

Daan van Leer.

Abbreviations

AGV	Automated Guided Vehicle
BDA	Break Down Analysis
CILT	Clean Inspect Lubricate Tighten
CPL	Cold glue Plastic Label (Machine)
CS&L	Customer Service and Logistics
EBI	Empty Bottle Inspector
FTE	Full Time Equivalent
HL	Hecto Liter
HNL	Heineken Nederland
HNS	Heineken Nederland Supply
IS	Information System (see MES)
KPI	Key Performance Indicator
MER	Mean Efficiency Rate
MES	Manufacturing Execution System
MRP	Material Requirements Planning
MTBA	Mean Time Between Assist
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MU	Movable Unit
OPI	Operational Performance Indicator
PDCA	Plan, Do, Check, Act
PLC	Programmable Logic Controller
QFD	Quality Function Deployment
SAT	Site Acceptance Test
SB	Star Bottle
TEI	Time Efficiency Improvement
ToC	Theory of Constraints
TPM	Total Productive Management
TQM	Total Quality Management

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1. Introduction

In the framework of completing my Master thesis, I performed research at HEINEKEN BV to improve the production line of the Star Bottle, introduced in 2013. This report describes the master thesis for the study Industrial Engineering and Management at the University of Twente. In this research, we analyze the production line with corresponding machines in order to improve the current situation. Section 1.1 contains general information and background information about HEINEKEN, where we describe in Section 1.2 the context of the research. In Section 1.3 we define the problem statement followed by the research question and sub-questions in Section1.4. In Section 1.5 we define the research focus followed by the research methods in Section 1.6. We end this chapter in Section 1.7 with a list of the main deliverables of this report.

1.1 Introduction HEINEKEN

HEINEKEN, a Dutch brewing company, is established in 1864 by the HEINEKEN family and is world's most international brewer. It has 165 breweries and is active in 71 countries in the world. With around 85,000 employees, HEINEKEN manages one of the world's leading portfolios of beer brands.

HEINEKEN in the Netherlands owns three breweries, one location for bottling of soft drinks and nine sales regions. Production takes place in breweries at Zoeterwoude, Den Bosch and Wijlre. The largest brewery of HEINEKEN is located at Zoeterwoude, which is also the location of the research. Figure 1.1 shows the brewery of HEINEKEN Zoeterwoude. The beer production at Zoeterwoude is 10 million hl in 2013, from which 60% is dedicated to export. The destination of the exported beer is especially the Americas and Asia Pacific. The distribution network of HEINEKEN BV is so efficient that distributing bottles from Zoeterwoude to America is more profitable than brewing in America. In Figure 1.2 we show in what way HEINEKEN is present in the world. Where HEINEKEN OpCo stands for "Operations Company" and means that in this country HEINEKEN has one or more breweries.

FIGURE 1.1:HEINEKEN ZOETERWOUDE

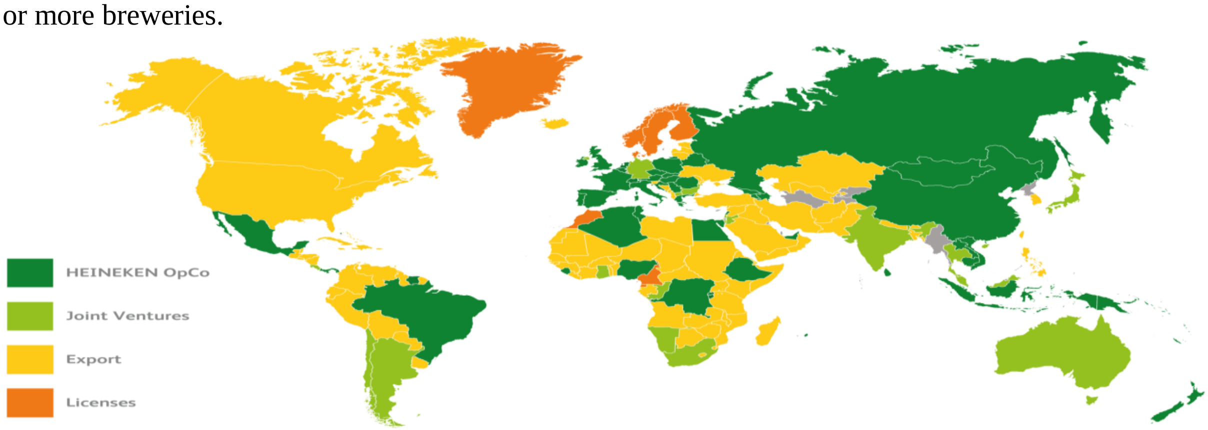

FIGURE 1.2: GLOBAL PRESENCE OF HEINEKEN

In total HEINEKEN brews and sells more than 250 brands including international, regional, local and specialty beers and ciders. Heineken® is the flagship brand and other brands that are part of the portfolio are Amstel, Desperados, Tiger, Foster's, Sol, Wieckse Witte but also ciders like Strongbow and Jillz. HEINEKEN has three brands that are positioned in the top ten of the world's leading brands, which are shown in Figure 1.3. Note that Heineken® is number one with 27.4 million hectoliter.

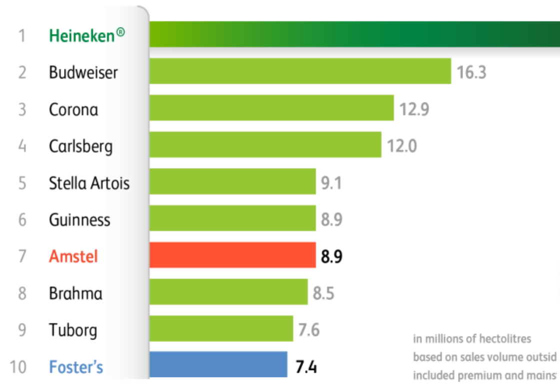

FIGURE 1.3: WORLD'S LEADING BRANDS (IN MILLIONS OF HECTOLITERS)

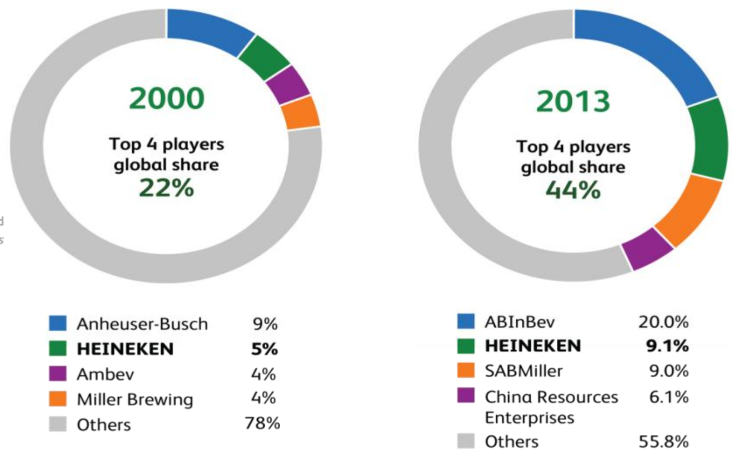

FIGURE 1.4: INDUSTRY CONSOLIDATION

In addition HEINEKEN BV (all brands together) ranks second in the top of the global market share, with a percentage of 9.1%. ABInBev (Belgium) and SABMiller (South-Africa) are respectively number one and three. In Figure 1.4 show these numbers. Nevertheless, based on volume HEINEKEN ranks third, after respectively ABInBev and SABMiller. ABInBev's portfolio consists of brands as Budweiser, Stella Artois, Jupiler, Hertog-Jan etcetera. Whereas SABMiller has brands like Miller, Grolsch and Pilsner Urquell.

Recently SABMiller proposed a takeover offer towards HEINEKEN, but HEINEKEN wanted to preserve the firm as "an independent company". Besides there has been speculation within the brewing industry, for months, that SABMiller has been targeted by the world's number one brewer ABInBev. This means that there is a frequent activity around the top of the breweries.

HEINEKEN Zoeterwoude

HEINEKEN Zoeterwoude is divided into two divisions, HEINEKEN Netherlands (HNL) and HEINEKEN Netherlands Supply (HNS). In this research we only focus on HNS which is shown in the organizational structure of HNS in Figure 1.6. The chart narrows on the area of interest for this research, which considers line 11. A rayon consists of (two or) three production lines which differ from bottles to kegs.

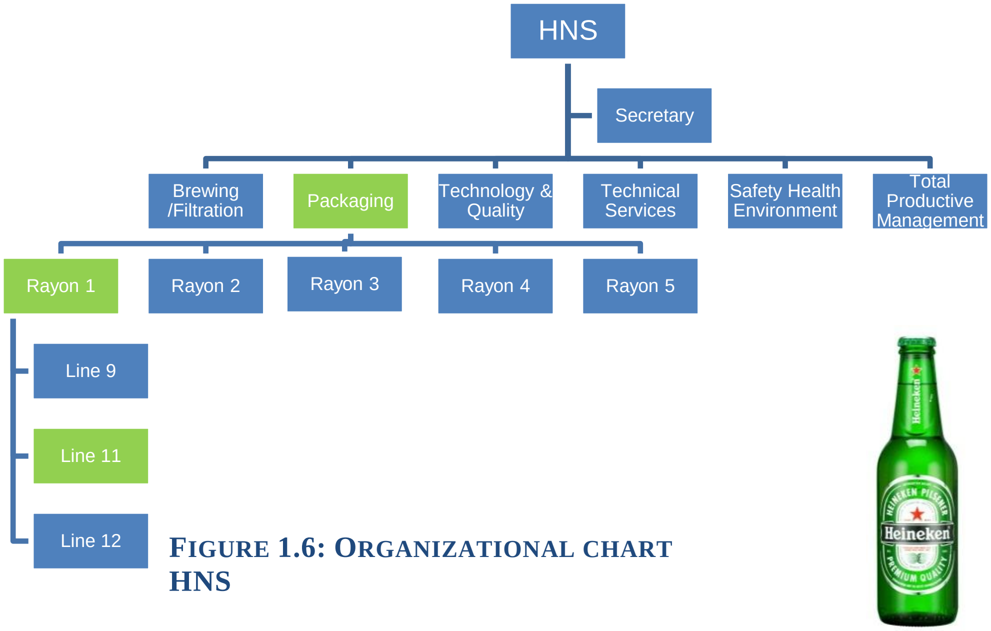

FIGURE 1.6: ORGANIZATIONAL CHART HNS

FIGURE 1.5: HEINEKEN STAR BOTTLE 0.3L

In 2013, HEINEKEN introduced the new Star-Bottle (SB) exhibited in Figure 1.5. In order to produce these new bottles, a new production line has been developed, which is line 11. So this research focuses on line 11 with the Start Bottles. In Section 2.1 we describe this line in detail.

1.2 Context Description

In today's highly competed beer market, HEINEKEN needs to stay ahead of its competitors. More beer brands will enter the market and as HEINEKEN Nederland Supply (HNS) states: "customer demand is changing, volume is decreasing, fixed costs as well as variable costs are increasing, and customers expect the same service and quality" (HNS visie 2015, 2011). Therefore, HEINEKEN is striving for continuous improvement of their performance in order to stay ahead of the competition. The main goal is to gain higher line performance, higher productivity, and eventually a lower cost price, while maintaining the quality. HEINEKEN has decided to perform this continuous improvement using Total Productive Management (TPM). TPM is an equipment management philosophy, focused on maximizing performance and the ultimate goal is to reach zero losses (Nakajima 1988). TPM is preferred above TQM and Six Sigma because of its strong focus on equipment and maintenance. Since the continuous improvement philosophy, TPM has a strong focus on maintenance and is useful in organizations that have a high level of equipment automation (Rolfsen, Langeland 2012). TPM is a philosophy to continuously manage, optimize and improve a supply chain by eliminating all losses, involving all employees of the organization (Chan, Lau et al. 2005, Ahuja, Khamba 2008). By systematically eliminating losses, TPM improves the performance of a production system (Nakajima 1988, Hartmann 1992, Chan, Lau et al. 2005).

In order to know what performance is improved, the performance measure should be clear. Currently, in most businesses, every performance is measured by various kinds of performance indicators (PIs). Also departments in a company have their own PIs. Consider for example a car manufacturer: where the sales department measures its performance on cars sold and number of customers satisfied and the production department measures its performance by cars produced and cars rejected by lack of quality. In literature it is a highly debated topic. According to Neely (2002), the definition of performance measurement is: "The process of quantifying the performance of actions". Measuring the performance is important in order to be able to perform improvement activities based upon these measures and to keep track of previous results (De Ron, Rooda 2006). In addition, only aspects, that have been measured, are actively improved by the stakeholders (Ridgway 1956, De Ron, Rooda 2006). Therefore it is important for businesses to identify the correct performance measurement and corresponding PIs for each process. With an incorrect performance measure, the problem will not be measured correctly and therefore it is unclear whether the problem is solved or not.

KHS

KHS, the German supplier of the Star Bottle production line, also matches the thoughts of TPM, where reducing losses are a point of interest. **The philosophy of KHS is to reduce losses by avoiding start/stop situations of a machine**. The losses that will be reduced are *equipment failure, idling, minor stoppage and reduced speed.* KHS implemented line 11 in 2013. Thus the machinery is relatively new and KHS expects less failure compared to other lines. Nevertheless there are some differences with older production lines due to new insights in technology. KHS has a new philosophy to increase line balance by introducing several speed levels in the machines, particularly on the filler. Previously, fillers on the production lines at HEINEKEN have just one production speed, the machine produces or does not (resp. at 100% or 0% of capacity). This stationary process is known as a **non-regulated production line**. Nowadays the machines on line 11 have different speed levels (e.g., 0/25%/75%/100% of capacity), which is a dynamic process. When a starvation/blockage impends, sensors on the conveyors will send a message to the machine that it must change to, e.g., 75% of the capacity in order to prevent downtime. This is in line with the philosophy of KHS, who believes that a continuous flow of products will reduce failures. This dynamic process is known as a **regulated production line.** HEINEKEN adopted this philosophy and line 11 is therefore a regulated production line.

1.3 Problem Statement

According to Nakajima's (1991) findings mentioned in the previous section, HEINEKEN should reduce their losses in order to improve their performance. First we have to clarify the definition of 'losses'. HEINEKEN uses an information system to get insight into their losses. A tool to determine the machine states is the "DNA strand", which is exhibited in Figure 2.8 . For a *non-regulated* production line this tool works well. A green bar means that the machine is producing (100% of its capacity). Nevertheless, for a *regulated* production line it is more challenging because on the green bar the production speed is not visible (e.g., if the machine is producing for 50% or 75% of its capacity). This means that the production losses of line 11 are not measured completely. It is complex to reduce the losses if they are hardly visible. There exists a mismatch between the philosophy of KHS and the measurement of losses at HEINEKEN.

It is hard to improve the line performance of line 11 because of the regulation and because losses are not visible. Nevertheless, line performance will not improve when only the losses are made transparent. An action or modification has to be made. Making these losses transparent is just a step in the process in order to improve the line performance. When losses are more transparent, the machine efficiency and relations could be determined and only then improvements can be made.

To summarize this section, we state that the main objective is how to improve the line performance and how can losses made transparent.

1.4 Research setup

Based on Section 1.3, we formulate the following research question to reach the problem statement:

How to improve line performance at the regulated production line (line 11) at HEINEKEN Zoeterwoude?

To answer the main research question, we formulate five sub-questions that give a deeper understanding of the research. Each sub-question contains a brief description of what will be discussed in this sub-question.

1. ***How is production line 11 currently organized?***
    a. *What kind of machinery is located?*
    b. *How is the line regulation organized?*
    c. *What KPIs are currently used?*
    d. *How is performance currently measured?*

First, the layout of line 11 is explained in order to delineate the problem situation. We need a clear understanding of how production line 11 is functioning. We need to know what the production processes are and how the line regulation works. Furthermore, the KPIs need to be clear in order to measure performance. Also the functioning of the different machines and conveyors are described.

2. ***What is the current performance of line 11?***
    a. *What losses can be identified?*
    b. *Which processes are bottleneck processes?*

The second question focuses on the current performance and on what kind of losses HEINEKEN has to deal with. A lot of losses are measured in the information system of HEINEKEN, but not every loss is visible. Therefore all the losses are clarified in order to compare them and to determine the focus for performance improvement. In addition, we give a clear definition of losses and what kind of performance measurement must be used. Moreover a tool for determining the speed losses on bottleneck processes is introduced.

3. ***What alternative approaches are described in the literature for the improvement of line performance? What is the best alternative approach to use at HEINEKEN?***

We conduct a literature study to increase the understanding of different approaches for improving line performance. Different methods are compared so the best method is applied to the problem. We search scientific articles in the field of production line improvement.

4. ***How can the alternative approach, described in sub-question three, be implemented in order to improve the line performance?***

In sub-question three, we compared different methods in order to improve the line performance. In this question we propose suitable improvements/interventions for HEINEKEN. To display the impact of these improvements, we develop a conceptual model. In order to validate and verify the authenticity of this conceptual model we will use simulation. A simulation model mimics the reality. Different scenarios can be experimented and the best alternative can be compared with the current situation. If this improves the current situation, then implementation can be considered.

5. ***What are the results of the identified improvements, and what are the recommendations for HEINEKEN?***

In sub-question five we analyze whether the results from sub-question four will have a positive impact on the current situation. Based on these results we describe the recommendations for HEINEKEN regarding implementations as for further research.

1.5 Research scope

We base the research scope on the argumentation of the management of HEINEKEN, which stated that the focus needs to be set only on the machines that have the biggest influence on the line performance. The management argued that the area between the bottle washer and packer works inefficient. This argumentation will be further explained in Chapter 3, using data analysis.

Furthermore, we decided not to include the breakdowns of the machines because these are mainly technical issues that can be solved by operators or electricians. Moreover it is the wish of HEINEKEN to improve the line with current breakdowns, because teams with operators/electricians will solve the technical problems. Besides, mechanical/technical improvements are not in line with the study background in which this research is conducted.

Also this research has a couple of restrictions that should be taken into account. Large investments (>10,000 euro) cannot be done. Likewise, the layout of the conveyors at the production line cannot be changed. Furthermore the quality and safety standards developed by HEINEKEN should be satisfied.

Below we give an enumeration of characteristics that **can** be changed, which is useful for developing the conceptual model and simulating this model. The characteristics are:

- Production speed of machines.
- Number of speed levels of machines.
- Moment of switching to a certain machine speed. This depends on the location of the sensor and the programming code related to the sensor. A more detailed explanation can be found in Section 2.2. Note that the location of the sensor is fixed, because modifications are restricted to the current layout.
- The combination of sensors that will lead to a certain action (e.g., production of a machine). Often one sensor is coupled to multiple actions.

These characteristics will be explained in Chapter 0.

1.6 Research methods

To answer the research questions, we will use several research methods. In order to answer the first and second sub-question, we use the knowledge at HEINEKEN. To describe the current layout and machinery it is useful to observe the line itself, with the use of empirical data. Furthermore some interviews will be done with supervisors, experts and operators to gather information about the production line. The nature of the interviews will also depend on the nature of the information that is to be gathered. Experts at HEINEKEN and from the academic community will be approached accordingly to the required information. Also the information from information systems and real life data is used to describe how production line 11 is currently organized. The information system MES, used by HEINEKEN, stores all relevant line and production data. This will be the main source in order to answer sub-question two. Besides, we apply a data analysis in order to determine the bottleneck machine/process. Also a tool for determining the speed losses will be introduced.

The research method for sub-question three, is a literature review. To perform all literature reviews, academic publications, books, reports, internet, databases and proceedings of conferences will be analyzed. These sources will also be used to perform desk research.

In sub-question four we use conceptual model building to design the solution. Furthermore, we use verification and validation methods to assess the data that is used. This validation and verification will be done, using **simulation.** It is appropriate to use simulation in order to mimic real life situations. A simulation model is a simplified model of reality and is used to test out different production rules (Wein & Chevalier, 1992). We will create several experiments in order to search for a best alternative.

Then in sub-question five the conceptual model will be developed by expertise and literature. In order to assess the solution, we run several experiments. When the model is finished and potential losses are identified, some improvements can be recommended. These recommendations will be discussed with experts at HEINEKEN in order to create reliability during the implementation period.

To gather data and to perform an analysis a multifunctional team, consisting of experts and programmers, is composed. The diverse knowledge in this team make the analysis more efficient and more valuable.

In Figure 1.7 we show a summary that depicts the research methods by making a difference between academic literature & knowledge and current practices & knowledge at HEINEKEN .

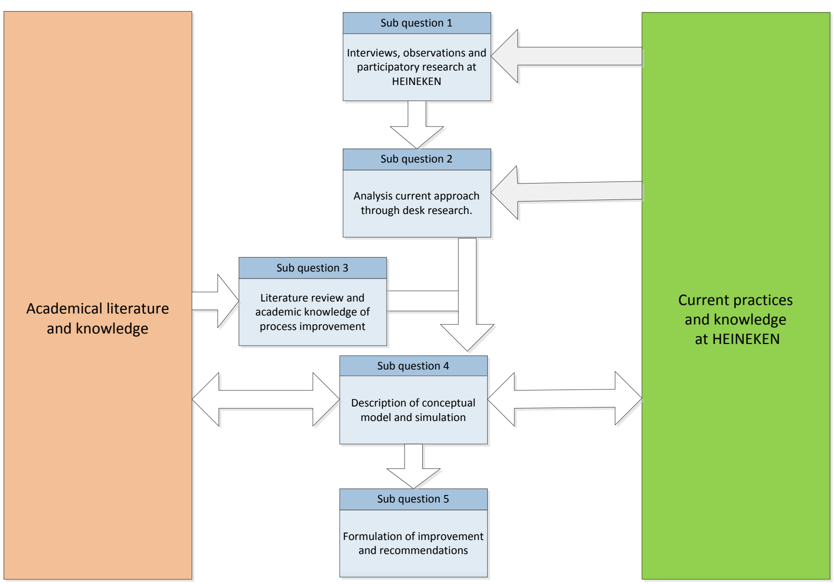

FIGURE 1.7: GRAPHICAL REPRESENTATION OF RESEARCH STRUCTURE

1.7 Research deliverables

- Process analysis.
- Data analysis.
- Insight into the operations of the regulated production line.
- Tool to visualize speed losses.
- Simulation model for production line 11, which can be used by the department of 'maintenance' and 'packaging' (when a product license is purchased).
- A guide that explains the concept behind the simulation model.
- An implementation plan that elaborates on the steps necessary to make the model operational.
- Recommendations for further research.

2. Process Analysis

In this chapter, we provide insight into the processes of packaging line 11. In Section 2.1 we explain the functioning of the different machines. Thereby we describe the functions of conveyors/buffers. The conveyors and machines are related with the sensors on the production line. All these separate components together are part of the line regulation and will be explained in Section 2.2. In Section 2.3 we narrow down on the definition of speed loss and how these losses occur. Also the impact on the technology is given. Followed by Section 2.4, where the performance measurement is highlighted. The measurement of performance is a preface for Chapter 3, where we determine the line performance.

2.1 Packaging line 11

Line 11 have been developed for the HEINEKEN Star Bottle (SB) which was introduced in 2013. Line 11 differs from other lines on several aspects. An aspect is that the SBs consists of returnable bottles, which means that they are recovered from the domestic market. Other lines (except Amstel, line 12) are one way bottles, these bottles are disposed by customers after consuming. The functioning of line 11 depends on the quality of the returned material. In this section the different machines with corresponding conveyors are explained. Furthermore the functioning of the buffers is described and we take a closer look at the structure of the production line.

2.1.1 Machinery

Line 11 consists of several machines. A brief description of the function of each machine is given below, in sequence from start to end. Thus the production process for the SB's starts at the depalletizer and ends at the foil taper. In Figure 2.1, all machines are displayed in a schematic overview. In this figure the green square represent the "wet area". The wet area consists of machines from the bottle washer till the CPLs (labeler). The management has argued that the most important machines of this research will be the filler, the pasteurizer and the CPLs. This will be proved in Chapter 3. Therefore only these machines are visualized.

Depalletizer:
The depalletizer removes the crates (returned from the domestic market) from the pallets, layer by layer, and drops it on the conveyor to the depacker.
De-packing machine (Decrater):
The depacker picks the empty bottles out of the crates. The bottles move to the bottle washer and the crates to the crate washer.
Bottle washer:
The bottle washer cleans the bottles. When the bottles are cleaned they move to the empty bottle inspection.
Crate washer:
The crate washer cleans the crates.
Empty Bottle Inspector (EBI):
At this stage, the bottles are inspected for being empty. Several pictures are made to ensure the bottle is clean according to predetermined standards. If a bottle does not meet quality standards it will be removed from the line. The bottles that pass the EBI will move to the filling machine.

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FIGURE 2.1: SCHEMATIC OVERVIEW PACKAGING LINE 11

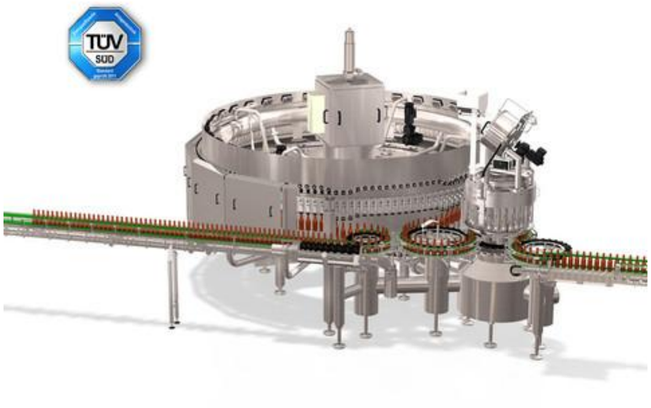

FIGURE 2.2: FILLER

__Fillers (or Filling machines):__
The fillers put the beer into the empty bottles and closes the bottles with a crown. A filler machine is shown in Figure 2.2.
__Full Bottle Inspector (FBI):__
The bottles are inspected again and are removed from the line if quality is not met. If the bottles passes the inspection they will move to the pasteurizer.

__Pasteurizer:__
In the pasteurizer the bottles are heated to deactivate all microorganisms and enzymes that can influence the quality of the beer, and to increase the shelf life. The cycle time of the pasteurizer is the largest of the whole line, with an average of 43.2 minutes. After the bottles are pasteurized, they will move to the labelers. The pasteurizer is shown in Figure 2.3.

FIGURE 2.3: PASTEURIZER

__CPLs/Labelers:__
The labelers stick three labels (front, back and the neck of the bottle). CPL stands for Cold glue Plastic Label. Again the bottles are inspected and, if necessary, removed from the line. The quality checks at this stage are strict, with a single deviation, the bottle will be removed. Perfectly labeled bottles move to the packer. A CPL machine with a detailed view on the labels is shown in Figure 2.4.

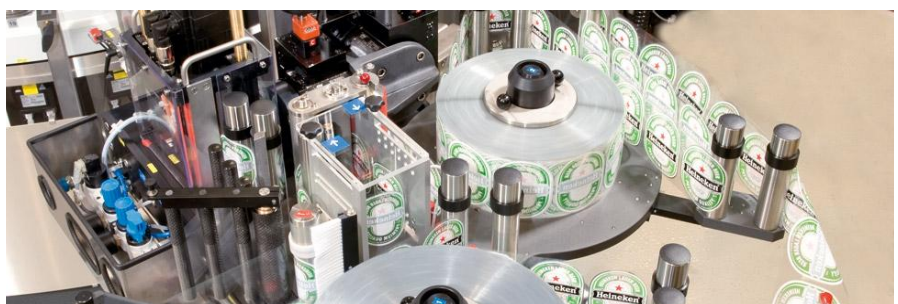

FIGURE 2.4: CPL/LABELER

__Packer (Crater):__
The packer puts full and labeled bottles

into a clean crate.

Cratecover:

The cratecover will put cardboard sheet on the upper side of the crate, covering the bottles (mostly with attractive marketing promotion). After this, the crates move to the palletizer.

Sorter:

Before the crates move to the palletizer, this machine spins (some of) the crates to optimize the way there are stacked on a pallet.

Palletizer:

The palletizer puts the crates on a pallet, layer by layer.

Sticker:

The sticker puts a foil and a label on the pallet. This label will be scanned and linked to an order in the information system. The system contains specific data of each pallet, such as the date of production and destination of delivery. When a batch needs to be retrieved from the market for some reason, HEINEKEN can easily detect the specific batch. At the end the pallet is ready to enter the market.

All these machines are connected with conveyors, what will be explained in Section 2.1.2. In Figure 2.5 we show the layout of line 11 where all the machines are exhibited. At the right side we show the depalletizer and sticker, these are the first and last machines. Therefore in front of the depalletizer there are pallets returned from the market, and after the sticker there are standing finished goods. This means that the department of Customer Service & Logistics (CS&L) with their Automated Guided Vehicles (AGVs) are located at the right side of this picture. AGVs are the vehicles that transport the pallets to and from the production line. This department is also responsible for the warehousing of the pallets.

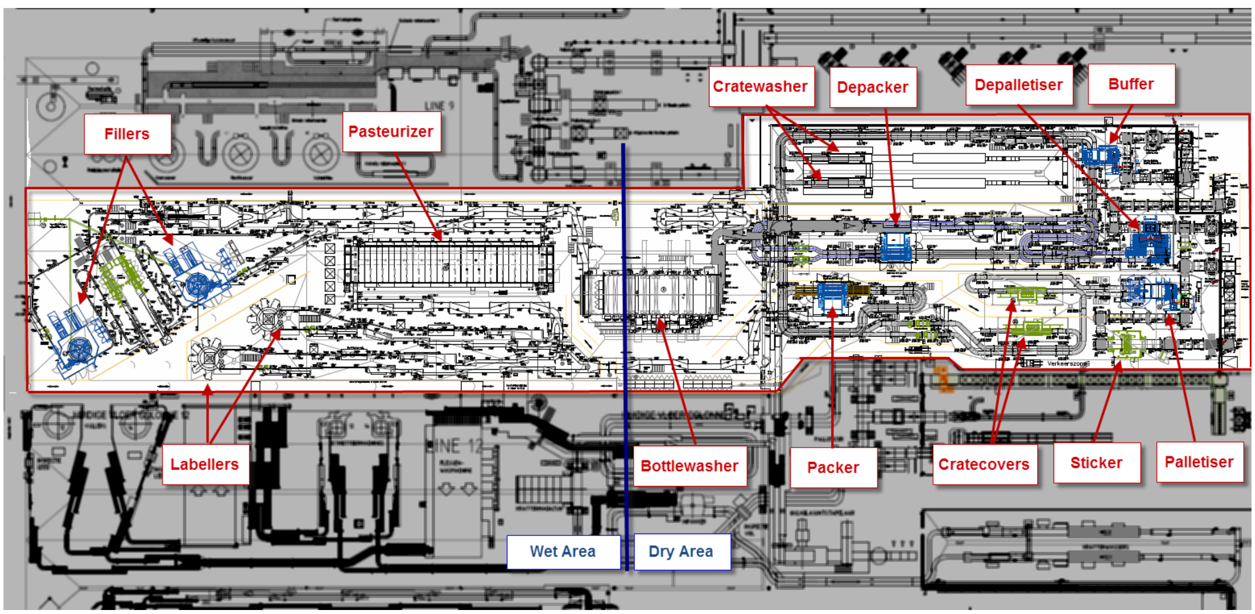

FIGURE 2.5: LAYOUT LINE 11

2.1.2 Conveyor/buffer strategy and sensors

Conveyors are used to transport the SBs from one machine to another. The conveyors have different sizes in width as well as in length. A conveyor can also be used a as buffer. A *buffer* is provided in order to cope with unexpected failures of the installation (machines), which may cause interruptions of the production process (Van der Duyn Schouten, Vanneste 1995). This is in line with the current situation at HEINEKEN where some conveyors are used as buffers. The speed (level) of a conveyor is predetermined and programmed into the IS. Mostly the conveyors have different speed levels in order to comply with the needs of the next conveyor/machine. The timing of switching speed levels is dependent of the occupation of the buffer (number of bottles on the conveyor). This can be measured by the use of sensors. In Figure 2.6 we show a picture of a regular sensor at line 11. On each conveyor one (or sometimes more) sensor is (are) located. The sensor is the metal 'arm' at the left side of the picture. These sensors are triggered with the presence of the SBs, the bottles will push the metal arm towards the left fence. Mostly the sensors are located in such a way that bottles will not directly trigger these sensors when arriving at the buffer. This happens when bottles stagnate and enumerate, due to the fact that machines further in the line are already stopped producing or when the machine is in failure as shown in Figure 2.7. The green bar at situation 1, is comparable with the two belts at the right side of Figure 2.6. The white bar, in Figure 2.7, is similar with the left belt in Figure 2.6. Mostly sensors are only triggered (yellow sensors) when the buffers are full *till* the corresponding sensor. Thus, when the succeeding machine is not producing, the bottles before this machine will enumerate, spread out and hit the sensor. When the upper bar in Figure 2.7 is full with bottles (green bar) the bottles are enumerated in front of the machine. There are two different kinds of sensors present on line 11: switches and photocells. A switch must be triggered physically with a bottle. A photocell beams a laser to a reflector and is triggered when the beam is interrupted by a SB.

FIGURE 2.6: SENSOR

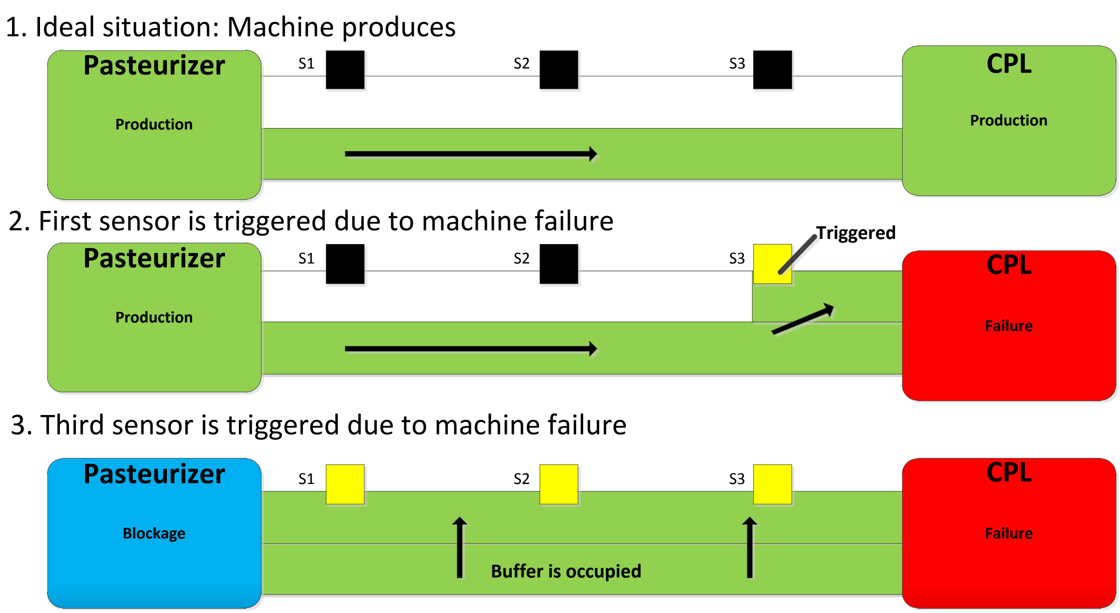

FIGURE 2.7: BEHAVIOR OF SBS ON SENSORS, WHEN BLOCKAGE ON PASTEURIZER OCCURS.

Figure 2.7 shows an example of how the sensors are located. In reality there are more sensors and conveyors placed between the pasteurizer and CPL. Furthermore the figure gives only a situation of blockage where the buffer is completely filled (situation 3). It is also possible that the buffer is completely empty and that the CPL has a starvation (no sensor is triggered) instead of a blockage as shown in Figure 2.7.

2.1.3 Different states of a machine

Since a machine is not producing all the time, there are several states that indicate the condition of the machine. A machine can be in different states, which are formulated below:

Producing: The machine is producing products. This could be with different speed levels.
Planned production stop: The machine is not producing due to planned maintenance.
Starvation: The machine is not producing due to a lack at the infeed. Mostly caused by failures of preceding machines.
Blockage: The machine is not producing due to a backup at discharge. Mostly caused by failures of succeeding machines.
Short failure: The machine has an internal or external failure with a duration ***less*** than 5 minutes.
Long failure: The machine has an internal or external failure with a duration ***longer*** than 5 minutes.
Unknown: The cause of the machine downtime is not registered. This state will be neglected in this research because the unknown time is nil. If this time arises it will be often a downtime due to a test.

A machine is either producing, or not producing for one of these seven reasons. Besides the distinction in short and long failure, there is a difference between an internal and an external failure. Internal failures are failures caused by the machine itself. External failures are failures caused from external factors, e.g. another department or bad quality of material.

In order to measure performance only on those aspects that are relevant for production line 11, some aspects will be neglected. The aspects that we neglect are the unknown state, the planned production stop and the external failures. The unknown state does not consist of valuable information and mostly arises when a test takes place. The planned production stop is necessary and is known beforehand, this aspect will not influence the performance of the production line. The external failures are not taken into account. These failures are caused by other departments but do have an influence on the performance of line 11. External failures could also arise by bad quality of material. Nevertheless, this research focuses on the machine/conveyor efficiency and not on material quality.

MES

In order to register all the different machine states and create visibility among the machine conditions, HEINEKEN uses the information system called MES. A print screen of the machine status of a 8-hour work shift is given in Figure 2.8.

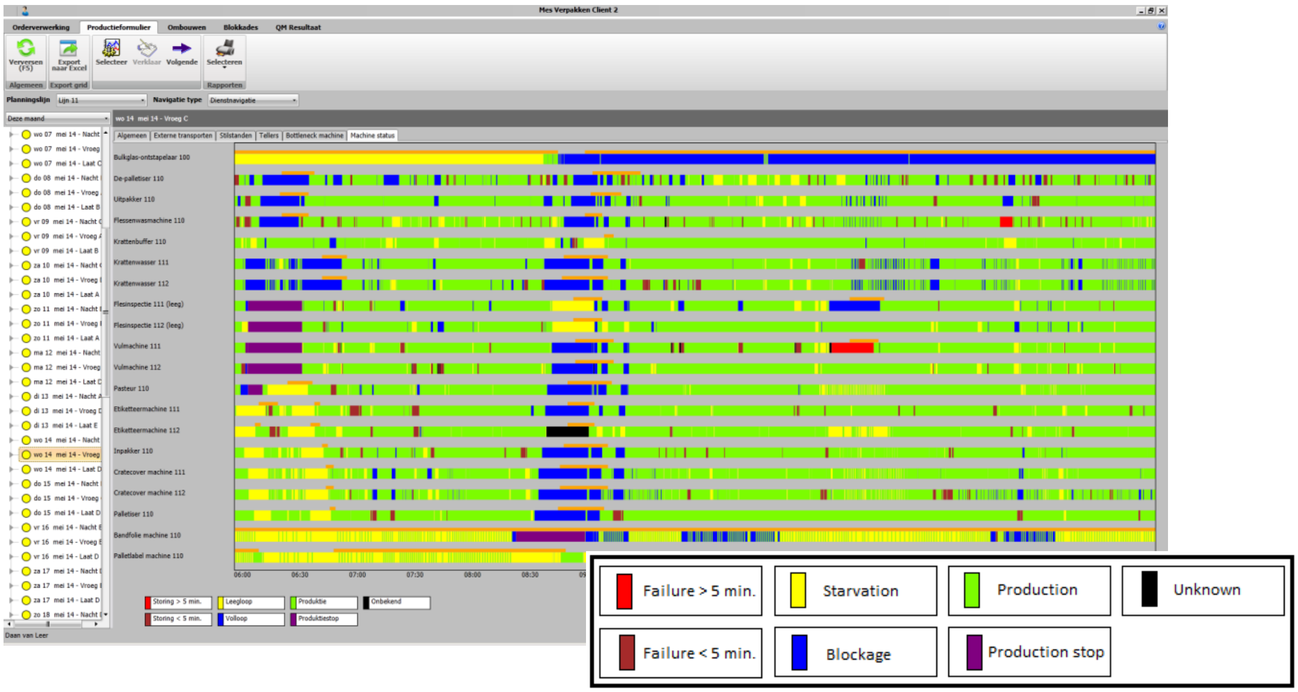

FIGURE 2.8: MES DNA STRAND - 8 HOUR WORK SCHEDULE

2.2 Line regulation

At this moment we described the machinery/conveyors and the different machine states. In order to create a continuous flow among these machines/conveyors, the packaging line uses line regulation. Line regulation is the overall term for speed changes and speed levels on different machines. First the term speed control is explained followed by determining at what moment the machines will produce and at what speed. At the end of this section we introduce the theory of the V-graph.

2.2.1 Speed control

In order to control the machine's speed level, HEINEKEN makes use of sensors located on the conveyors. The location and/or combination of the sensors play an important role by determining the efficiency of a machine. Considering Figure 2.9, one can see a simplification of sensors located on a conveyor around the CPL. Here s1, s2 and s3 are sensors placed before the CPL and s4, s5 and s6 are placed after the CPL.

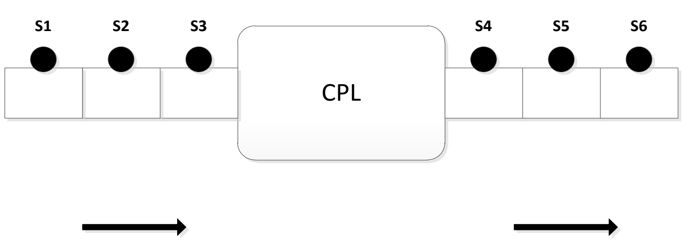

FIGURE 2.9: SIMPLIFICATION OF SENSORS AROUND CPL

Each sensor manages a conveyor belt, which means that in the illustration there are also three conveyors before and three after the CPL (illustrated as separated blocks). The sensors before the CPL will regulate the starvation of the CPL. They measure the input quantity of the CPL, thus if there are enough bottles available that should be labeled. On the other side of the CPL, the sensor measures the output and therefore if there is no blockage.

Figure 2.10 shows three situations that indicate three different states. These three states are exhibited: 1. Production, 2. Starvation and 3. Blockage.

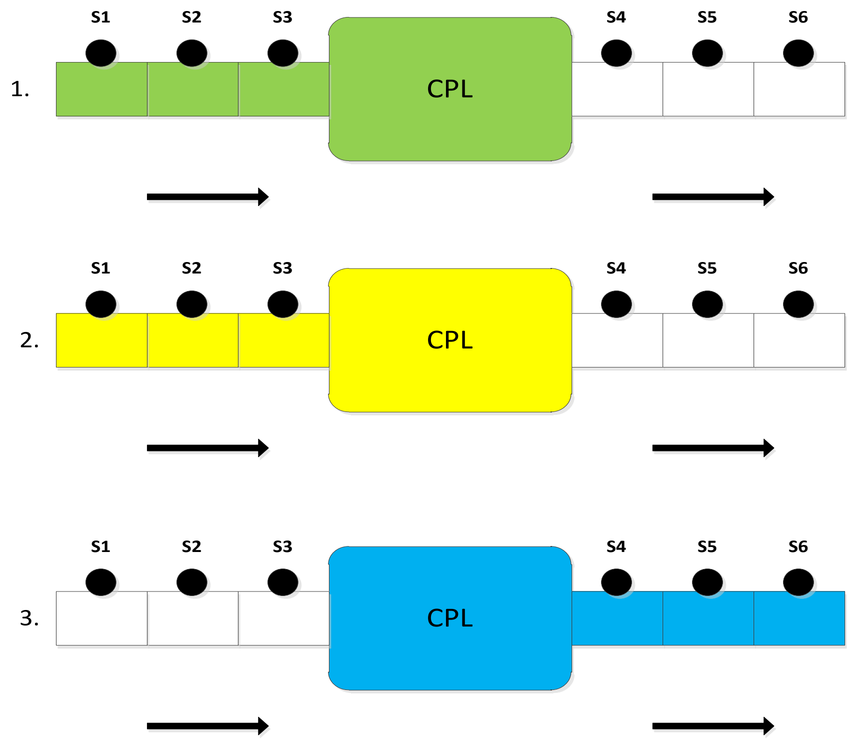

FIGURE 2.10: SENSOR POSITIONS IN 1. PRODUCTION 2. STARVATION 3. BLOCKAGE

In an ideal situation there are always bottles available at the in feed and there is no backup at discharge. In the first situation this perfect scenario is given, all input sensors (s1,s2,s3) are triggered by bottles and the output sensors are free (no bottles at the conveyor). In situation two the CPL has no bottles so sensors s1,s2 and s3 and not triggered, hence the CPL will not produce. Also in situation three the machine is down because sensors s4, s5 and s6 are triggered by bottles which create a blockage. The colors of this image are equivalent to those of MES. Green is production, yellow is starvation and blue is blockage.

Line regulation endeavors a continuous flow on the production line, which is favorable according to the philosophy of KHS. Multiple sensors accompany multiple conveyor belts. Besides, multiple sensors should be available to create different speed levels. Some sensors are directly linked to the speed level of the machine. The location (first, second or third) of the sensor has a correlation with the speed level of the machine.

The start/stop of a machine can *also* be regulated by just one sensor before and one after the machine. When the sensor before the machine is triggered and the one after is not, the machine should produce (otherwise it should not). The disadvantage of this approach is the fluctuating activity of a machine, because there is just one sensor. This leads to more start/stop situations compared to a situation where more sensors are located. In Section 1.1, KHS stated that reducing start/stop situations will reduce losses.

We can conclude that start/stop situations should be avoided, what will be achieved when a continuous flow is created. To create a continuous flow, several sensors and speed levels are necessary on the machines at the production line.

2.2.2 Speed levels

As mentioned in the previous section, speed levels are correlated with the location of the sensor. We continue with the situation from Figure 2.10. The situation is explained after the machine is repaired, see Figure 2.11. This figure shows three sensors, and we assume that every sensor has a relationship with the CPLs. This means that every sensor triggers a speed level at the CPL. In the coming figures we assume that the CPLs have three speed levels: full (or max), nominal and low (or half). It is not usual that a machine has more speed levels. For example, the pasteurizer has only one speed level.

Again consider Figure 2.11. The conveyors are occupied which mean that s1, s2 and s3 are triggered. Now, the machine needs to reduce the buffer as quickly as possible to prevent a blockage of the pasteurizer. Therefore, sensor s1 is linked to the CPL and sends the message to produce at full speed. In order to control the continuous flow and prevent start/stop situations, the speed level of the CPL will reduce when s1 is not triggered any more. The same holds for sensor s2 and s3. When even sensor s3 is not triggered anymore the CPL will shut down. The reason for reducing this buffer, even when the pasteurizer is producing, is the fact that the CPL has a higher production capacity per hour than the pasteurizer, if the CPLs are producing on full or nominal speed. We will explain this in Section 2.2.3. The maximum, nominal and low speed is different per machine and is therefore not exact. In Chapter 3 we will mention the exact speed level(s) of the machines.

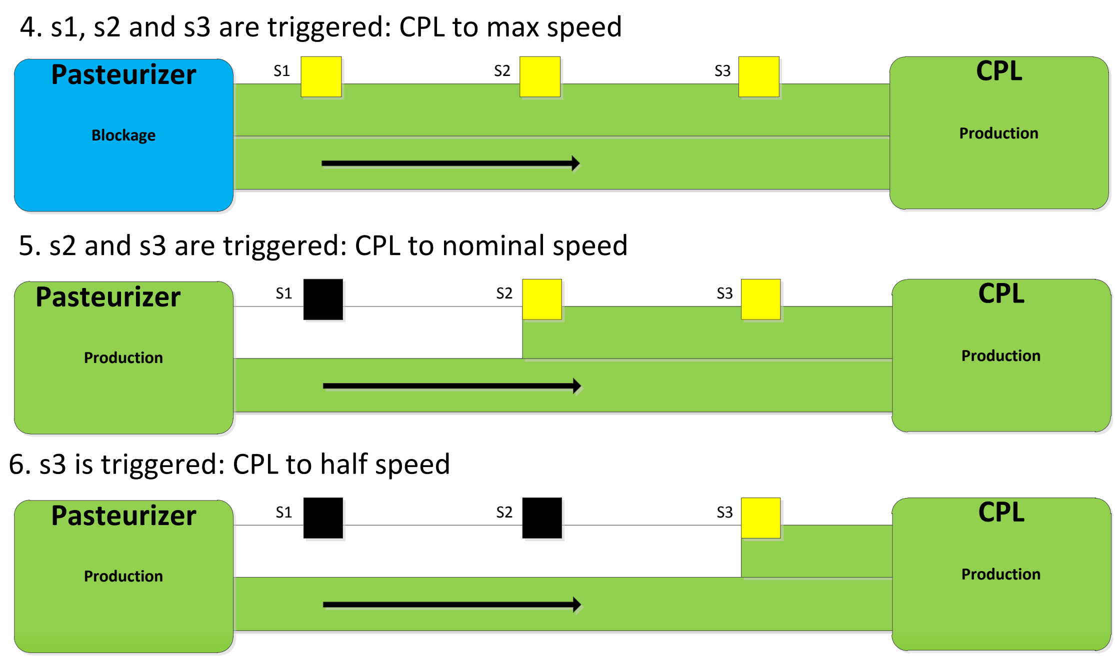

FIGURE 2.11: CORRELATION BUFFER & MACHINE SPEED

2.2.3 V-graph

The figures in the previous section only show a small selection of the whole production line. As explained during the layout one can see that there are several machines. A main task to enhance the performance is that buffers should be cleared in order to prevent blockages and should be filled in order to prevent starvation. To fulfill this task, the machines should react on each other and speed levels should enhance the continuous flow, with the help of sensors. To control the situation, HEINEKEN uses the theory of the V-graph in order to establish the predetermined speed levels for all machines.

Härte (1997) stated that the V-graph is a theory based on the bottleneck machine, which contains the bottom of the V. Härte (1997) stated that: *"The machines on either side of the core machine have extra capacity to restore the accumulation after a failure has occurred"*. This overcapacity increases for machines that are located at a larger distance from the core machine. Theoretically, the machine with the lowest capacity, the *core machine*, on line 11 is the pasteurizer with a capacity of 80,000 bottles/hour. This means that the capacity of the machines before and after this core machine should be higher. Meaning that the de-palletizer and foil taper (as can been seen in the first and last machine in the line) must have the highest capacity of the line. The V-graph is developed to cope with machine failures thus when there is no machine failure, the graph will be flatten. The theory of the V-graph ensures that the core machine has enough bottles as input to prevent the lack at infeed, and the machines after the core machine will have a higher capacity in order to prevent backup at discharge.

A core machine can also be called the bottleneck machine, if it has in reality also the lowest capacity. The situation can occur that the core machine is not the bottleneck machine. For example, if the filler has a high failure rate and therefore produces less than the 80,000 bottles/hour of the pasteurizer. Then the filler is the bottleneck machine and the pasteurizer is the core machine. So the core machine is theoretically the machine with the lowest production capacity and the bottleneck machine is operationally the machine with the lowest capacity.

Losses made by the bottleneck machine cannot be corrected by other machines. Thus a loss on the bottleneck machine is a direct loss on total line performance.

In order to determine the bottleneck machine, Härte (1997) introduced the Mean Efficiency Rate (MER). In Figure 2.12 we show an image where the machine capacity is compared with the Mean Efficiency Rate (MER). The machine efficiency rate is calculated with the following formula:

$$MER = \frac{Production\ time}{Production\ time + internal\ failure\ time} * Machine\ capacity$$

The production time plus the internal failure time is the actual time that the machine could produce, so the machine's ***availability***. This proves that the core machine is not the same as the bottleneck machine. Every machine could be the bottleneck machine, dependent on the internal failure time. The machine with the lowest MER is called the bottleneck machine. Note that in Figure 2.12 the bottleneck machines is the filler.

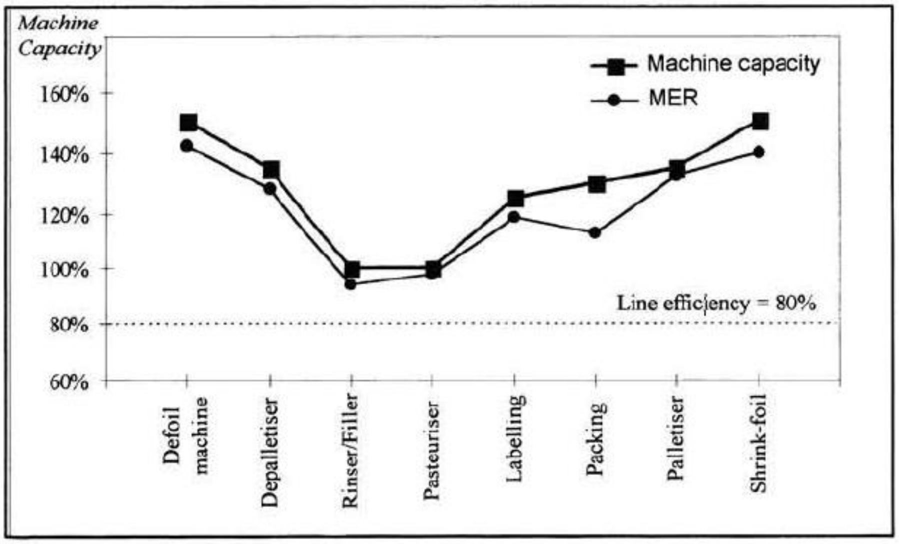

FIGURE 2.12: V-GRAPH: MACHINE CAPACITIES, MER AND LINE EFFICIENCY (Harte 1997)

Regarding the theory of Härte (1997) the V-graph developed by the supplier of the line is given in Figure 2.13. Here 1 (=100%) is equal to the theoretically capacity of 80,000 bottles per hour of the pasteurizer. This is also called the *nominal speed* of the production line. Thus the nominal speed is the speed of the core machine. The pasteurizer is located at the bottom of the V-graph and represents the core machine.

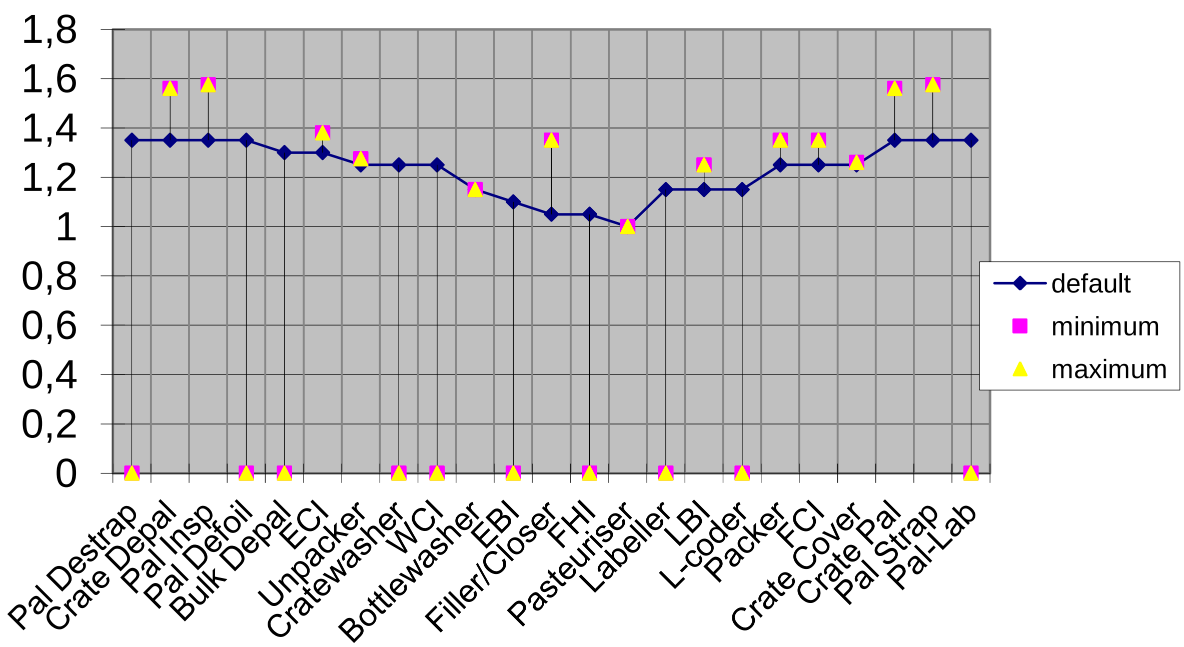

FIGURE 2.13: V-GRAPH LINE 11 (BY KHS)

As shown in Figure 2.13, every machine has a higher default speed than the pasteurizer. For example, the filler is calculated to have a higher capacity of 5% relative to the pasteurizer, and for the CPLs (labelers)

this is 15%. Therefore the capacity of
- The pasteurizer is 80,000 bottles/hr.
- The fillers is 1.05*80,000 = 84,000 bottles/hr. This is 42,000btls/hr per filler.
- The CPLs 1.15*80,000 = 92,000 bottles/hr. This is 46,000btls/hr per CPL.

The minimum and maximum speed levels shown in Figure 2.13 are related to the machine capacities of KHS in general. This speed levels are neglected in our research.

A side note for line 11 is that not the pasteurizer but the filler determines the nominal speed. The speed of the pasteurizer is hard to measure, because no counters are available on the pasteurizer. Besides the filler has a higher failure rate than the pasteurizer. This can result in a situation where filler is the bottleneck machine (if other machines work normal). HEINEKEN determined, from the practical point of view, to measure the performance on the fillers.

2.3 Speed loss

Speed loss is one of the losses considered by Nakajima (1991). Speed loss is defined by the losses due to reduced speed of a machine during operations. Speed loss arises from the fact that a machine has different speed levels. There are two terms that will cover a machine's speed usage. Machines produce dichotomously or continuously. Dichotomous production means that a machine has only two speed levels, not producing (0%) or producing (100%). Where continuous production can have different speed levels between the 0 and 100%. To clarify, a machine that is down or up (0-100%), so *without* different speed levels, does **not** have speed losses but has blockage, starvation, failures or planned downtime. A machine *with* different speed levels can create speed losses when it produces on a lower speed than the nominal speed. Important to know is that speed loss is a machine state (Section 2.1.3.), but is not mentioned before because HEINEKEN's information system is not capable of measuring this continuous state correctly. Considering the V-graph, some machines have an overcapacity. This is called the maximum speed, which is therefore higher than the nominal speed.

Example (maximum speed is not included):
- a machine runs for 3 minutes on 75% of the nominal speed
- the nominal speed is 80,000 bottles per hour (on line 11; the pasteurizer)

Then:
(100-75%) * 80,000 = 20,000 bottles per hour
for 3 minutes = 3/60 * 20,000
Speed loss = 1000 bottles

Speed loss is defined as the *number of bottles produced under the nominal speed minus the number of bottles produced above the nominal speed*. The speed loss cannot be negative because the nominal speed of the production line determines the output. An example is given below.

For HEINEKEN it is important to realize what amount of bottles they miss due to speed loss. HEINEKEN compares the different production lines with each other to measure the performance and set targets. When the speed losses of line 11 are not taken into account, an incorrect comparison is made and targets can be misplaced.

Technology

Negative about introducing different speed levels is that the information systems of HEINEKEN, including MES, do not match with the technological needs. This means that, looking at the DNA strand in the IS as shown in Figure 2.14, it cannot be perceived whether a machine is producing continuously.

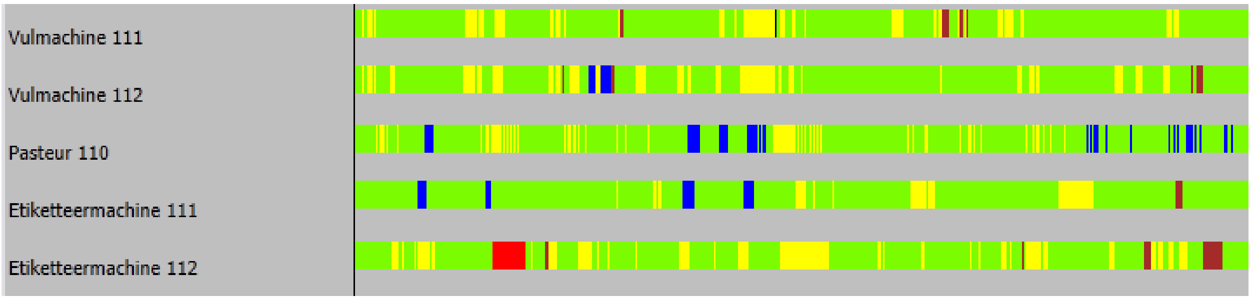

FIGURE 2.14: MES - DNA STRAND

The problem is that a machine can run for 10 minutes on 10.000 bottles/hour but can also run for 1 minute on 110.000 bottles/hour and have a failure of 9 minutes. According to the DNA strand option 1 will be preferable because the strand is all green (option 2 is almost fully red). Nevertheless, looking at production quantity option 2 is better, because of a higher output. However, first the speed loss of production line 11 should be made visible, then problems can be detected.

2.4 Measuring Line Performance

HEINEKEN uses the *Operational Performance Indicator (OPI)* as measure for its packaging performance per production line. In Figure 2.15 one can find the calculation of OPI which is explained below. OPI exists of three main components and its formula is given below:

$$\boldsymbol{OPI = Availabilty * Performance * Quality}$$

Where the availability is explained in Section 2.2.3. This can also be given as

$$Availabilty = \frac{Operating\ time}{Manned\ time}$$

The performance is calculated with the following formula:

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

The production time is the time needed for producing the total number of products (good product + reject and rework). The operating time is the production time + the speed losses and minor stoppages. Where the minor stoppages are the failures of a machine less than 5 minutes.

The quality is defined as the fraction needed to produce the 'good product'. This is the time needed to produce the actual output divided by the production time (= good product + reject & rework). The formula is shown below:

$$Quality = \frac{Theorethical\ prodution\ time}{Production\ time}$$

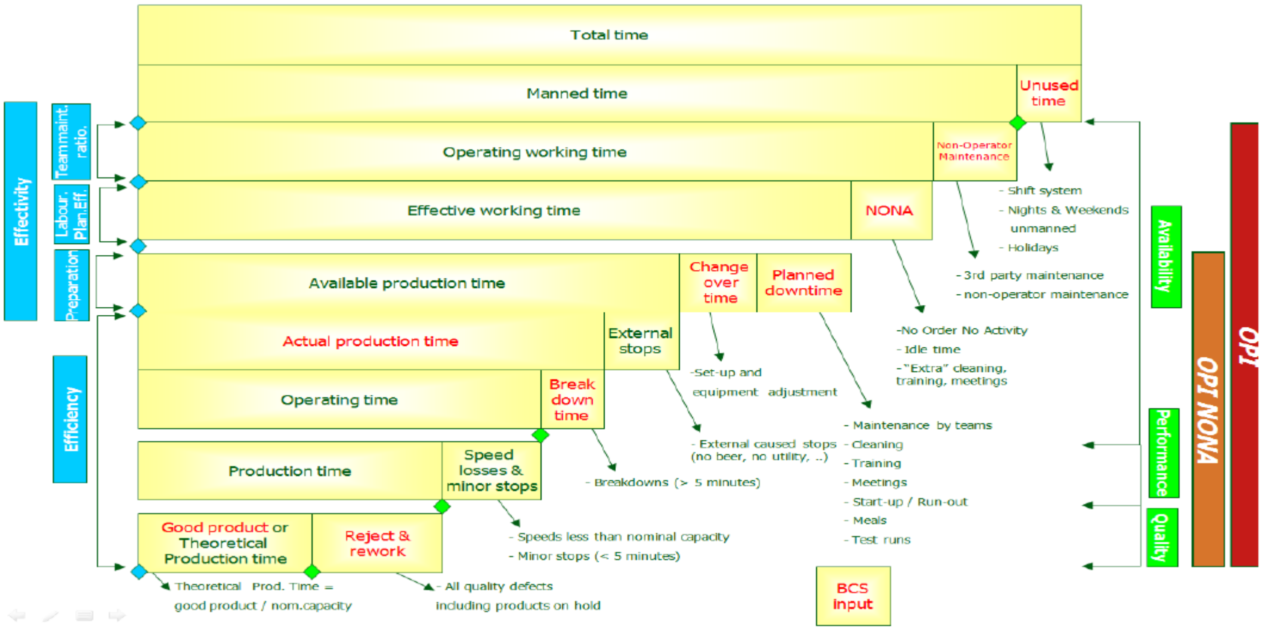

FIGURE 2.15: CALCULATION OPI

HEINEKEN uses also the OPI to determine the performance of line 11. Nevertheless one can see in Figure 2.15 that it also includes the external stops, changeover and planned downtime. As mentioned earlier, these factors have no direct influence on the machine efficiency and the line regulations. For example, considering department *Customer Services & Logistics (CS&L)*. The situation occurs that an Automated Guided Vehicle (AGV), a vehicle that is computer controlled and stores the pallets into the warehouse, is in failure. Then this failure is for line 11 an external failure because the depalletizer (last machine in line) is in blockage. It therefore decreases the OPI, even when all machines operate perfectly. For that reason these external stops are neglected in this research. Even the changeover time is neglected because line 11 produces just one product, so no changeovers take place. At last the planned downtime (e.g., maintenance) will be neglected because it will not influence the machine efficiency *during* production. It does not mean that planned downtime is not important, because with no maintenance the production performance reduces excessive.

This research focuses on improving the line performance. For that reason the focus is on the *performance* component. Therefore the minor stoppages and the speed losses are the main focus in order to improve the current situation. These minor stoppages will influence the whole production line, which results in different losses. These are shown in MES as the machine states other than the production state (described in Section 2.1.3).

In order to focus on the performance measurement, the production time should be considered. The issue arises that the production time says nothing about the output quantity because of the fact of different speed levels. When the machine produces for 100% of the time at 10% of the capacity, the performance will be 100%. Therefore the line performance should consider the output of the machines and compare these numbers with the production time. Line performance is therefore measured as:

$$Line\ performance = \frac{Production\ quantity}{Operating\ quantity}$$

Where operating quantity is the number of product that *could* be produced in a certain period. Production quantity is the number of 'good products' that are produced.

Summary

After reading this chapter we have a clear thought about the production line 11. We know what machines are located on the production line. Furthermore the functioning of the sensors is explained and the different machines states are described. The theory of the V-graph is given with the explanation of the speed losses. We know that the technology of HEINEKEN does not fit with the speed levels which are implemented by KHS. In the next chapter we discuss the different data of the production line and focus on the losses.

3. Data Analysis

An overall view of the layout and the philosophy of packaging line 11 was given in the previous chapter. Based on these findings the current performance of the line will be determined. In Section 3.1 we show the V-graph of the current situation. Further the problem scope will be narrowed down to create a structural approach to detect the specific problems. In Section 3.2 we describe the problem in relation with the layout. In Section 3.3 we will summarize both sections.

After this chapter the focus of the problem on line 11 should be clear in order to improve the line performance. As been mentioned in the research scope, the focus will start on a few machines. According to the management and operators opinions the scope should be between the bottle washer and the CPLs, because problems arise in this area.

3.1 Line Performance

As the V-graph is an important philosophy at HEINEKEN, it is relevant to sketch the current situation according to the theory of Härte (1997). In Figure 3.1 we show the V-graph. The blue line, with corresponding rhombuses, represents the capacity of a machine when the line produces normally. It can be stated that the pasteurizer is the core machine since it has the lowest capacity. Therefore the other machines should have a higher production capacity. The red line with corresponding triangles represents the MER, as explained in Section 2.2.2. The graph is expressed in an average amount of crates during an 8-hour production shift.

Availability x minimum capacity = (production time + starvation + blockage) x minimum capacity

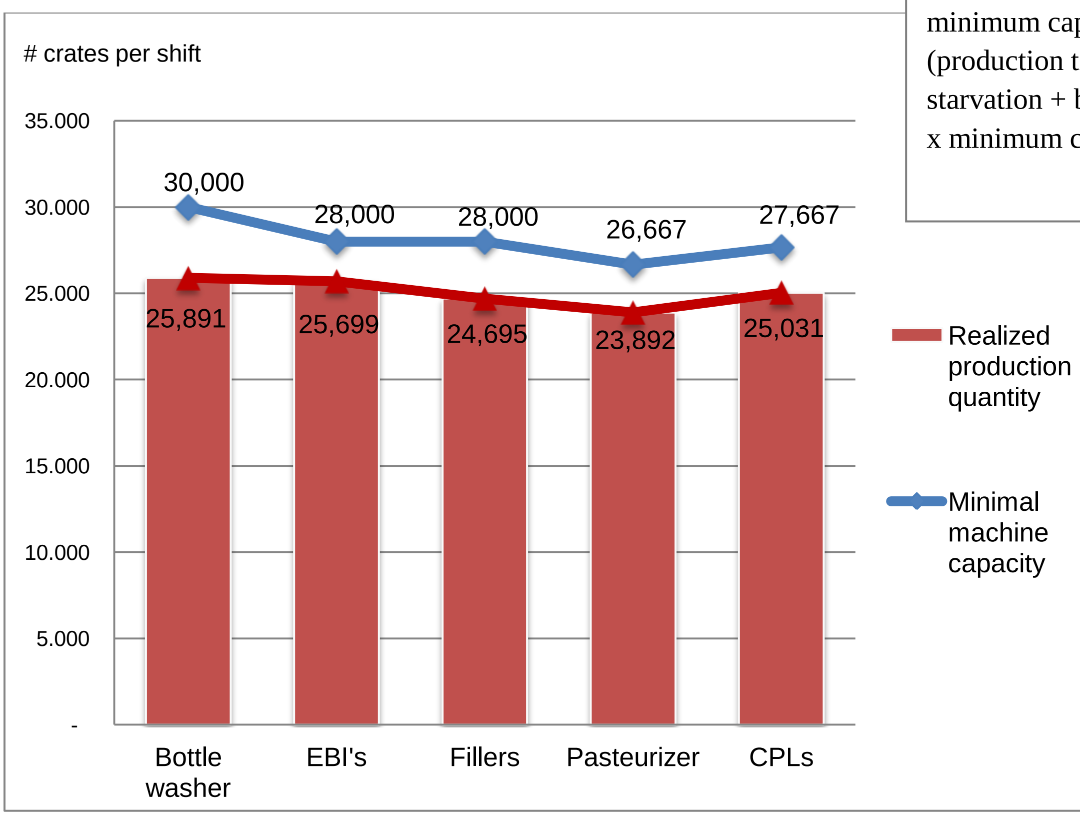

FIGURE 3.1: V-GRAPH CURRENT MACHINE PERFORMANCE (AVERAGE)

According to Figure 3.1 we can conclude that the pasteurizer is the machine with on average the lowest realized production, and is therefore the bottleneck machine. This is consistent because the pasteurizer has the lowest machine capacity. In order to improve the output quantity and therefore the line performance, it is necessary to further improve the machine with the lowest realized production quantity (Härte, 1997). It is not efficient to focus on the other machines, because improving these will not lead to a constant higher output quantity of line 11. The bottleneck machine determines the output quantity of the production line and therefore further analysis has to be done.

First the number of times that the pasteurizer is the bottleneck machine has to be determined. There is a possibility that the average production quantity is influenced by outlying work shifts. The variation in production quantity of the pasteurizer should be excluded to make the data valid and reliable.
In Figure 3.2 we show the number of shifts when a certain machine is the bottleneck. The left figure shows the number of times a machine is the bottleneck at all shifts from 1 July '14 till 31 August '14. The total amount of shifts is 100 whereof 30 shifts above 19,000 crates. The right figure shows the shifts that are above the 19,000 crates in the same period. Shifts above 19,000 crates are defined by HEINEKEN's management as the performance target of production line 11 (line performance of 71%).

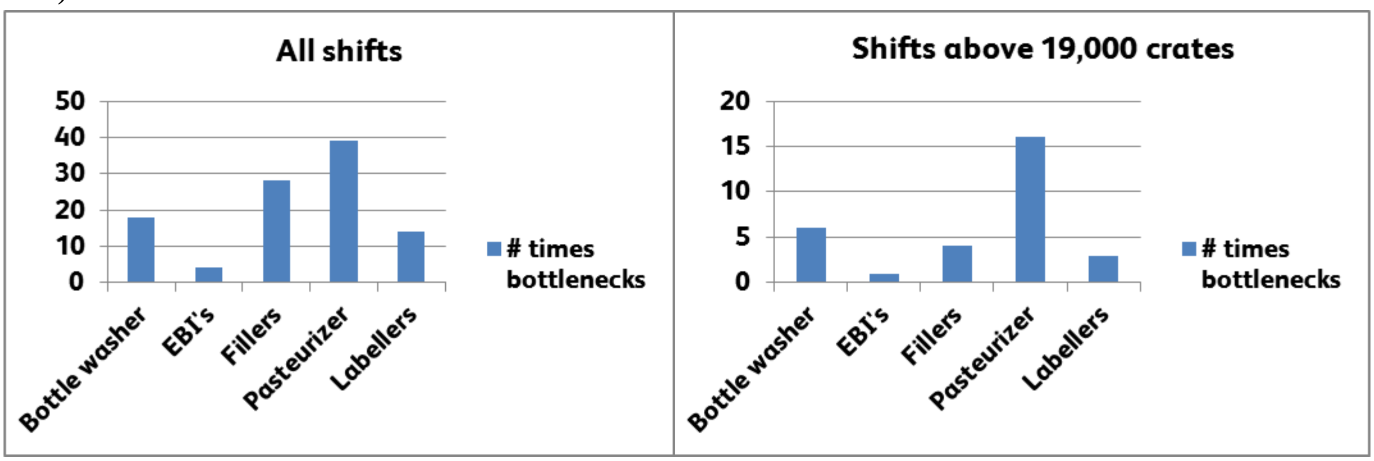

FIGURE 3.2: NUMBER OF TIMES THAT A MACHINE IS A BOTTLENECK – TOTAL SHIFTS: 100/ ABOVE 19,000 CRATES: 30

The following conclusions can be made from Figure 3.1:

- The bottle washer scores worst on machine efficiency. The biggest gap between machine capacity and operational production is on the bottle washer.
- The fillers score second worst.
- Including the internal failures the pasteurizer is still the bottleneck.

The following conclusions can be made from Figure 3.2:

- Considering all shifts, the pasteurizer is 33% more often the bottleneck than the fillers and more than 50% compared to the bottle washer.
- Fillers are less often the bottleneck machines when shifts are above 19,000 crates (5/30=16,67%) compared with all shifts (29/100=29%).

Considering the conclusions we could focus on the bottle washer, the fillers, the pasteurizer or a combination of these. According to Härte (1997) the focus should be on improving the bottleneck machine. Therefore and because of the following reasons, we choose to focus on the pasteurizer:

- The efficiency of the bottle washer depends of the quality of the returnable materials from the market. The biggest problems at the bottle washer arise from falling bottles. When the quality of the returned material is bad, more bottles will collapse. When bottles collapse they will block the entrance of the bottle washer, whereby the utilization of the bottle washer is below standard. This problem will be solved by starting a ‘Break Down Analysis’, which is not part of this research.
- The inefficiency of the bottle washer arises because crates from the market are not filled completely. The capacity of the depacker is based on crates with 24 bottles, which is often not the case. This reduces the efficiency of the bottle washer. The management of HEINEKEN is busy with solving this problem by introducing a new sorting machine.
- The bottle washer covers a relatively high position in the V-graph. This means that when the quality of the material meets the expectations, the bottle washer will not be the problem.
- The fillers are considered to be the most important machines of the production line. HEINEKEN has a close relationship with KHS in order to optimize the use of these fillers. The failures of the fillers have the most influence on the efficiency of the fillers. Focusing on the failures of the fillers will lead a mechanical approach. Besides, KHS is nowadays constantly looking for improvements on these fillers. When we focus also on the fillers, our interests could struggle and measurement can be become invalid.
- At the end, the pasteurizer is the bottleneck machine. When improvements are made on this machine, it will directly positively influence the line performance.

According to Härte (1997) the focus should be on the bottleneck machine and according to Nakajima (1988) companies should reduce their losses in order to improve the line performance. Therefore we focus on the losses of the pasteurizer. These losses are shown in a pie chart in Figure 3.3.

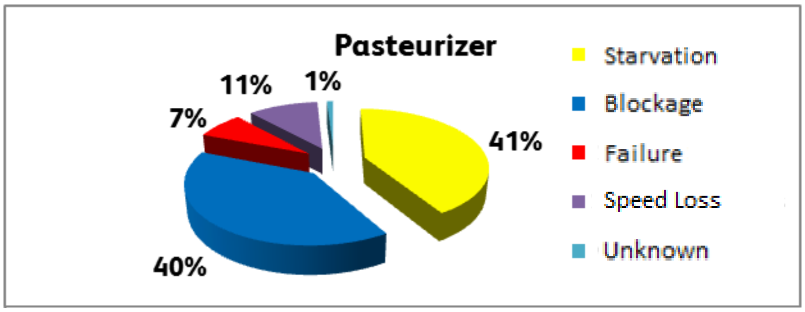

FIGURE 3.3: LOSSES PASTEURIZER

Up to now we have considered the bottleneck machine by determining the machine efficiency. From here we can determine the efficiency between the machines, the conveyors and corresponding sensors. According to the management of HEINEKEN, this part is forgotten most of the time. The management looks only at the machine efficiency, because the efficiency of the conveyors and sensors is not registered in their information system (e.g., MES). To determine the efficiency between machines, MES can be considered and a special speed loss tool can support the correctness of MES. This tool will be explained at the end of this section.

We focus on the pasteurizer and look further at the efficiency from the filler to the CPLs. Again consider Figure 3.3. As one can see, the biggest losses on the pasteurizer are starvation and blockage. The starvation and blockage of a machine occurs due the fact that other machines are in failure. Nonetheless there could be other aspects that determine the length and reason of a starvation and blockage. For example, if sensors are not aligned efficiently with the machines. For that reason an analysis is done to determine the starvation and blockage of the pasteurizer. This can easily be done with the DNA strand from MES. In MES, the relations of the machines are clearly visible. Furthermore, to validate the information in MES, it should be compared with real-life situations at the production line. Different DNA strands of different work shifts are analyzed and we show an example of a remarkable situation in Figure 3.4.

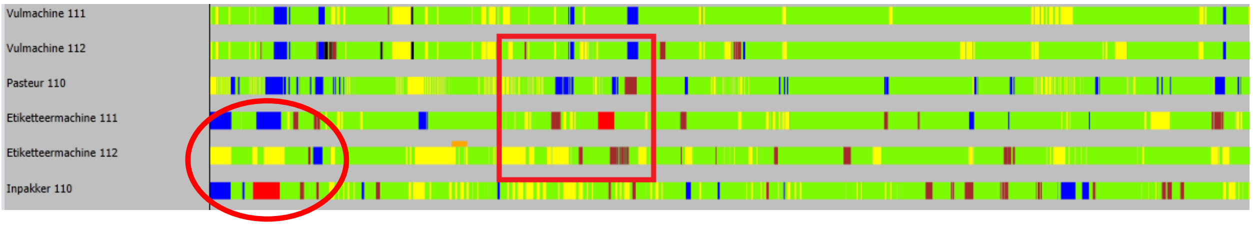

FIGURE 3.4: MES DNA STRAND (EXPLANATION BLOCKAGE PASTEURIZER)

In Figure 3.4 two inefficiencies are shown. The first one, specified with the red circle, shows that the packer is in failure. When the packer is in failure, both CPLs should create a blockage after the buffers between CPLs and packer are filled. But as situated in the red circle, CPL112 has created a starvation state. This means that the *Programmable Logic Controller* (PLC) measures the wrong indicator or MES translates the wrong message. A PLC is "a digital computer used for automation of industrial electromechanical processes" (Lin, S., Huang, X. 1998). This means that a PLC measures predetermined variables and indicators on the production line itself, this can vary from the number of bottles produced till the amount of detergent in a bottle. This will be translated by MES in order to make it visible for operators and the management. The registration fault can be present on both situations. Furthermore the red square presents a huge inefficiency. As stated in before mentioned sections, a blockage/starvation on the pasteurizer results in a direct loss in output quantity. In Figure 3.4 the red square shows such a direct loss. CPL111 is in failure, CPL112 is in starvation and the pasteurizer is in *blockage.* When the pasteurizer is in blockage, a CPL may *never* be in starvation. In this situation the production of CPL112 could prevent that the pasteurizer will create blockage, and therefore prevent a loss in production quantity. This loss in production quantity has an average of **5 minutes**. This is based on an analysis of MES where all strands of the past two months are considered. Some examples of those strands are shown in Appendix A.

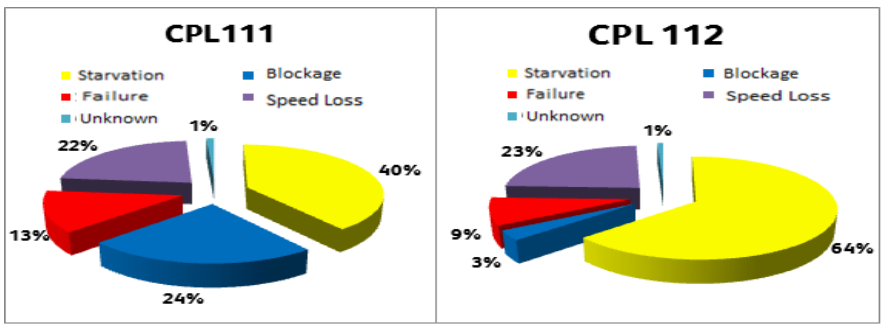

FIGURE 3.5: PERCENTAGE OF LOSSES CPLS

Comparing these red shapes we can see a difference. The situation given in the red square is *not* a measurement or translation error, such as the red circle. We can conclude this by looking at the state of the packer. Consider the DNA strand of the packer ("Inpakker110" in Dutch) shown in Figure 3.4. Below the red square the packer is in the starvation state. This means that the packer has no bottles at infeed. For that reason it is valid to say that CPL 112 has to be in starvation mode too. This is different from the red circle, where CPL 112 should create a blockage state because the packer is in failure. We can conclude that the situation in the red square is not a translation error as shown in the red circle, but a loss in production due to inefficiencies. The red square shows that the blockage of the pasteurizer arises from inefficiencies on the CPLs. The losses of the CPLs are shown in Figure 3.5 to brighten these inefficiencies. Three remarks regarding these losses/inefficiencies are explained below.

The **first** thing to notice is the large starvation percentage (64%) of CPL 112 and the small blockage percentage (3%). This is in line with the situation we show in the red circle (Figure 3.4), this problem arises from the fact of an error in data storage. From this point of view it is hard to define the losses on CPL112 regarding the starvation and blockage. Expected is that some of the blockage time is measured as a starvation time, in MES. Comparing the real-life data on the production line with the registered data in MES, it can be stated that the regulation of CPL112 does not operate efficiently. This inefficiency is described in Section 3.2. After noticing the incorrect regulation of CPL112 also the data registration of CPL111 is checked by experts. Nevertheless, the registration of the data of CPL111 works correct when the real-life data and the data in MES are compared. For that reason we consider that the blockage and starvation percentages are valid.

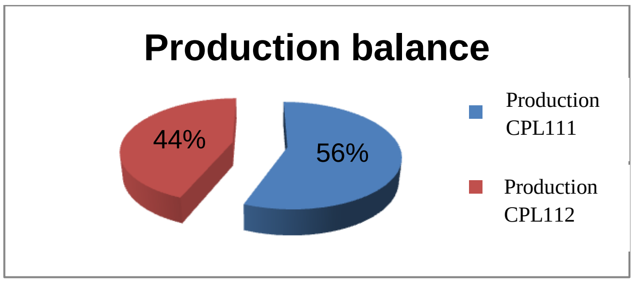

FIGURE 3.6: PRODUCTION BALANCE CPLS

The **second** inefficiency is the difference in production quantity of the CPLs. The production quantity of both machines is given in Figure 3.6. This difference is another argument for the inefficiency of the area from the pasteurizer and the CPLs. The maintenance schedule of production line 11 is for parallel machines exactly the same, so also for both CPLs. The activities that should be done for operators are called CILT activities. CILT stands for **C**leaning, **I**nspection, **L**ubrication and **T**ightening. These activities are unequal because CPL111 produces more bottles than CPL112. For example, when we consider parts that should be replaced after 1000 production hours. The production hours of the CPLs are based upon the number of parts that are produced, measured in output quantity. This amount of parts is divided by two to calculate the parts produced per CPL machine, because the maintenance department assumes that both CPLs will produce the same amount. Thus the maintenance department creates their maintenance schedule based on equal production. This means that in the current situation at the CPLs problems arise. Parts on CPL111 are changed too late and parts on CPL112 are changed while they are in good condition. In Appendix J we show the differences per CPL, registered by operators.

The difference in production quantity of Figure 3.6 emerges for different reasons. In order to prevent that some aspects are overlooked and to determine the reasons for the unbalance we organized a brainstorm session. This session is done in the presence of the operators which are familiar with the packaging process and problems encountered with this process.

The **third** inefficiency is empirically observed at the production line. When CPL111 starts producing it takes +/- 9 minutes before CPL112 starts with the production. This could overlap the two notes mentioned before, but should definitely be taken into account.

Visibility/Transparency

In Section 1.3 we conclude that first the losses should be made visible for HEINEKEN. Especially the speed losses are hard to define when we consider the MES DNA strand. For example, in Figure 3.4 we see in the red square a large blockage time at the pasteurizer. It is hard to see what influence the blockage time has on the fillers and CPLs. The reason is explained before, in Section 2.3 – Technology. The conclusion was that the different speed levels on the fillers and CPLs can result in invisible losses in MES. The fillers and CPLs can produce at a low speed level, where the pasteurizer has only the nominal speed. Considering the red square in Figure 3.4, we can see that simultaneous with the blockage of the pasteurizer, the filler is producing. Without different speed levels on the filler this situation cannot occur. Nevertheless, the problem described in Section 3.1 holds, because the CPLs are in starvation state. When the CPLs are producing, like the fillers, there is no visible problem. This means that the inefficiencies between the pasteurizer and CPLs still exist.

Measuring Speed Loss - Excel Tool

In order to create insight into the non-transparency of MES, we developed a tool in order to measure the speed losses. The goal of this tool is to visualize the speed losses on the fillers and CPLs. When these speed losses are known, we can focus our research more specifically. This tool uses the bottle stop of the CPL as measure. The bottle stop determines whether SBs are able to pass the CPL or not. This is dependent on failures, material availability and operator presence. Nevertheless, the bottle stop is the most reliable sensor on the CPL. The combination of the bottle stop with the speed level of the CPLs determines the amount of bottles passed. This amount will be used in the data analysis. Figure 3.7 shows the graph that is the result of the tool. In this graph we see at what level the CPLs have produced during a work shift and during a production week. Thus, the tool measures the speed level of the fillers and CPLs and visualizes these into a graph. This tool will be used as a KPI in order to measure the performance of the line during this research. We describe the use of this model in more detail later on.

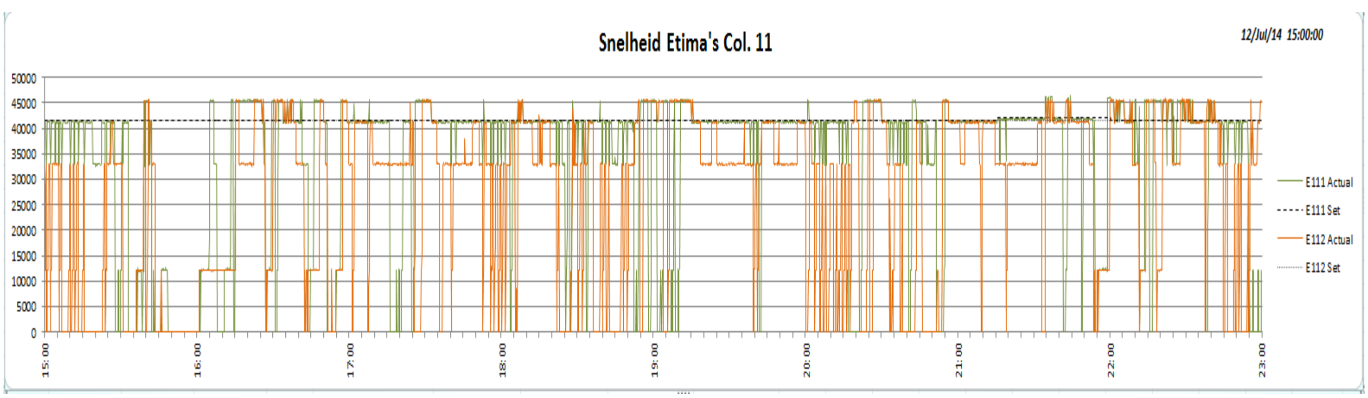

FIGURE 3.7: SPEED LEVEL CPLS - EXCEL TOOL

3.2 Problem design – layout

The conclusion from previous sections is that the current situation at the area between the pasteurizer and the CPLs is not efficiently organized. In order to determine the causes of these inefficiencies this area should be outlined specifically. Therefore the layout of this area is shown in Figure 3.8. In this figure, the bottles move from the pasteurizer (left) to the CPLs. Parts A, C and E represents the lower deck of the pasteurizer and part B, D, F and G represents the upper deck. The green octagons show the location of the sensors, where no distinction is made of the nature of the sensor (switch/photocell). Every sensor is linked with its corresponding conveyor. The use of the sensors on the conveyors and how these are triggered was explained in Section 2.1.2. Triggering a sensor can lead to several actions. For example, sensors determine the speed level of the conveyor. Besides, some sensors also determine the speed of the pasteurizer and/or CPLs. These sensors determine when a machine starts/stops producing and at what speed. We start with focusing on these sensors. The sensors that determine the speed of the machines are interesting, because these sensors determine the production quantity of the machine. Other sensors just have the function of determining the moment of changing of a conveyor speed.

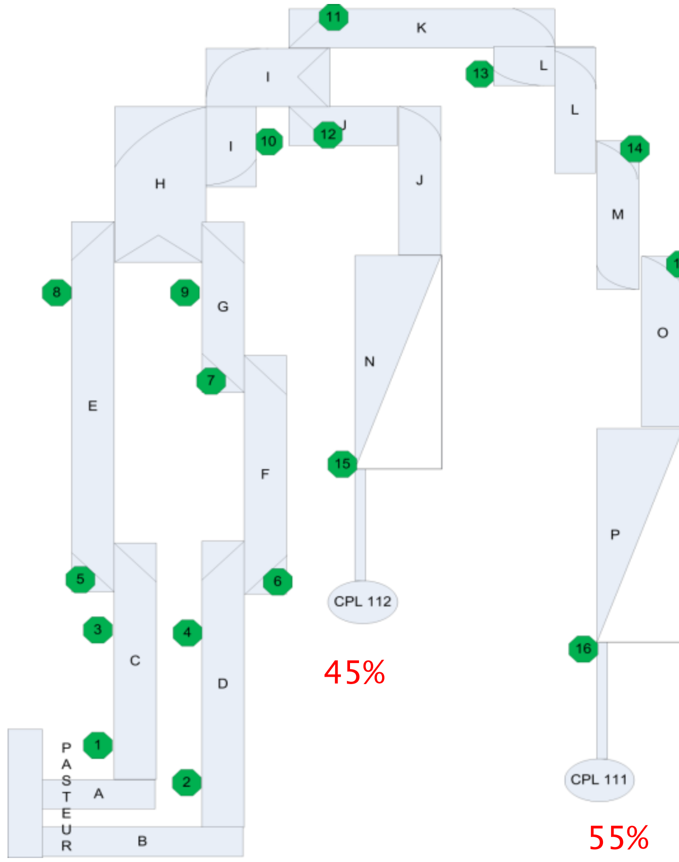

FIGURE 3.8: LAYOUT CONVEYOR BETWEEN PASTEURIZER AND CPLS

The sensors that trigger the CPLs are highlighted in three different situations. Situation 1, shown in Figure 3.11, explains when CPL111 starts producing to low speed. The triggered sensors are colored blue and the non-triggered sensors are colored green. As explained in Section 2.1.2, sensors are triggered when SBs enumerate from the CPL to the concerning sensor, this means that a CPL or a succeeding machine is in failure. Note that CPL112 has no low speed. Situation 2, shown in Figure 3.10, explains when the machines start at nominal speed. Note that CPL112 directly moves to nominal speed. The last situation is number 3 and is shown in Figure 3.9. This figure displays the situation that both CPLs move to high speed. The number of speed levels is predetermined and the values are fixed. **We can conclude from the figures explained above, that CPL111 has three speed levels and CPL112 has only two.**

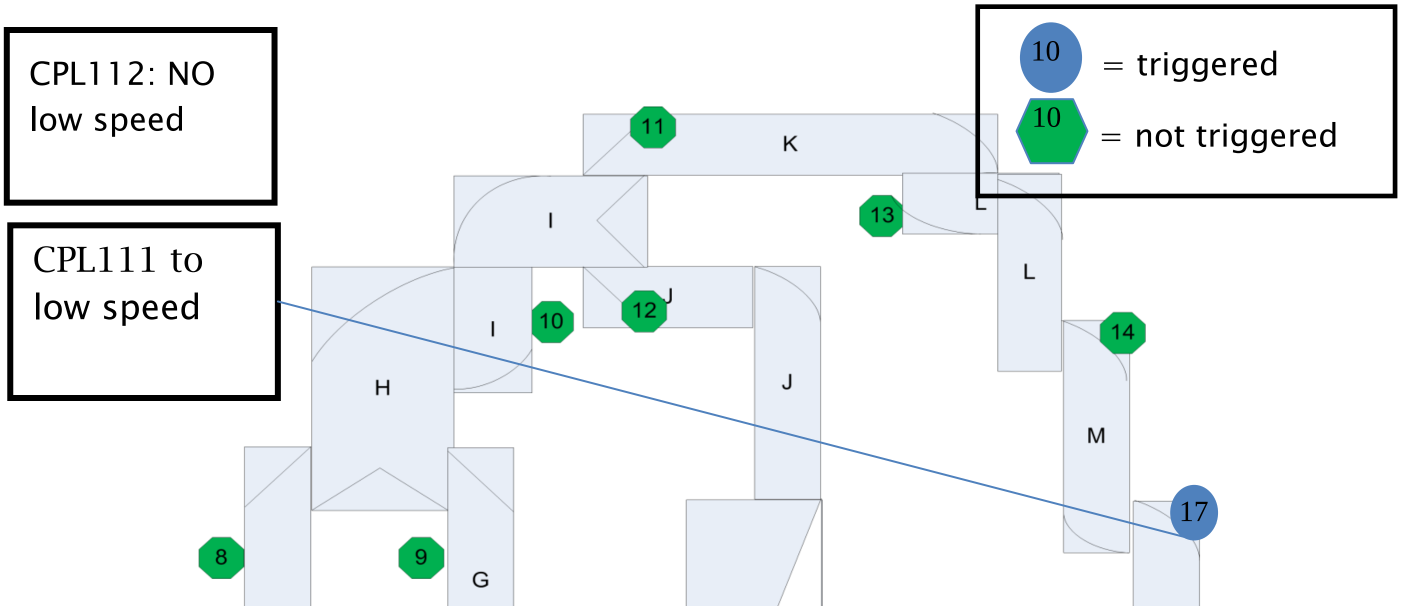

FIGURE 3.11: SITUATION 1: CPL111 TO LOW SPEED

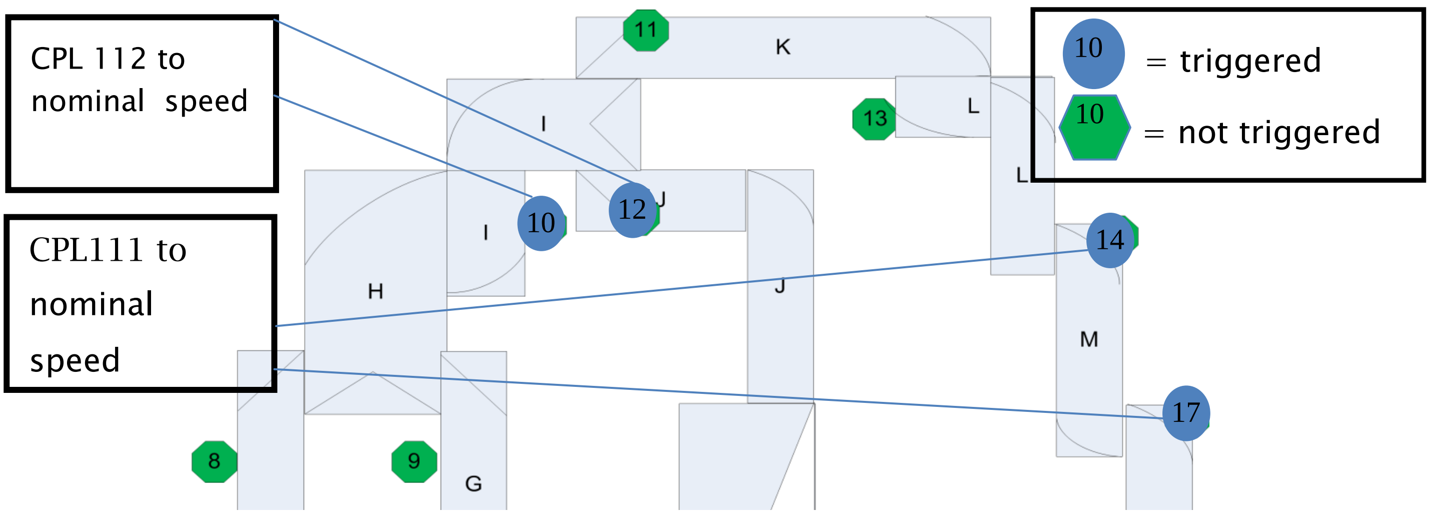

FIGURE 3.10: SITUATION 2: CPLS TO NOMINAL SPEED

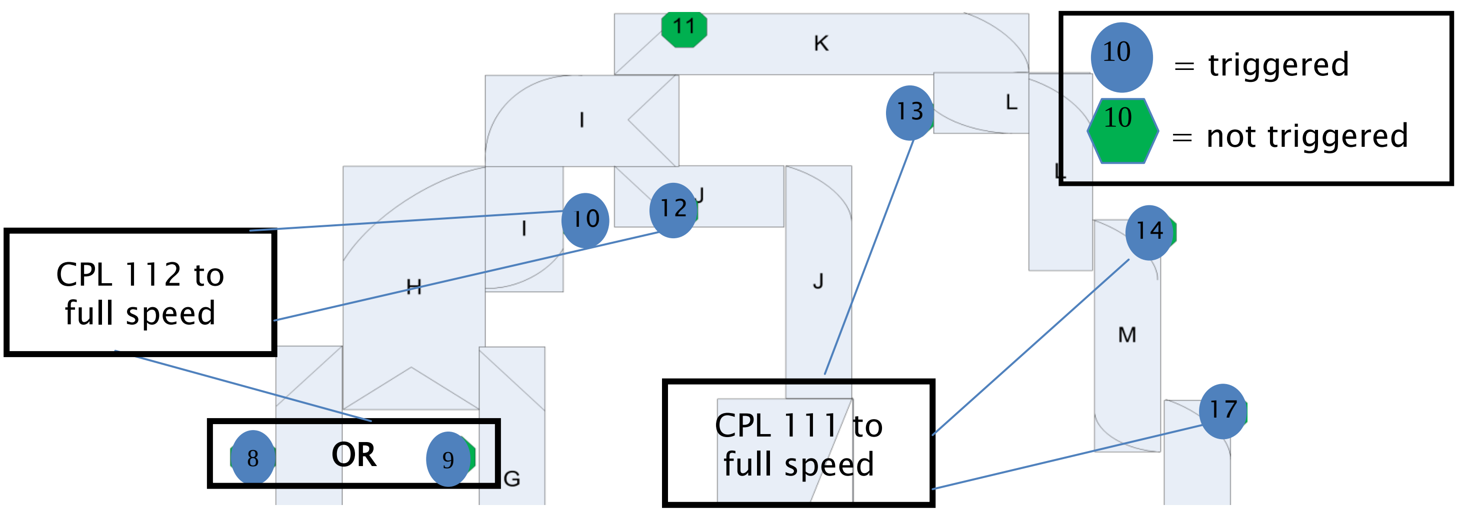

FIGURE 3.9: SITUATION 3: CPLS TO FULL SPEED

When the CPL or the succeeding machine that was in failure is repaired, the amount of products on the line decreases. This means that the CPLs will now produce at a higher frequency than the pasteurizer. The buffer/conveyors will slowly decrease in occupation as we explained in Section 2.2.2. This decrease will influence the sensors and therefore the CPLs. This happens in the same way as the figures on the previous page shows, but the other way around. This means that at sensor 10 in Figure 3.9, CPL111 will change from full speed to nominal speed if sensor 13 is not triggered anymore. CPL112 will reduce its speed from full to nominal if sensor 8 or 9 is not triggered anymore. CPL111 will change from nominal speed to zero if sensor 14 is not triggered anymore. CPL112 will fall down if sensor 10 is not triggered for **30 seconds**. This is the only difference compared to the enumeration of the bottles, explained before. This delay of 30 seconds ensures the continuity of the material flow and the start/stop situations of CPL112. Without this delay, CPL112 would stop if the sensor is not triggered and start again if the sensor is triggered. Experience has shown that the material flow around sensor 10 is highly fluctuating. Therefore the delay of 30 seconds ensures continuity.

Figure 3.12 shows a detailed version of the conveyor belt part I. Location A represents the output from the lower deck of the pasteurizer and B is the output from the upper deck. Exit X move towards CPL111 and exit Y moves to CPL112. We would expect that if a SB enters conveyor belt H at location A it exits I at location X and when a SB enters at location B it exits at location Y. In real-life this will not be the case, if conveyor H is not completely filled. For example, bottles arrive (entrance) at locations A and B. Then the SBs **all** move to the red dot, because bottles are transported to the end of conveyor belt H and are 'guided' by the fence towards conveyor I. As a result, the bottles will all exit at location X. Note that if bottles reach part I at the blue dot, they will exit at location Y.

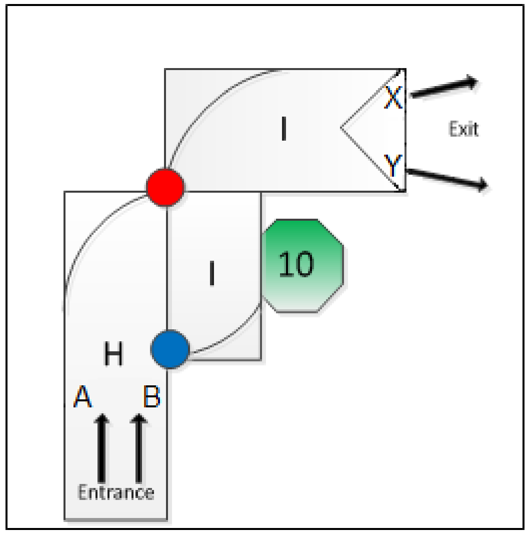

FIGURE 3.12: BEHAVIOR OF SB AT BENDED CONVEYOR BELT

If we zoom out from this picture and get back to the three situations on the previous page we can conclude that, if conveyor H is not fully occupied, CPL111 (X) gets more SBs than CPL112 (Y). This is one of the reasons that explain the production unbalance between the CPL111 and CPL112. If both conveyor H and I are filled with SBs, this bend is not a problem regarding the production balance. So, if just *one deck* of the pasteurizer is filled (entrance A or B) the bottles will move to exit locations X and therefore towards CPL111. This whole situation is clearly exhibited in Figure 3.13. In this figure the upper right corner shows from which angle this picture is taken. The entrance of part H is at the right side of Figure 3.13 and the exit at part I is at the upper left corner. Furthermore, sensor 10 is highlighted. The bottles at the right side of the 'T-junction' at part I will move to CPL112 and the left side moves to CPL111.

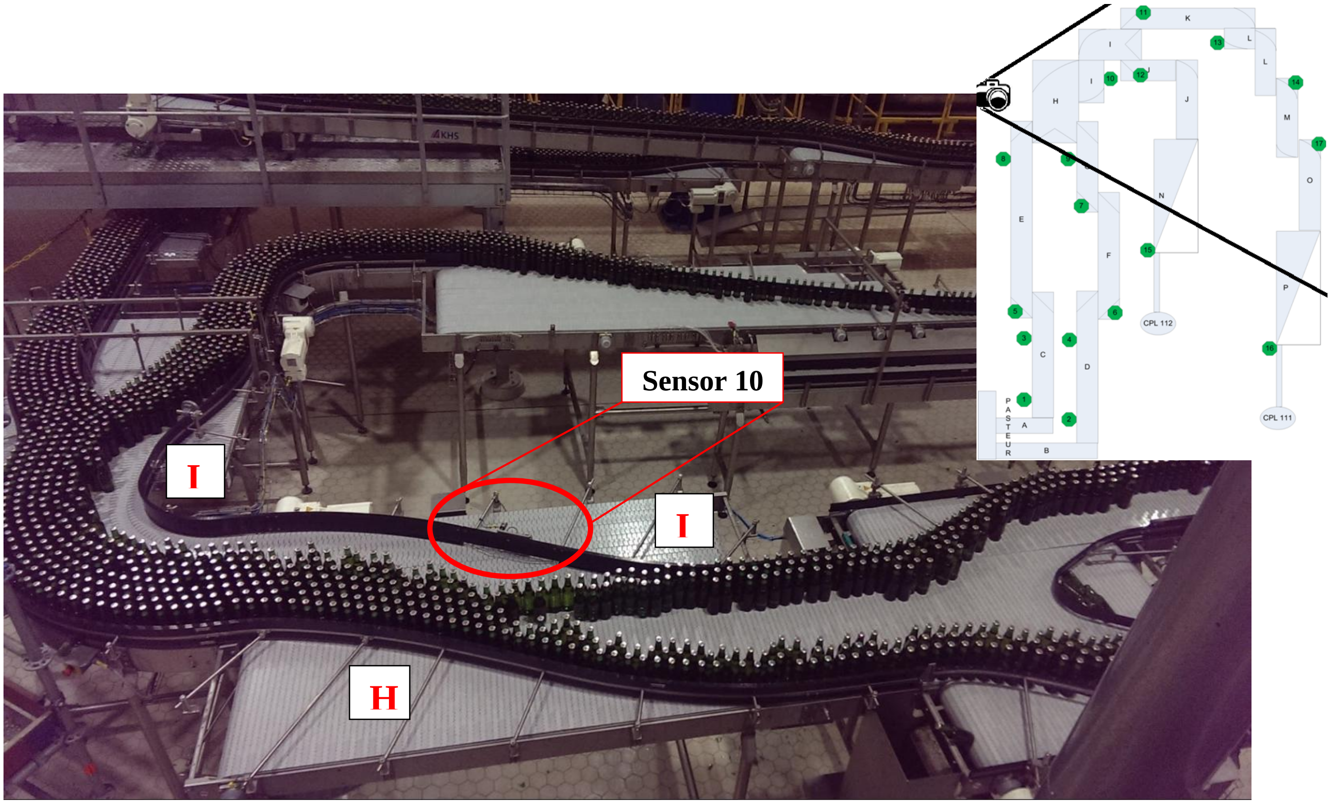

FIGURE 3.13: PROBLEM SITUATION - REAL LIFE

The problem that we explained in the previous paragraph ‘triggers’ another problem. Again consider Figure 3.12. From previous pictures we know that the green octagon represents a sensor, which is triggered when bottles ‘hit’ the sensor. As we know from the previous paragraph, it will be hard to trigger sensor 10 because all bottles will move towards the red dot. Sensor 10 is only triggered when conveyor belt I is completely filled with bottles. This is clearly visible at Figure 3.13, where we can see that the bottle flow move along part H and not towards the sensor. Besides it occurs that if CPL111 fails, the material flow on conveyor H also stops. When sensor 10 is not triggered, CPL112 will stay down, while it is ready to produce. This situation was already known and showed in Figure 3.4, in the red square.

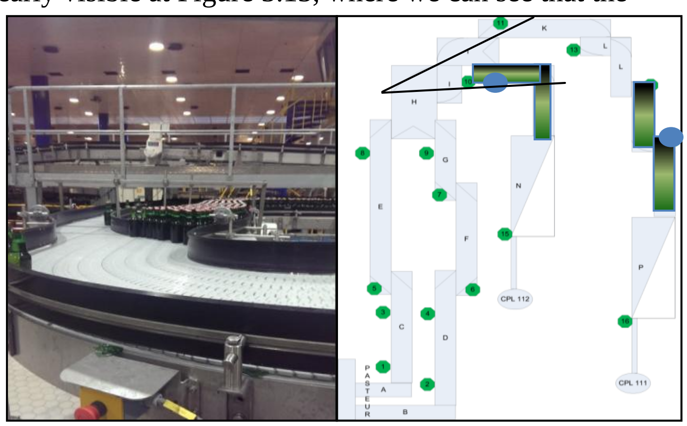

FIGURE 3.14: CPLS IN STARVATION MODE - GREEN BAR: FILLED WITH BOTTLES

When the entrance at H (locations A and B) is not completely filled, bottles move towards the red dot. From there all the bottles will move to the exit X. As we know from Figure 3.10, CPL111 will start producing when sensors 14 & 17 are triggered. When CPL111 is producing it will prevent that conveyor belt I is completely filled, therefore that sensor 10 is triggered and at the end that CPL112 starts producing. Even worse, CPL111 will start producing at full speed, even when CPL112 is not started yet.

We can conclude from this section that the input towards CPL111 is higher than the input towards CPL112 because of layout inefficiency, the transition from part H to part I. SBs will move to the outer of the bended conveyor I. Therefore CPL 111 starts earlier with the production and also 'stealing' the bottles in front of sensor 10, wherefore CPL112 does not start producing.

At the moment that the pasteurizer or a preceding machine is in failure, no bottles will enter part A & B. As explained before CPL 111 & CPL112 will produce until the corresponding sensors are not triggered anymore. In Figure 3.14 the green bars represent the conveyors filled with bottles.

3.3 Summary of data analysis

Summary of analysis (Section 3.1)

As determined in this section, the scope of this research will be on the area between the pasteurizer and the CPLs. The pasteurizer creates blockage while the CPL 112 is in starvation. This means that the regulation of the CPLs is not operating efficiently. The results from before mentioned analysis and the results from the brainstorm sessions that contribute to losses of the pasteurizer are listed below:

- Blockage at CPL 112 is not registered correctly. The blockage time is displayed as starvation time.
- Sensors are not efficiently regulated with the CPLs.
- The CPLs do have inefficient predetermined speed levels.
- The conveyors between the pasteurizer and CPLs are not reacting efficiently to the sensors.
- The conveyors do have inefficient predetermined speed levels.

The first node is explained before and is a problem within the information system and has to be solved by the *PA/PI-engineering* group within HEINEKEN. The other nodes will be discussed in Chapter 5.

Summary of problem design (Section 3.20)

Based on the layout of line 11 we can summarize the following points:

- If part H of the production line is not completely filled, bottles will mainly move to CPL111.
- CPL111 produces at full speed even when CPL112 is not started.
- CPL111 'steals' bottles from CPL112 and therefore prevents that sensor 10 will be triggered and prevents CPL112 to start producing.
- If CPL111 fails and sensor 10 is not triggered, than CPL112 will stay down and the pasteurizer creates blockage. Note that this happens not all the time, but is dependent of the utilization of the bottles.

From these summaries we define the next 'keys issues' that define our problem and which will contribute to the line performance of line 11.

- How should the sensors be regulated, in order to create an equal production balance.
- What is/are the ideal speed levels of the CPLs (to minimize the failures).

4. Literature Review

A lot of research is done in the field of improving line performance. A lot of improvements are based on continuous improvement theories. In order to know how HEINEKEN continuously improves the performance, a comparison is made between HEINEKEN's Total Productive Management and alternative improvement strategies that are made in literature. This is explained in Section 4.1. Based on the comparison the strengths and weaknesses of HEINEKEN's TPM are shown, which we explain in Section 4.2. Furthermore in Section 4.3 we will discuss the performance measurement according to the literature. In Section 4.4 we consider some related research. At last, in Section 4.5, we describe what simulation is and what types there exist. These sections will serve as the basis of our research.

4.1 Continuous improvement strategies

There are multiple improvement strategies and it hard to separate them from each other. There are some close related programs such as Total Quality Management, Just in Time (Cua et al., 2001), Lean (Arlbørn & Freytag, 2013), Theory of Constraints (Rahman, 1998), and Six Sigma (de Mast & Lokkerbol, 2012; Schroeder, Linderman, Liedtke & Choo, 2008). These improvement strategies have grown to comprehensive management strategies. Implementing them requires a changing a working culture towards a continuous improvement culture, which can prove to be difficult and have an impact on involved personnel (Farris et al., 2009). There are discussed four of these strategies in more detail, which are: Lean management, Six Sigma, Theory of Constraint and Total Productive Maintenance. For every strategy an analysis from literature is made. The Total Productive Maintenance in covered in Section 4.2.

Lean management

There is no commonly accepted definition of lean management, and therefore there are a number of views on lean: "Ranging from a focus on waste elimination, utilizing operational tools and implementing specific production-related principles, to identifying conditions that are linked to the product and/or the service and the predictability of demand and its stability" (Arlbørn & Freytag, 2013). Nevertheless, the basic principle of lean management is *eliminating waste*. Wastes are all activities that add no value to the end product. The principle assumes that eliminating waste will increase the business performance. The focus lies on the improvement of small improvements, where the overall flow time can be reduced, the variation can be reduced and the quality will increase (Shah & Ward, 2003). However, critiques against lean management involve a decrease in operator autonomy and multi-skilled labor qualities.

Six Sigma

Six Sigma tries to solve problems from a data driven point of view (Pepper & Spedding, 2010). Six sigma focuses on process variation reduction. Projects are addressed from start to finish, and each project is controlled by a certified project leader. A project is signed off only when the target financial savings are verified (Bendell, 2006). Critique on Six Sigma is aimed on three main aspects. The first one is the lack of taking into account the system interaction. The second one is that it is a cost driven approach instead of focusing on the customers. The third aspect is that tools as innovation and creativity are neglected and only the (statistical) data analysis is taken into account (Bendell, 2006).

Theory of Constraint (ToC)

The principle of the Theory of Constraint can be formulated into two statements according to Rahman (1998):

- Every system must have at least one constraint (no constraints means unlimited profit).

- The existence of constraints represents opportunities for improvements (positive constraints determine the performance of a system).

Therefore these constraints form the focus of improving the production processes within a company. The main focus lies on the throughput. The theory also involves the research to hidden bottlenecks. The critique on the theory is aimed at the lack of involvement of operating employees. The ToC focuses on the whole system and therefore, employees working at part of this process can contribute a very limited way.

4.2 Total Productive Maintenance (TPM)

TPM is mostly known from Japanese car manufacturers like Toyota, and was introduced in the early 1970s. The section 'TPM philosophy' will discuss this concept in more detail. This philosophy consists of several "pillars" that represents together the framework of TPM. The explanation of TPM is relevant because HEINEKEN uses also TPM.

TPM philosophy

TPM is founded by Nakajima (1988) and is a continuous improvement philosophy. The definition in literature states that Total Productive Maintenance is a methodology to continuously mange, optimize and improve a supply chain by eliminating all losses, and involving all employees of the organization (Ahuja & Khamba, 2008). The methodology aims to "increase the availability and effectiveness of existing equipment in a given situation, through the effort of minimizing input and the investment in human resources which results in better hardware utilization" (Chan, Lau et al. 2005, Ahuja & Khamba, 2008). TPM is applied through the entire organization and involves directors, management, support and operators. By training employees, a working culture can be created in which losses are not accepted and processes are structurally improved. Especially the cooperation between maintenance and operations is very important, since operators shift from pure operational tasks to a more all-round shop floor management role (Ahuja, 2001). TPM is an aggressive maintenance strategy that focuses on actually improving the functioning of the production equipment (Tsarouhas, 2007). TPM is especially used in organizations with a high level of equipment automation (Rolfsen & Langeland, 2012).

Due to its focus on personnel, the fragile point of the methodology is the capability of the personnel (Willmott & McCarthy 2001). The capability of the personnel determines in what way TPM can be successful in an organization.

TPM pillars

According Nakajim (1988), TPM has eight different pillars. Within an organization these pillars together form the framework for TPM (Rolfsen & Langeland, 2012). These pillars have their own direction regarding losses. Ahuja & Khamba (2008) defined each pillar in relation with operational skills. These combinations are shown in Table 4.1.

Pillar	Operational skills
Autonomous maintenance (AM)	Fostering operator ownership Perform CILT, adjustment and readjustment of production equipment
Focused improvement (FI)	Systematic identification and elimination of losses.

	Working out loss structure and loss mitigation through structured why-why, failure mode and effects analysis. Achieve improved system efficiency. Improved OEE on production systems
Planned maintenance (PM)	Planning efficient and effective PM, predictive maintenance and time base maintenance systems over equipment life cycle. Establishing PM check sheets. Improving mean time before failure, mean time to repair and mean time between assists.
Quality maintenance (QM)	Achieving zero defects Tracking and addressing equipment problems and root causes Setting 4M (machine/man/material/Method) conditions
Training and Education (T&E)	Imparting technological, quality control, interpersonal skills Multi-skilling of employees Aligning employees to organizational goals Periodic skill evaluation and updating
Safety, health and environment (SHE)	Ensure safe working environment. Provide appropriate work environment. Eliminate incidents of injuries and accidents. Provide standard operating procedures
TPM office	Improve synergy between various business functions Remove procedural hassles Focus on addressing cost-related issues Apply 5S in office and working areas Measurement of TPM performance
Development management (DM)	Minimal problems and running in time on new equipment Utilize learning from existing systems to new systems Maintenance improvement initiatives, Early equipment management

TABLE 4.1: TPM PILLARS (AHUJA & KHAMBA, 2008)

4.3 Performance measurement

Neely et al. (1995) define performance measures (PMs) and metrics as the process of quantifying the efficiency and effectiveness of an action. The term metric refers to the definition of the measure, how it will be calculated, who will be carrying out the calculation, and from where the data will be obtained. According to Fitzgerald et al. (1991), there are two basic types of PMs in any organization; those that relate results (competitiveness and financial performance) and those that focus on the determinants of the results (quality, flexibility, resource utilization and innovation).

According to Neely (1999), two features are necessary for a business performance measurement system; performance measures and a supporting infrastructure. Although the existence of measures is often taken as a given, there is no such agreement on the nature and design of those measures. A supporting infrastructure can vary from very simplistic manual methods or recording data to sophisticated information systems and supporting procedures which might include data acquisition, collation, sorting, analysis, interpretation and dissemination (Neely, 1999).

Six big losses

Nakajima (1991) stated that a loss of an production facility is the difference between an OPI of 100% and the actual OPI. By reducing the losses, the actual OPI increases. Nakajima (1991) categorizes losses into “six big losses”. Nakajima (1991) categorizes these losses into “six big losses”: e*quipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in process and reduces yield.* As one can see in Figure 4.1, these losses are used to compute the OEE.

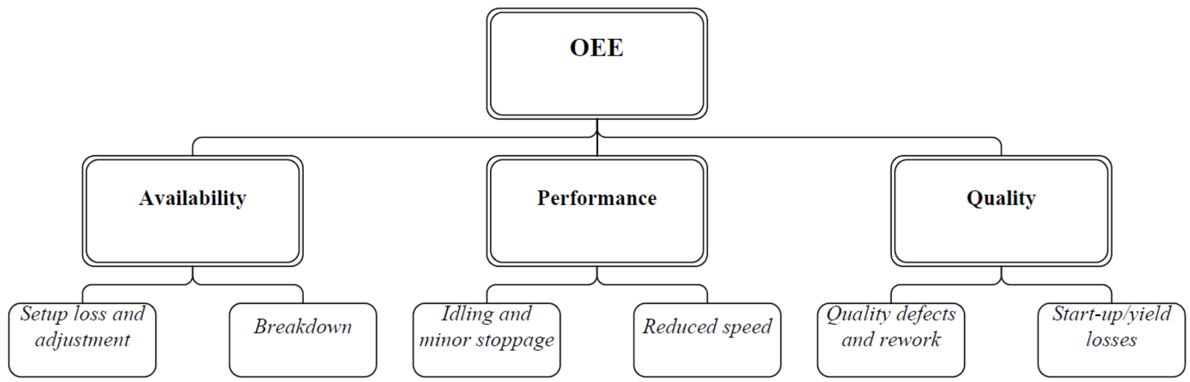

FIGURE 4.1: RELATION BETWEEN OEE AND SIX BIG LOSSES - (CHAN, 2005)

With OEE, an organization looks at the total time that is available, down time losses, speed losses and defect losses. These three types of losses are translated into Availability, Performance and Quality.

Operational Performance Indicator (OPI)

Within the PIs there can be made a difference between performance indicators (PI) and key performance indicators (KPIs), the last one indicates which actions are needed to dramatically increase performance (Parmenter 2010).

To measure the performance, HEINEKEN uses a variant of Nakajima’s (1988) overall equipment effectiveness (OEE) in TPM, as a KPI. This variant is the Overall Performance Indicator (OPI). The OPI is measured over the performance of the **fillers.** The OPI is determined by the product of Availability, Performance and Quality, like the OEE. As stated by Nakajima (1991), the OEE identifies (hidden) losses related to any decrease in performance by evaluating each component. Eliminating these losses results in a higher performance, where according to Nakajima (1991) zero losses will result in an OEE of 100%.

The Operational Performance Indicator (OPI) is calculated as follows:

$$\textbf{OPI} = \textbf{Availability} * \textbf{Performance} * \textbf{Quality}$$

Where these three indicators have their own equations which are stated below

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

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

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

These indicators are calculated in order to measure the line performance of a production line. As stated above, these indicators are multiplied which means that the weight of these indicators are the same. The *quality* measures the ratio of good products, which are the products that exit the production line in order to enter the market. The *performance* measures the efficient production time of all operating time. The

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

This means that only the blockage and starvation times are the difference between operating time and production time. These times are used in order to calculate the performance. The *availability* is the operating time (described above) divided by the manned time. The manned time is the time that operators are working on the production line, which is in total 9600 minutes per week.

CILT

An important part of TPM for production line 11 is the use of CILT-activities. CILT consists of **C**leaning, **I**nspection, **L**ubrication and **T**ightening. These activities play an important role in order to maintain the machines. Every operator on the production line has its own responsibility. These activities should prevent machine breakdowns and improve the line performance.

4.4 Related Research

According to Kegg (1990), in the 1970s, companies with transfer lines began to study the productivity of their lines. Each found that the actual number of parts produced per year was about half of the theoretical maximum. This result was widely discussed and published, but the causes of these production losses were kept classified. This led to the conclusion that *sensors* were needed in order to measure inefficiencies on different places on the production line. These sensors are called the Programmable Logic Controllers (PLCs). It was the first major milestone in the use of electronics to extract information from sensors in manufacturing. The PLCs became a reliable measure to collect data from the production line. The data from the PLCs supports technicians to detect problems earlier and therefore the productivity increased (Kegg, 1990). In the 80s the combination of PLCs and use of measurement systems allows to detect trends on machine failures and other inefficiencies, therefore the PLCs play in important role in the automation of production lines.

Another use of sensors on a production line was to cope with high flexibility and productivity (Mahalik, Lee, 2001). Sensors do not only register information about machine breakdowns but also about starvation and blockage at the production line. Sensors are linked with conveyors, but also with machines. Often the PLCs are positioned on the conveyors and collect information of the (number of) products.

Conveyor Theory

Conveyor systems can most of the time be built from basic units as linear conveyor systems. “Conveyor systems are typically installed as simple straight assembly lines and a number of workplaces are set on each side of the conveyor for manual and/or automated operations.” (Yeung & Moore, 1996). For simple configurations the design and implementation of conveyor system is relative easily. Furthermore, the control programs are easily developed and executed by PLCs. Nevertheless, the demand for multi-product mixes and flexibility can require more complex conveyor systems (Yeung & Moore, 1996). Conveyor systems which support the multi-product mixes and variable product routing need high control requirements.

Bastani (1988) analyzes in his paper a multiple homogeneous closed-loop conveyor system with discrete and deterministic flow of material, taking into consideration the unit length of products. Where Kwo (1958) established three fundamental principles that govern the satisfactory operation of conveyor systems, also known as the Conveyor Theory:

- The speed of the conveyor must be within the permissible range (Speed Principle).
- The conveyor must have enough capacity (Capacity Principle).
- The number of items loaded onto the conveyor must equal the number of items unloaded (Uniformity Principle).

Kwo’s work is expanded by Muth (1974) who has treated both continuous time and discrete time material flow, multiple load and unload stations (input/output) and stochastic material flow. Additionally, according to Belzer et al. (1978) several authors have applied waiting line analysis and *simulation* to the problems included with the field of conveyor systems.

Conveyor systems in simulation

“Conveyor systems in simulation can be classified by the type of conveyor as well as the size of the load moving on the conveyor” Banks(1998). Difference is made between a non-accumulating conveyor, where a load stops when the entire conveyor stops and an accumulating conveyor. On accumulating conveyors, loads continue moving and bench products from behind that are stopped. Banks (1998) considers different load sizes as pallet conveyors, case conveyors and power-and-free conveyors. Power-and-free conveyors have carriers that attach to the load being transported and are often seen in automotive paint applications (Banks, 1998).

Note that single product conveyors are not discussed.

Choice of method

Two types of models are typically used to estimate performance measures: simulation models and analytical models. The definition of simulation is: "*the process of designing a model of a system and conducting experiments with this model for the purpose either of understanding the behavior 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" (Shannon, 1975).* Discrete-event simulation models mimic the real system by constructing a list of events that occurs in the real life. At each event occurrence, such as a process completion or a breakdown, new events are scheduled and added to the event list. The randomness in times between two events (arrival or breakdowns) is captured by drawing random numbers from pre-specified distributions. These distributions can be derived from data of the production system; both empirical and fitted distributions can be used. These distributions can be translated into stochastic variables. "A great benefit of simulation is the ability to include stochastic variables, for example the inter arrival time of products and the breakdowns of machines" (Wein & Chevalier, 1992). A simulation model is a simplified model of reality and is used to test out different production rules.

Analytical models try to capture the system in terms of sets of equations and then solve these equations. In many cases, the solution of these equations is numerical. Since most systems in practice are too complex to analyze exactly, heuristic methods need to be constructed to obtain approximate results. According to Tino & Khan (2013) *"Simulation techniques are often time consuming. Therefore, analytical models are often used to generate solutions in a fraction of the time. These models however are complicated and take effort to derive."*

An analytical analysis is basically a set of formulas, where simulation is a graphical tool for analysis. Simulation enables us to analyze the impact of, e.g., breakdowns and inter arrival times. At the production line of HEINEKEN these events should be considered to mimic real life situations. This would be too hard to solve with an analytical model due to the dynamic production environment.

Simulation type

Law (2006) distinguishes several types of simulation models. First we determine which dimensions are applicable to this research. There are three dimensions, which are:

- Dynamic or static simulation models. A dynamic model shows how a system evolves over time while a static simulation model represents the system at a certain time.
- Stochastic vs. deterministic simulation models. A stochastic simulation model exists of random input components while a deterministic model does not contain any probabilistic components.
- Discrete vs. continuous simulation models. In a discrete simulation model the state variable changes at different points in time while a continuous model has continuous state changes.

Furthermore there is a distinction between terminating and non-terminating simulations. In terminating simulation there is a natural event that specifies the end of the run. This can be for example, the end of a shift or end of a day. Non-terminating simulations consider a steady state performance measure. The performance depends on initial conditions, and after time *t* the simulation can turn into steady state behavior. This is not always the case, because parameters might be changing over time which results in a continued transient system behavior. Considering steady state parameters, the time it takes until the system turns in a steady state has to be determined in order to measure performance.

Other subdivisions of simulations discussed by Law (2006) are:

- Monte Carlo simulation. This contains a static discrete simulation model and can be stochastic or deterministic.
- Spreadsheet simulation. Spreadsheet simulation refers to the use of a spreadsheet as a platform for representing simulation models and performing simulation experiments.
- Continuous simulation
- Discrete-event simulation
- Combined discrete-continuous simulation

The discrete-event simulation, models the operation of a system as a discrete sequence of state changes in time.

Conclusion

TPM is used by HEINEKEN and the philosophy is based to "increase the availability and effectiveness of existing equipment in a given situation, through the effort of minimizing input and the investment in human resources which results in better hardware utilization". The performance measure at HEINEKEN is based on the six big losses of Nakajima (1988). The performance is measured by the Operational Performance Indiactor (OPI). *OPI = Availability * Performance * Quality.* All these performance measures have the same weight.

We use simulation in order to determine a solution for the problem statement. The discrete-event simulation fits the best with our parameters and therefore we use this. This is explained in more detail in Section 5.3. Furthermore we use accumulating simulation in order to model the Star Bottles. Nevertheless, we considered the related research in order to simulate products on the conveyor system at HEINEKEN. In the literature only single loads are discussed, as pallets, cases, automobiles etc. No literature is written about how to simulate multiple products in a sequence on a conveyor system in discrete-event simulation. In this paper we describe how to perform this.

5. Solution design

In Section 5.1 we describe the conceptual model. In Section 5.2 we describe the simulation model and how we transformed the conceptual model. In Section 5.3 we describe the experimental setup in order to determine the input data, warm-up period and the number of replications. In Section 5.4 we explain the verification and validation of the model. Furthermore we describe the experimental design in Section 5.5. At the end a conclusion is made, based on the whole chapter.

5.1 Conceptual model

In this section we describe what the model is and how it is functions.

Model overview – Movement of Star Bottles

As described in the previous section, the model in a simulation study is a simplification of the reality. This model overview is intended to explain this simplification compared to the real-life situation of the SB production line.

The model is divided into several lines that depict the conveyors. The length and width of the lines are developed on scale. These lines transport the SBs to the CPL machine.

This model focuses on the behavior of the bottles when changing from conveyor part. In real life the SBs are positioned in multiple rows next to each other. This makes it different compared to an assembly line, where products are positioned in a single line. See Figure 5.1 'Real life' for the difference between the SB line and an assembly line. The green circles are SBs and the red squares are example products, which we need to compare the situation. These are generally large products and transferring in single rows. For the simulation study this difference is important, because SBs cannot be modeled in multiple rows next to each other. To simulate the movement of each different SB across the line we choose to split the line in several conveyors. The model conveyor SB production line, separated in three conveyors, is shown in Figure 5.1 'Model'.

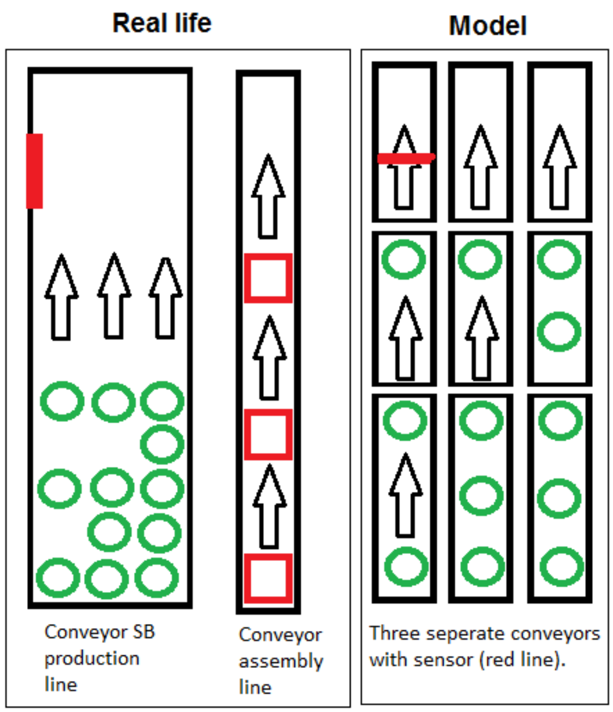

FIGURE 5.1: CONVEYOR BELT - DIFFERENCES REAL LIFE AND SIMULATION

Another aspect that needs attention is the sensors positioned on the production line. The specific working of a sensor was discussed in Section 2.1.2. In real life sensors are triggered when bottles hit the sensor. This *only* occurs when a conveyor is occupied. In real life, the sensor is placed vertically at one side of the conveyor as shown in Figure 5.1 'Real life' with the red line. In the model, a sensor could only be placed horizontally confiscating a total line, shown in Figure 5.1 'Model' again with the red line. This sensor is triggered every time when a single bottle passes. This sensor is denoted by the horizontal red line. In order to prevent that a sensor is triggered by every bottle, first the conveyors are divided into multiple parts. Now consider the upper left conveyor belt, with the red line. Secondly, when a SB enters this conveyor a method is triggered which can determine how much SBs there are currently on the other conveyor. The capacity is known and therefore the occupancy can be determined. When this conveyor in the model is occupied, the sensor is triggered, just like in real life.

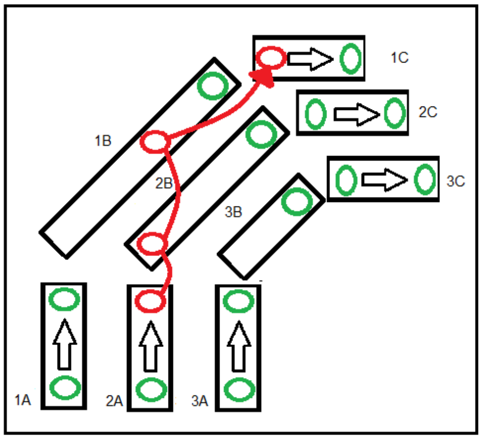

FIGURE 5.2: BEHAVIOR OF A SB IN A BEND

As described in the previous section, the model should determine the production balance between the CPLs. Therefore it is important how the distribution of bottles is modeled. Consider Figure 5.2, where the movement of SBs is shown in the conceptual model. This conveyor consists of a bend, which can be compared with part I in Figure 3.10 and Figure 3.9. Section 3.2 also considers this bend, but then in real life. The conclusion from this section was that SB will move towards the outside of the bend.

Figure 5.2 consists of three line conveyors 1,2 and 3. These conveyors are separated into three parts, A, B and C. In this figure we consider a red SB that moves towards the outside of the bend, which happens in real life. Considering the conceptual model, we see that the SB moves from 2A → 2B → 1B → 1C. Therefore the conceptual model should take into account the distribution of the SBs between conveyors. Furthermore the possible successors of a SB should be determined. For example, it is *not possible* for a SB to move from 1A to 3B, if a bend 'turns' right.

The destination table determines the behavior of a SB. We make a distinction between straight lines and bended lines. For the explanation of the destination table at input data, we only consider a bended line. Bottles on a bended line have a tendency to move towards the outer of the bend. As mentioned before we consider this as a deterministic process, which is modeled with priorities. Figure 5.2 explains the behavior of a bottle. A SB actually wants to move towards the outside of the bend. These priorities are determined in a destination table.

In order to determine possible successors we consider Figure 5.3. In the conceptual model there are four possibilities where the SB can flow after triggering a method at the 'end of the line'. In s**ituation A** we can see the different possibilities, shown with numbers. Consider the red SB (with number 4 in it). This SB has four succeeding options; number 1, 2, 3 and 4. The SB can move to three positions: 1, 2 or 3. Number 4 means that the SB stays on the *same position*. This can only occur when 1, 2 and 3 are not available. Note that at the right side of number 3 is also space, but it is not a possible successor. It is not realistic to move to this position, because the distance is too large. So, determining the possible successors is the *first* step in the conceptual model.

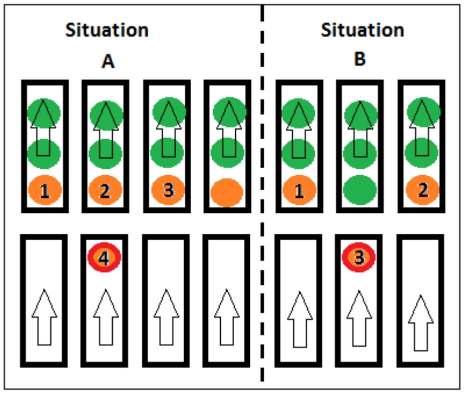

FIGURE 5.3: POSSIBLE SUCCESSORS FOR A MU

The second step is determining the occupancy of the first position. The first position is the one with the orange circles (this means that in this example, the lines have three positions). In **situation B** we can see that the middle conveyor is occupied, and that it is not a possible successor anymore. Determining the occupancy of the first positions is the *second* step in the conceptual model. This is done by determining the capacity of a line and counting the current amount of SBs on this line. If this is equal, the succeeding conveyor is occupied.

The *third* step is prioritizing the possible successors. We consider two different scenarios, a straight line and a bended line. In a straight line the SB will, when possible, move in a straight line. In Figure 5.3 this means that the red SB (with #4) will move to number 2 with priority 1. When **situation B** occurs the SB will move to position 1 or 2. These positions have the same priority in a straight line and therefore the chance of moving to these positions is random. Considering a bended line the chances are deterministic. As explained in Figure 5.2, the SBs will move to the outside of the bend. This means that considering the SB in Figure 5.2, it will move *eventually* to position 1C with priority 1, to 2C with priority 2 and to 3C with priority 3. These priorities are determined beforehand, and are *input data* to this conceptual model. Prioritizing the possible successors is the third step in this conceptual model.

When there is a possible successor that has a free first position, the SB moves to this position. If there is no possible successor and option 4 is chosen, the SB is placed on the blocking list. As the name reveals, it is a list of all blocked SBs, which are 'waiting' to move to a possible successor.

The sensor that triggers the blocking list is placed on the succeeding production line. Thus, when a first position becomes empty, a method checks whether there are SBs on the blocking list. When there are SBs on the blocking list, we must check if the SB in the list is allowed to fill the first position, as described in Figure 5.3. When this is the case, pick the SB which is ranked highest in the blocking list (longest waiting), and delete this SB from the blocking list. *This means that a SB from the blockings list has preference above a part that triggers the end of a line, and wants to move directly from a conveyor.*

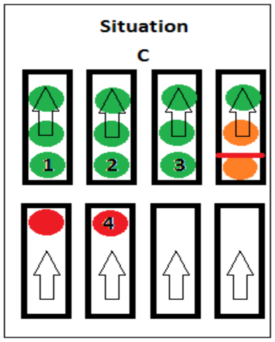

FIGURE 5.4: SBs IN BLOCKING LIST

When there are SBs on the blocking list, but when a SB is not permitted to transfer to the first position, the neighbor lines should be considered. Consider Figure 5.4, the red SB (4) is located in the blocking list. A succeeding line triggers a sensor (red line) and therefore a method of the conceptual model. However, the orange (first) position is not a possible successor of the red SBs. In real life the conveyors will be constantly flowing, and therefore the SB with number 3 *eventually* moves to the orange position. This is also taken into account in the conceptual model. The model includes a method that compares the amount of SB on the line of the neighbor, if no SBs are available on the blocking list. When the amount of SBs on the neighbor line is more than 2, it takes the last SB of the line. In Figure 5.4 the succeeding line has only one neighbor, and the amount of SB on the line next to the orange circles is more than 2, so it moves SB #3 to the orange circle. Then it is possible for the red SB to move to position 3.

Summary

In order to summarize the previous steps, we created two flowcharts. In Figure 5.5 we describe the flowchart of a moving a SB over the lines.

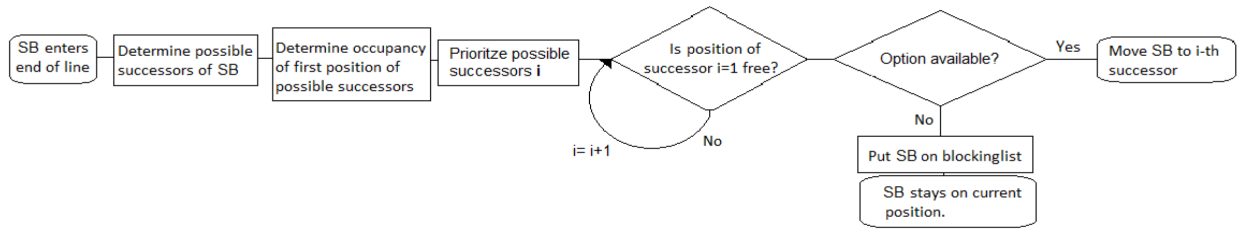

FIGURE 5.5: FLOWCHART CONCEPTUAL MODEL 1A - MOVING SB FORWARD

This blocking list is triggered by another part of the model, which is described in Figure 5.6.

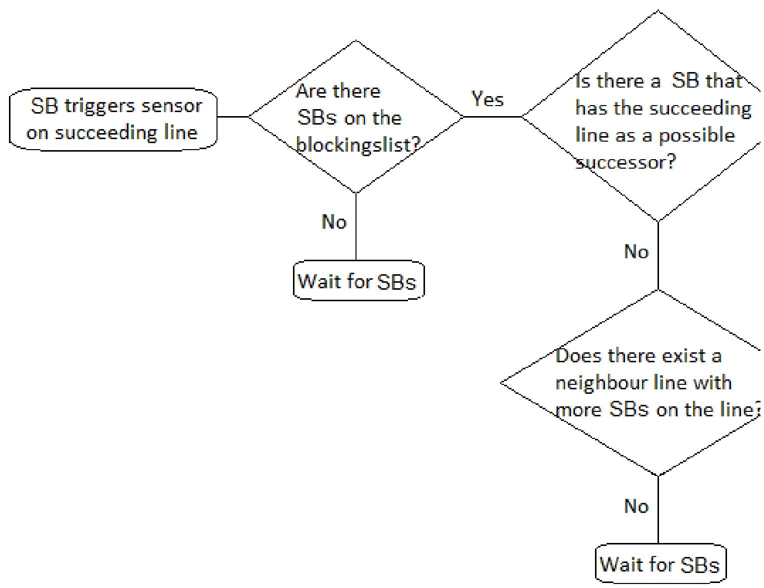

FIGURE 5.6: FLOWCHART CONCEPTUAL MODEL 1B - TAKE SB FROM BLOCKING LIST

Model overview – Regulation

To create a better understanding of the scale of conceptual model **part 1** we consider Figure 5.7. Here we zoom in into part H, and consider Figure 5.4 again. Note that part H in the conceptual model consists of eight lines, but in this example it is simplified to four lines. As mentioned in Section 3.2, there is a sensor (sensor 10) located at part H/I. This specific sensor ensures that CPL112 will start producing when triggered, and stops producing when it is not triggered anymore.

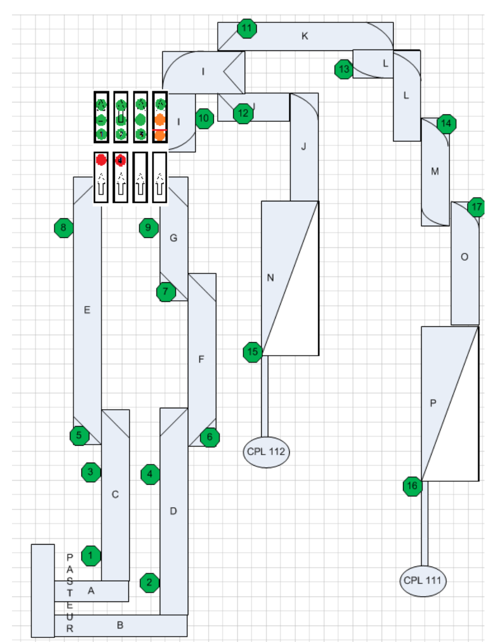

FIGURE 5.7: REGULATION IN CONCEPTUAL MODEL

In the conceptual model, the conveyor line with the orange circles is the one where the sensor is located. Due to the separated conveyor lines, we can easily model that CPL112 should start producing by counting the amount of SBs on the conveyor with the sensor. In this example there are three possible positions on the conveyor. This means that when all three positions are occupied, the sensor should be triggered. Therefore it is modeled that when the number of SBs on the conveyor with the sensor is equal to three, the processing time should go to nominal speed. If all three positions are empty for 30 seconds, CPL112 will stop. This modeling is done for all relevant sensors explained in Section 3.2.

Furthermore, the conceptual model works with aggregated sizes of SBs. In real life every hour there are entering about 70.000 SBs and staying in the system for several minutes. It costs a lot of processing time in order to mimic the real life situation, and for that reason the conceptual model uses aggregated size of 1:100. Thus, 1 SB in the conceptual model represents 100 SBs in real life.

Components of simulation model

We use several components for the simulation model. These five main components are:
- *Input data.* This is data that will not be changed during the experiments. It is implemented once, and will not be influenced.
- *Stochastic variables.* The values of these variables are subject to variations due to chance (e.g., a machine failure).
- *Experimental factors.* These are controllable variables, set by the experimenter and can be different per experiment.
- *Output data.* This data results from a run of an experiment. It is influenced by the stochastic variables and experimental factors.

We use the input data with the stochastic variables and the experimental factors which results in the output data.

Input data

The input data we use for our model is:

- Process times. The time it takes for a machine to perform an activity (e.g., filling or labeling).
- Aggregated size of Star Bottles. In the conceptual model the SBs are aggregated to a ratio 1:100 (*in real life 1 bottle equals 100 bottles in the conceptual model).*
- Speed per conveyor.
- Length per conveyor.
- Strokes per conveyor (this determines the width of a conveyor).
- Buffer capacity per line.
- Machine failures

Stochastic variables

The stochastic variables of the model are:

- *Machine availability*. In the conceptual model the machine availability includes the machines that are not modeled (fillers & packer) but have an influence on the machines described in the conceptual model. For example, the impact of starvation, blockage and failures of machine outside our scope on the machines modeled. It also includes the breakdowns of the machines modeled.
- *Arrival times*. Arrival times of the Star Bottles are dependent on the machines availabilities of the pasteurizer and preceding machines. These machines are analyzed and this stochastic variable is used in order to ‘create’ new bottles.

Experimental factors
The experimental factors of the model are:

- *Speed level of the machine.* This will be the processing time of a machine and the level of the speed might differ per experiment.
- *Number of speed levels*. Some machines have multiple speed levels. The amount of speed levels might differ per experiment.
- *Position of sensors/ moment of switching speed of CPLs.* Machines are dependent of the sensors when they will change to a certain speed. This might differ per experiment.
- *Position of buffers.* The position of the buffer determines the effect on the pasteurizer.

Output data/ performance indicators
To measure output data we use five performance indicators. These indicators are:

- *Production/ Output quantity.* The total quantity that is produced on both CPLs.
- *Production balance*. The production balance between the CPLs.
- *Time of machine failure.* The failure time of the CPLs.
- *Time of machine stopping of a machine.* The stopping time of the CPLs is dependent on the position of the sensors. When sensors are positioned inefficiently the stopping time will increase.
- *Time of waiting of a machine.* The waiting time of the machine is dependent on the output of the pasteurizer. This is also the starvation time of the CPLs.

These five performance indicators determine the performance per experiment. The weights of the performance measures are described in Section 6.1.

Assumptions

We made several assumptions because it is almost impossible to approximate a real life situation. We will formulate the assumptions that we made below:

- No bottles will collapse on the production line. This means that we create no losses due to bad quality of the material.
- Bottles react the same on an identical situation.
- Processing times of machines have fixed values.
- The average mean time to failure and mean time to repair of the last year is representative. Therefore we can use this as input data for the model.
- The lines/conveyors will not fail/ have breakdowns. The machines breakdowns are included, but the conveyor breakdowns are excluded. In real life these are negligible.
- No maintenance activities have to be done.
- Extra material is available and setup times are zero. For some machine extra material should be present in order to fulfill the machines' activity (e.g., the labeling machine needs labels).

Conclusions

The conceptual model is a simplification of reality and contains two parts, 1A and 1B. Part 1A consists of three steps:

- First the possible successors should be determined
- Secondly the occupancy of the possible successors should be determined
- The third step is to prioritize the possible successors.

When all these steps are performed a MU moves towards the next positions, or it is moved to the blocking list. Subsequently we consider part 1B which continues from the blocking list. This part:

- Check whether there are SB on the blocking list
- If this SB matches a possible position
- And if there is no SB on the blocking list, it checks neighbor lines.

Furthermore, this sections described the components needed for a simulation model and the assumptions made during this conceptual model.

5.2 Simulation model

We choose to work with Siemens' Tecnomatix Plant Simulation. Tecnomatix Plant Simulation is a simulation tool to create digital models of logistical problems (e.g., production systems), in order to examine the system characteristics and optimize performance (Siemens, Tecnomatix Plant Simulation, 2012). Furthermore, Tecnomatix Plant Simulation is used by the University of Twente in their simulation coursed

The representation of the different flows should correspond with reality. Some assumptions are made, which are described at the end of the previous section. We use the simulation in order to find optimal locations for the sensors with ideal speed levels for the CPLs. Figure 5.8 shows a print screen of the simulation model from Tecnomatix Plant Simulation.

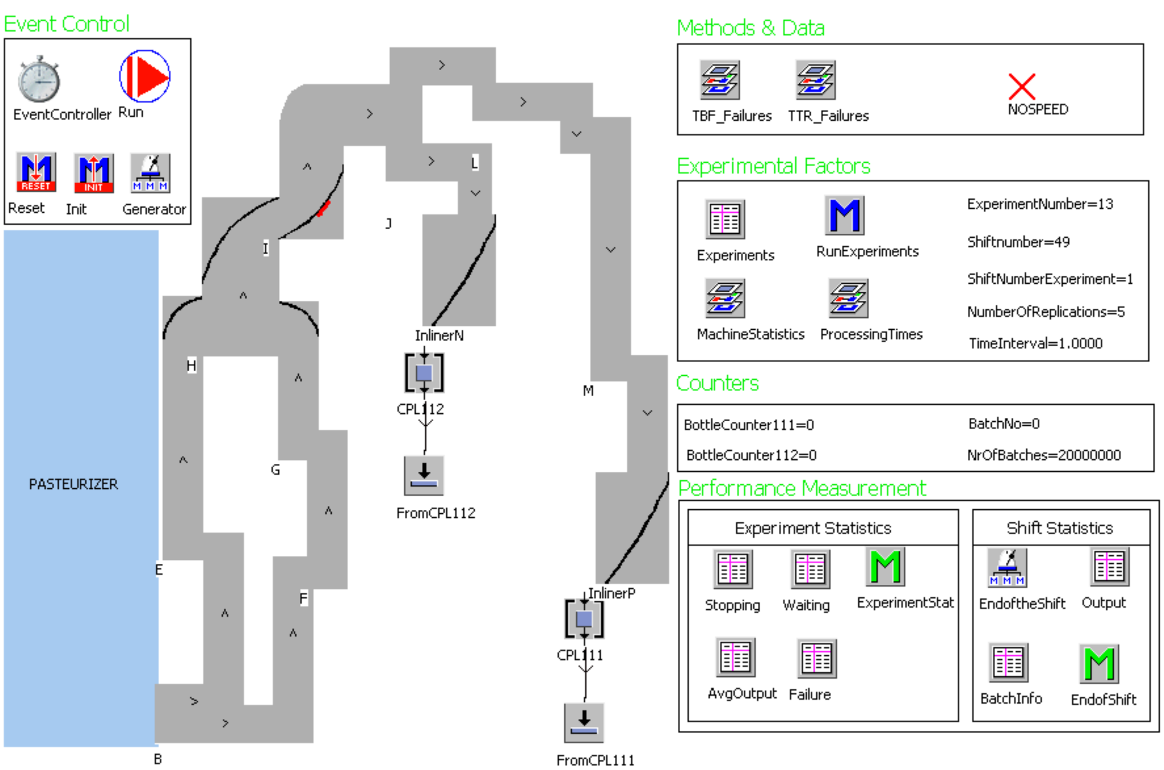

FIGURE 5.8: PRINT SCREEN OF MAIN FRAME PLANT SIMULATION

In this main layer we consider different frames and the flow line of bottles. A frame consists of data and/or methods for a specific area. A detailed explanation of the flow line is given in Appendix A. Besides the Layout of the Pasteurizer-CPLs, there are five different frames which are:

- Event Control
- Methods & Data
- Experimental Factors
- Counters
- Performance Measurement

Description of the simulation model

Here we explain the different frames that are used during the simulation study as mentioned before:

Layout Pasteurizer-CPLs
The layout consists of all conveyors that are positioned between the pasteurizer and the CPLs. Differences between conveyors are the straight and bended lines, as explained in Section 5.2. The characteristics of the conveyors are the same as reality. This means that the length, wide and speed of the conveyors are similar. Furthermore the aspects discussed in Section 5.2 are considered.

Event Control
The event control regulates the simulation from initializing till resetting. The generator triggers a method that ensures that different experiments and shifts will run.

Methods & Data
Methods are indicated with the large blue Ms. In these methods we program different codes in order to run the model. The aspects discussed in **model overview** are written into these methods, such as the behavior of SBs and the regulation of the CPLs.

Experimental factors
The experimental factors determine the different experiments that will be done. For example the different locations of sensors can be implemented in the experimental factors.

Counters
Counters easily serve for determining the amount of SBs produced and the number of batches produced. In this way it is clearly visible during a run of an experiment.

Performance measures
The frame with performance measures contains all table files. A table file is a table in Tecnomatix Plant Simulation that collects data from the experiments. Performance is measured using the data from these table files. In the table files the producing times, waiting times, failures is measured. Furthermore the output of the process with the production balance is stored into the table files.

5.3 Experimental setup

We described the conceptual model and the simulation model. Before we can run our model we have to determine the input data, the warm-up period and the number of replications. This is covered in this section.

Simulation type

Several types of simulation models are defined by Law (2006), as we explained in Section 4.1. In our simulation model, the stochastic variables indicate that the system evolves over time and the state of the system changes, which means that we should use random input components. Our model is a discrete event simulation, because the state of the system only changes when an event occurs. Furthermore, the processing times of the SBs are stochastic, because breakdowns on machines can occur. Taken the different dimensions into account and the reason that we deal with a complex system, the conclusion is that we use a discrete-event simulation.

Input data

There are three types that we have to define in our simulation model.

- Processing times. Time that a machine needs to produce a SB.
- Mean Time Between Failures (MTBF). This is the mean time it takes between machine failures.
- Mean Time To Repair (MTTR). Time it takes for repairing a machine after it failed.

In order for the simulation model closely mimic to reality we try to define these three types with a theoretical distribution. If this is not possible, the empirical distribution function will be used. Considering a theoretical distribution function, several distributions in Tecnomatix Plant Simulation can be used. These distributions are described in Appendix A. From this appendix we can conclude that we will use both a Chi-squared test, as a Kolmogorov-Smirnov test to check if the data fits and theoretical distribution.

Furthermore, the three types discussed need to be determined for the machines that are available in our simulation model. These machines are:

- CPL111
- CPL112

Besides these functions and distributions we need a deterministic destination input table, to determine the behavior of the SBs. As mentioned in Section 5.2, this is different for straight lines and bended lines.

In the following sub-sections the processing times, MTTF, MTTR and destination table are determined.

Processing times

The processing times of the Pasteurizer and CPLs are not registered at MES. This means that there is no data available to determine a theoretical distribution. An empirical distribution is time consuming to measure and validate. Therefore we determine the processing times on the set points of the machine speed. As one can see in the Figure 5.8, the pasteurizer has two sources, one for the upper deck and one for the lower deck. The lower deck is the *left side* of the lines from the pasteurizer towards part I and the upper deck is the *right side.* As described in Section 3.2, the lower deck is always filled with SBs, due to the failure mode of the fillers. Therefore, we can state that the source of the lower deck produces more SBs compared to the upper deck. In order to determine the processing time of sources, we have done a test on the pasteurizer. This test determines the output of the pasteurizer measured over both sources, and was described in Section 3.2. The SBs were counted with a production counter. The partition of the deck was as follows:

- Lower deck: 39138 bottles per hour.
- Upper deck: 36257 bottles per hour.

The difference between the lower and the upper deck is 7,4%. This means that the upper deck should produce 7,4% less than the lower deck. The source at the upper deck has therefore a failure rate of 7,4%. This should make our model more realistic. In order to create relevant results, we make this a constant failure rate, so it would not influence our results that much. This means that the upper deck has a availability of 92,6% and we entered a MTTR of 1 minute. Therefore 92,6% of the total time, the upper deck has SBs at in feed.

The machine speeds of the CPLs are shown in Figure 5.9. Note that the speeds should be multiplied with factor 10. The use of batches requires that the machine speeds have the current setting.

Low_Speed_CPL112=3000	Low_ProcessingTime_CPL112=1.2000
Nominal_Speed_CPL112=4150	Nominal_ProcessingTime_CPL112=0.8675
High_Speed_CPL112=4675	High_ProcessingTime_CPL112=0.7701
Low_Speed_CPL111=3000	Low_ProcessingTime_CPL111=1.2000
Nominal_Speed_CPL111=4150	Nominal_ProcessingTime_CPL111=0.8675
High_Speed_CPL111=4675	High_ProcessingTime_CPL111=0.7701

FIGURE 5.9: MACHINE SPEEDS/PROCESSING TIMES

MTBF

To calculate the MTBF we use operating-dependent failures, this means that a machine can only have a breakdown when it is in operation. To determine the mean time between failures we will look at the production time between to machine failures, which means that we exclude starvation and blocking periods. In the information system MES, which is explained in Chapter 2, the information is stored. From the data in MES, we try to find a theoretical distribution. In Appendix B this approach is described.

Nevertheless we can conclude that for the machines there is no theoretical distribution that fits with the data from the process. Therefore we use an empirical distribution which is also explained in Appendix B.

MTTR

In order to calculate the MTTR we first have to consider the duration length of a machine failure. In MES there is a distinction between short (< 5 minutes) and long (>= 5 minutes) failures. The conclusion from a discussion with the production manager and operators is that short failures can be considered as incidents. These are for example fallen bottles and are not part of a pattern in the duration of the failure mode. For that reason we only consider the long failures. Appendix C describes the result of the analysis for determining a theoretical distribution of the MTTR in more detail. Regarding this appendix we can conclude that of the MTTR there is a theoretical distribution that fits the data from the process, namely the Weibull distribution. In Table 5.1, one can find the parameters of the Weibull distribution of both CPLs.

	Distribution	Parameters	
CPL111	**Weibull**	**α = 0.83029**	**β = 36.428**
CPL112	**Weibull**	**α = 0.78302**	**β = 28.755**

TABLE 5.1 – DISTRIBUTIONS WITH CORRESPONDING PARAMETERS - MTTR

Destination Table

In order to deliver these priorities as input to our simulation model, we developed a destination table. An example of a destination table in Plant Simulation is shown is Figure 5.10.

File Edit Format Navigate View Tools Help

	object 0	integer 1	integer 2	integer 3	integer 4	integer 5	integer 6	integer 7	integer 8	integer 9
object		.Models.PasteurCPL.I.I1	.Models.PasteurCPL.I.I2	.Models.PasteurCPL.I.I3	.Models.PasteurCPL.I.I4	.Models.PasteurCPL.I.I5	.Models.PasteurCPL.I.I6	.Models.PasteurCPL.I.I7	.Models.PasteurCPL.I.I8	
1	.Models.PasteurCPL.I.I11	1	1	0	0	0	0	0	0	
2	.Models.PasteurCPL.I.I21	2	2	1	0	0	0	0	0	
3	.Models.PasteurCPL.I.I31	3	3	2	1	0	0	0	0	
4	.Models.PasteurCPL.I.I41	0	0	3	2	1	1	0	0	
5	.Models.PasteurCPL.I.I51	0	0	0	3	2	2	1	0	
6	.Models.PasteurCPL.I.I61	0	0	0	0	3	3	2	1	
7	.Models.PasteurCPL.I.I71	0	0	0	0	0	0	3	2	
8	.Models.PasteurCPL.I.I81	0	0	0	0	0	0	0	3	
9										
10										
11										
12										

FIGURE 5.10: DESTINATION TABLE PART I OF LAYOUT

This destination table shows the priorities from the first layer at part I to the second layer at part I.

Warm-up period

We use initial conditions for the start-up and therefore the steady state behavior is not directly reached. The warm-up period is the period before the steady state is reached. The warm-up period should be determined in order to neglect warm up ‘problems’. To enter the steady state in our system, the first SBs should exit the system. This takes in our system 6 minutes for the CPL112 and 8 minutes for the CPL111, which is negligible. Therefore we do not use a warm-up period.

Number of replications

We have to determine the number of replications that should be done within an experiment. According Law (2006) we can use the replication-deletion method in order to determine the number of replications. By means of the number of replications we guarantee that the 95% confidence interval has a width of at most 5% of the mean. We use the following formula to compute the required precision: $\gamma' = \frac{\gamma}{1+\gamma}$. Where γ' is the required precision and has a value of: $\gamma' = \frac{0.05}{1+0.05} = 0.04619$. If the precision is not sufficient, another replication is executed in order to decrease the confidence interval half width until the required precision is achieved. In Table 5.2 the computation of the number of replications is shown. The required precision is achieved in replication **5** where the width of the confidence interval is lower than the relative error. This means that we will run 5 replications per experiment.

Replication	Data	Average	Variance	T-value	Relative error	Confidence interval width
1	461600	461600			0,047619	
2	427580	444590	578680200	12,7062	0,047619	0,48613901
3	448250	445810	293805300	4,302653	0,047619	0,095511502
4	435920	443337,5	220323225	3,182446	0,047619	0,053275405
5	423330	439336	245302430	2,776445	0,047619	0,044264771
6	451950	441438,3	222760777	2,570582	0,047619	0,035481758
7	402980	435944,3	396925895	2,446912	0,047619	0,042266183
8	468830	440055	475405971	2,364624	0,047619	0,041423091
9	401590	435781,1	580375361	2,306004	0,047619	0,042493735
10	461570	438360	582395889	2,262157	0,047619	0,039382294
11	456620	440020	554467900	2,228139	0,047619	0,03595106
12	454830	441254,2	522339736	2,200985	0,047619	0,032908964
13	459530	442660	504504200	2,178813	0,047619	0,030662698
14	411750	440452,1	533941049	2,160369	0,047619	0,030290872
15	466360	442179,3	540550207	2,144787	0,047619	0,029117766

5.2: NUMBER OF REPLICATIONS

5.4 Verification & validation

Verification and validation is an important part of our simulation study. A verified and validated model means that we can use our model to run experiments, and assures that the model mimics a real life situation. Below we discuss briefly the meaning and importance of verification and validation.

Verification

Verification is the process to ensure that the simulation model is correctly implemented with respect to the conceptual model. Verification is practically seen as debugging the simulation model, which can be done with several tools. The tracing function within simulation is very useful, and mostly used in Tecnomatix Plant Simulation. There is a possibility to use 'breakpoints' which in order to go through a method, step by step. In this way, different parameters can be controlled which contributes to the verification of the model. This function helps to debug the code and fix programming mistakes.

Another verification tool within Tecnomatix Plant Simulation is the animation. By running experiments, there is a possibility to have a look at the Movable Units. This animation makes us aware if MUs stuck on a certain conveyor. When this is the case, we know that there is a bug in our model otherwise the MUs will move to the next conveyor.

The last possibility to check the verification of our model is to compare the output of the model with the input, which should be equal if no MUs remain in the system. To further verify the simulation model we check how this aspect sustains regarding the output, when we change the input variables, e.g., distributions and processing times. We used all of these verification tools in order to check our simulation model.

Validation

When the verification of the model is done, we continue with the validation. Validation of the model measures the accuracy of the simulation model, with reality. There are several options to measure validation. Sargent(2005) states that a possibility to measure the validity of the model, is to determine the output quantity of the MUs. Furthermore the *lead time* is important in order to validate our model. In order to check the lead time we consider the output quantities over a time period of 8 hours. The output of our simulation model compared with the output in real life is shown in Table 5.3. Furthermore the production balance is checked in order to validate the model. The production balance consists of the production quantity between the CPLs. CPL111 produces in real life 55% of the total output and CPL112 produces 45%. As shown in Table 5.3, the difference between real life and the simulation model is sufficiently small. **Even note that the production balance in our simulation model is 55,15% (CPL111) against 44,85% (CPL112).**

	Output = (crates * # of btls. in crate)	Real life	Simulation model - # of SBs
CPL111	**Output**	(18109 * 24) * 0,55= 239038 btls.	253100 btls.
CPL112	**Output**	(18109 * 24) * 0,45= 195577 btls.	206990 btls.

TABLE 5.3 - VALIDATION OF SIMULATION MODEL

In Chapter 7 we discuss the implementation of an alternative solution. The results after the implementation confirm the validation of our model. The results of the implementation are discussed in Section 7.2. Also the real life output before and after the implementation is compared, which supports the validation in this section.

5.5 Experimental design

In Section 5.2 we mentioned that there are several experimental factors for the configuration of the experiments. The main experimental factors are the location of the sensors and the number of speed levels of the CPLs. When considering all sensors and a lot of number of speed levels, the number of experiments will be too high which takes too much calculation time. Therefore, it is necessary to make a well-advised decision about which factor should be taken into account. The rayon manager and installation administrator are asked for advice to make that decision, after the improvement team proposed some recommendations.

The first decision is that the moment of switching of the CPLs should be programmed on current locations of the sensors. This means that it is not possible to choose random positions to switch to another speed of the CPLs. The current positions of the sensors should be used. This makes a potential solution less expensive because sensors do not have to be displaced.

Furthermore the different speed levels of the machines will be **three** or **four**. CPL112 has at the current situation no *low speed* and therefore it has only three speed levels. CPL111 has four speed levels, which are:

1. Down.
2. Low.
3. Nominal.
4. High.

In the past, multiple improvement teams have determined the ideal amount of speed levels. These differ per machine, but labelers at other production lines at HEINEKEN vary at three or four levels. To reduce the amount of experiments we agree with three or four levels. Thus at CPL112 we should add a position of a sensor and at CPL111 we should skip one sensor in a certain experiment.

The improvement team made some recommendations to the management, in order to reduce the amount of experiments. In these recommendations they have taken the problem definition and KPIs into account. These were an optimal production balance, and a high output of the CPLs. The conclusions are some specific possible positions of sensors. These positions will be taken into account in order to reduce the amount of experiments. There are 17 sensors where the speed of CPLs can be regulated with, as described in Section 3.2. The current layout of the CPLs concerning the change of speed is shown again in Appendix F and Appendix G. Trying to combine and change all these sensors together with the different speed levels will not be realistic for the experiment. Therefore we will use the sensors that are recommended by the improvement team and approved by the management. These are the most relevant scenarios for our simulation study.

Possible options for our simulation study are shown in Figure 5.11. The sensors colored green will be neglected in our simulation study for several reasons. Sensors 1 till 7 are too close to the pasteurizer, and are used to determine the speed of the pasteurizer. When we use these sensors for changing the speed of the CPLs, the risk that the pasteurizer will create blockage will increase significantly. This has a reverse result on the desired situation. Sensor 9 will not be used because we use sensor 8. As described in Section 5.4 the lower deck from the pasteurizer is always filled. Skipping the use of sensor 9 will decrease the amount of experiments, without having any influence on the outcome. Sensors 15 and 16 will be neglected because these sensors serve for a security. When these are not triggered the line has an emergency shutdown. If not, the CPLs will be damaged. When there are no SBs, the labels stick in the machine. Sensor 11 is neglected because, according the improvement team, this has little value when also sensor 13, 14 and 17 are regulating CPL111. Sensor 11 regulates conveyor K, and therefore it is positioned at that location. The colors in Figure 5.11 mean that these will change over the experiments. Sensor 12 (yellow) and sensor (17) are only considered that the CPLs have a low speed or will not (on/off).

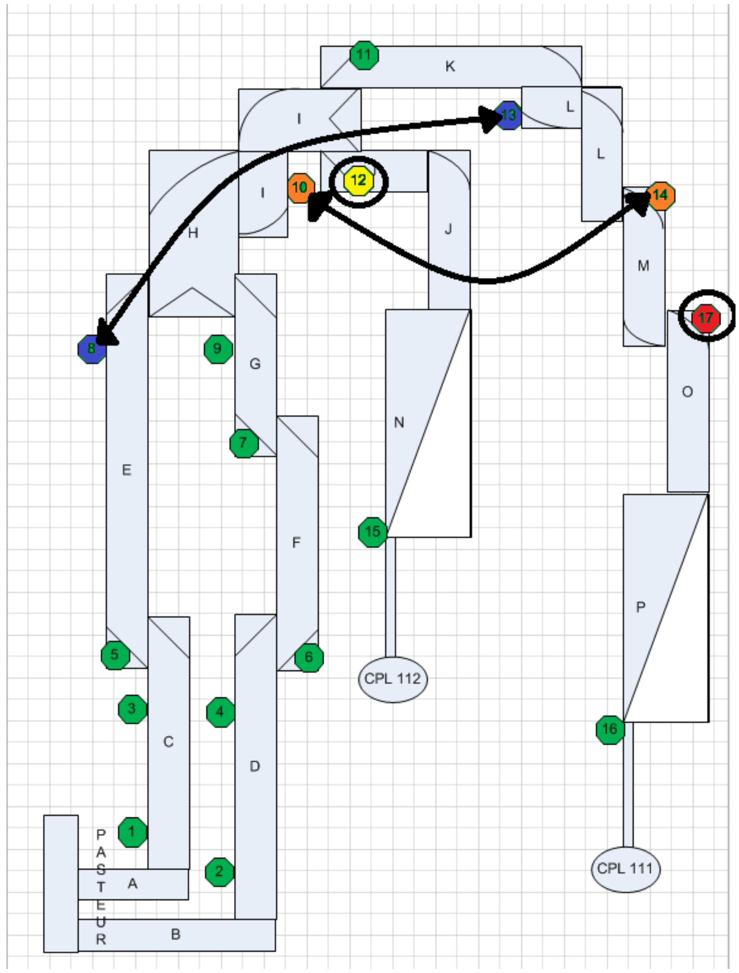

FIGURE 5.11: POTENTIAL SENSORS FOR CHANGING SPEED OF CPLS IN EXPERIMENTS

Besides this figure one should consider Table 5.4. In this table the experimental changes are shown. These are beforehand discussed with the management as mentioned earlier. One remark on this table is, that when a sensor of a higher speed is triggered, the sensor of the lower speed is overruled. For example when in the current situation sensor 13 is triggered, so CPL111 changes to high speed , then sensor 14 is overruled until sensor 13 is not triggered anymore.

As we can see in Table 5.4, we have 4 different factors which have two different speed levels. N**o low speed** means that the CPLs directly change to the nominal speed, so only three speed levels are available. Thus, at the moment CPL112 has no low speed, and the alternative situations checks if is valuable to add a low speed on the CPL112 on sensor 12. The colors are equal to those of Figure 5.11, so one can see what is changing. This means that we have 2^4= 16 different experiments. This amount of experiments is realistic. However, there is one combination that is not valid. It is not relevant to change from low speed to high speed and then change to nominal speed. This situation would occur if sensor 10 and sensor 13 will be in an alternative solution. This combination will be excluded, and therefore we have only 12 different experiments. Table 5.5 shows the different experiments. *Note that the first experiment is the current situation.*

Machine – ‘Change to’	Current situation	Alternative situation
	Triggered Sensor	Triggered Sensor
CPL112 – Low speed	No low speed	Sensor 12
CPL111 – Low speed	Sensor 17	No low speed
CPL111 – Nominal speed	Sensor 14	Sensor 10
CPL111 – High speed	Sensor 13	Sensor 8

5.4: SPEED CHANGES DEPENDENT ON SENSORS - CURRENT AND ALTERNATIVE SITUATION

The speed changes from Table 5.4 are translated into the letters in Table 5.5. The letters correspond with the conveyors given in Figure 5.11. These are explained below:

NOSPEED : No low speed
O4 : Sensor 17
M4 : Sensor 14
L111 : Sensor 13
I8 : Sensor 10
E51 : Sensor 8
J4 : Sensor 12

The columns of Table 5.5 consist of changing the speed of the machine indicated. First column therefore means: changing low speed of CPL112.

	CPL112 <> low speed	CPL111 <> low speed	CPL111 <> nominal speed	CPL111 <> high speed
Experiment 1	NOSPEED	O4	M4	L111
Experiment 2	NOSPEED	O4	M4	E51
Experiment 3	NOSPEED	O4	I8	E51
Experiment 4	NOSPEED	NOSPEED	M4	L111
Experiment 5	NOSPEED	NOSPEED	M4	E51
Experiment 6	NOSPEED	NOSPEED	I8	E51
Experiment 7	J4	O4	M4	L111
Experiment 8	J4	O4	M4	E51
Experiment 9	J4	O4	I8	E51
Experiment 10	J4	NOSPEED	M4	L111
Experiment 11	J4	NOSPEED	M4	E51
Experiment 12	J4	NOSPEED	I8	E51

TABLE 5.5: EXPERIMENTS

Running all these experiments takes s certain period. In order to calculate how long it takes to run all experiments we determine the total run time. The total run time of all experiments is, 2.5 hours (= $\frac{60\ (Number\ of\ experiments) * 2.5\ (\ run\ time\ per\ experiment\ in\ minutes)}{60 (convert\ minutes\ to\ hours)}$).

5.6 Conclusion

We started this chapter with the explanation of two possible methods to analyze our problem. Then we described our conceptual model and explained the simplifications from reality. We used this conceptual model to build our simulation model. We looked at the processing times, MTBF, MTTR and the destination table. Furthermore we determined the warm-up period and the number of replications in order to run our experiments. After designing this model, we verified and validated the simulation model. We can conclude that our simulation model is valid. The experimental factors of the simulation model are the positions of the sensors and the number of speed levels. This covers the last section of this chapter. We described why we have chosen for the different experiments.

6. Experimental results

In this chapter, we discuss the results that are retrieved from our simulation model. In Section 6.1, we first introduce how we compute the scores of the experiments. We use different performance measures and therefore we have to determine the weight. In Section 6.2 we describe the results of the experiments and consider alternatives to improve the current situation. In Section 6.3 we make a risk analysis in order to assess the new settings in real life. In Section 6.4 we will write a conclusion of the experiments.

6.1 Performance measures

First we will describe the different performance measures. In Section 5.2 the different performance measures are mentioned, but one can find them below:

- *Production/ Output quantity.* The total quantity that is produced with both CPLs, which consists of the output of our model.
- *Production balance*. The production balance between the CPLs.
- *Time of machine failure.* The failure time of the CPLs.
- *Stopping time of a machine.* The stopping time of the CPLs is dependent on the position of the sensors. When sensors are positioned inefficiently, the stopping time will increase.
- *Time of waiting of a machine.* The waiting time of the machine is dependent on the output of the pasteurizer. The waiting time increases when the upper deck of the pasteurizer has a higher failure rate.

The stopping time together with the waiting time is the starvation time of a CPL. It means that the efficiency of the positions of the sensor together with the failure rate of the upper deck of the pasteurizer, determine the starvation time. In this research we measure the stopping and waiting time separate, but we look at the total starvation time of the CPLs to determine the results. The blockage time is neglected because this state is for the conveyors after the CPLs, which is not part of this research.

In consultation with the management, there is decided that the output quantity is by far the most important performance measure. The output quantity of the production line at HEINEKEN is used in order to measure the line performance. Nevertheless the production balance is also very important to reduce the start/stop situations, as discussed in Section 3.1. Start/stop situations will increase the failure rate of a machine, which is the philosophy of the supplier and is confirmed by the management of HEINEKEN. The combination of start/stop situations and the failure rates is not included in our simulation model, but should be included to determine the best alternative solution. Therefore is the production balance an important measure to compare the alternatives. According the management at HEINEKEN these two performance measures are far more important than the other three performance measures, mentioned in the bullet points. We could use a graph to get a first impression of the results. Thereafter we could use weights to include the last three bullet points. The combination of these tools will underpin our choice for the best solution. First we discuss the results of the experiments, which is done in the next section.

6.2 Simulation results

This section covers the simulation results from the experiments. As mentioned in Section 5.6 the first experiment contains the current situation. Therefore we start with the results of the first experiment, then we describe the rest of the experiments.

Current situation

The total average output of experiment 1 is 441313 bottles per shift, with a production balance of 57% on CPL111 and 43% on CPL112. The other performance measures are shown below in Table 6.1.

	CPL111	CPL112
Waiting	0,78%	38,08%
Stopping	28,99%	0,00%
Failure	2,22%	0,85%

6.1: RESULTS EXPERIMENT 1 CONTINUED

As mentioned in the previous section, the waiting time + the stopping time is the starvation time. We can conclude that the starvation time of CPL111 (29,77%) is less than on the CPL112(38,08%).

All experiments

As mentioned in Section 6.1 we use the two most important performance measures, in order to get a first impression of the best alternative. In Figure 6.1 we show all the experiments in a graph, with on the X-axis the output quantity and on the Y-axis the production balance. The experiment which lies the closest to the 50% (marked with the red line) **and** the closest to the 460,000 is the best option. Experiments located above the red line have more SBs produced on the CPL111 than the CPL112, and for experiments below the red line it is the reverse. Consider Figure 6.1. Option 1 is the *current* situation and option 6 is the best alternative. Alternative 6 scores the best on both performance measures. The second best will be 10 or 12, depending on the weight of the performance measure as described in the previous section.

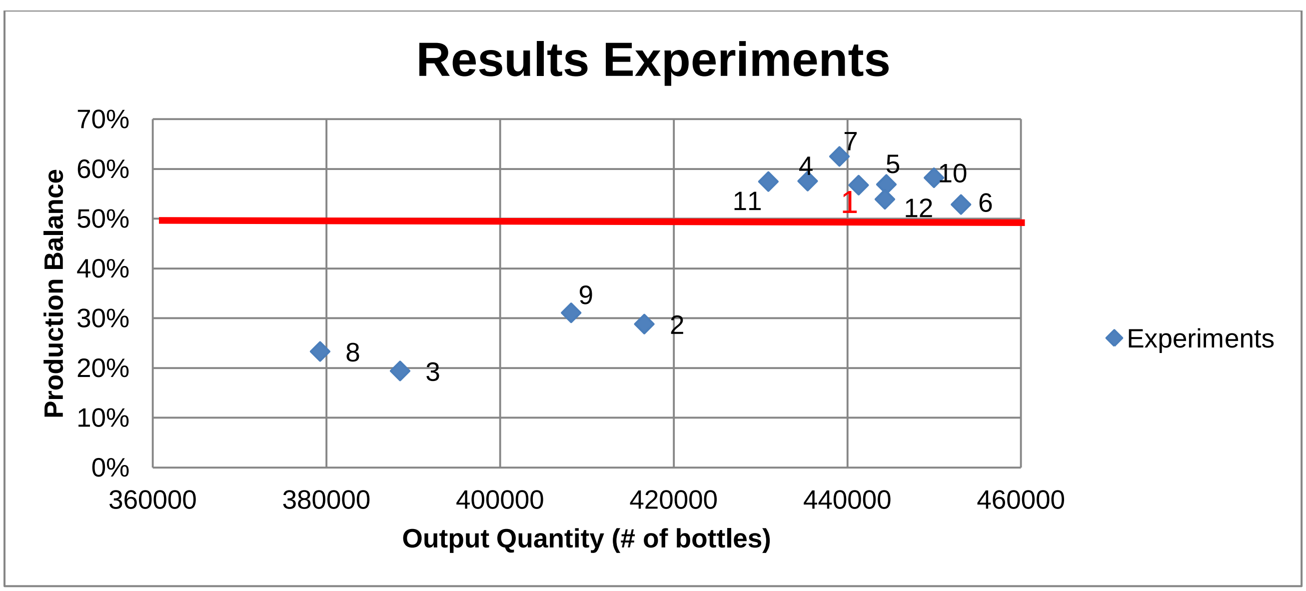

FIGURE 6.1: RESULTS OF EXPERIMENTS REGARDING OUTPUT AND BALANCE

In Table 6.2 all the results from experiments 1 till 12 are shown. The stopping time and waiting time are combined as the starvation time. In Appendix H the whole table, including the stopping time and waiting time is shown. Looking at the starvation time and the failure time we see that alternative 6 is the best solution. The second best solution is alternative 10 or alternative 12. As mentioned earlier, the management's main target is to increase the output quantity and then option 10 would be preferable. Also the starvation percentage of experiment 10 is lower which means that this performance measure is also better in experiment 10.

As one can see in Figure 6.1: Results of experiments regarding output and balance, experiments 8 and 3 have a lower output quantity compared with the other experiments. When all buffers are completely filled with star bottles, the source will stop producing. This means that when sensors are positioned inefficiently and therefore the output reduces, a **source block** will occur. The source block is in line with the *Uniformity Principle* (Kwo, 1958) explained in Section 4.4.This principle states that the input quantity equals the output quantity.

Experiment	**Output (# of bottles)**	**Production balance**		**Starvation**			**Failure**	
	Average	CPL111	CPL112	CPL111	CPL112	Total	CPL111	CPL112
1	441313	57%	43%	29,77%	38,08%	67,85%	2,22%	0,85%
2	416625	29%	71%	67,77%	9,51%	77,28%	0,43%	1,33%
3	388495	19%	81%	69,40%	7,03%	76,42%	1,03%	0,24%
4	435440	58%	42%	1,72%	39,03%	40,75%	1,65%	0,54%
5	444508	57%	43%	0,82%	38,79%	39,61%	1,20%	0,18%
6	453103	53%	47%	0,01%	30,61%	30,62%	1,42%	0,04%
7	439100	62%	38%	24,65%	48,17%	72,82%	0,84%	0,13%
8	379278	23%	77%	76,67%	10,80%	87,47%	0,46%	1,36%
9	408198	31%	69%	66,44%	13,59%	80,03%	0,39%	1,06%
10	449990	58%	42%	2,90%	28,48%	31,38%	1,99%	1,03%
11	430915	57%	43%	0,78%	37,09%	37,86%	2,83%	0,86%
12	444338	54%	46%	0,08%	33,84%	33,92%	0,78%	0,80%

6.2: RESULTS EXPERIMENTS 1 TILL 12

Experiment	Output	Production balance		Waiting		Stopping	
	Average	CPL111	CPL112	CPL111	CPL112	CPL111	CPL112
1	441313	57%	43%	0,78	38,08	28,99	0,00
2	416625	29%	71%	0,05	9,51	67,71	0,00
3	388495	19%	81%	0,00	7,03	69,40	0,00
4	435440	58%	42%	1,72	39,03	0,00	0,00
5	444508	57%	43%	0,82	38,79	0,00	0,00
6	453103	53%	47%	0,01	30,61	0,00	0,00
7	439100	62%	38%	2,45	0,00	22,20	48,17
8	379278	23%	77%	0,03	1,39	76,64	9,41
9	408198	31%	69%	0,00	1,34	66,44	12,25
10	449990	58%	42%	2,90	8,77	0,00	19,71
11	430915	57%	43%	0,78	34,63	0,00	2,46
12	444338	54%	46%	0,08	33,33	0,00	0,51

6.3: Experiment 10 vs 12

Correlation

In Figure 6.2 we consider the results of the experiments again, but now we determine if there is a correlation with the production balance and the output quantity. In first instance it seems that there is a correlation between the performance measures. Nevertheless, there should be some correlation because one CPL cannot produce more than 360,000 bottles (45,000btls/hr*8hr) bottles. Thus when the production balance is out of proportion, the output quantity should be less than average.

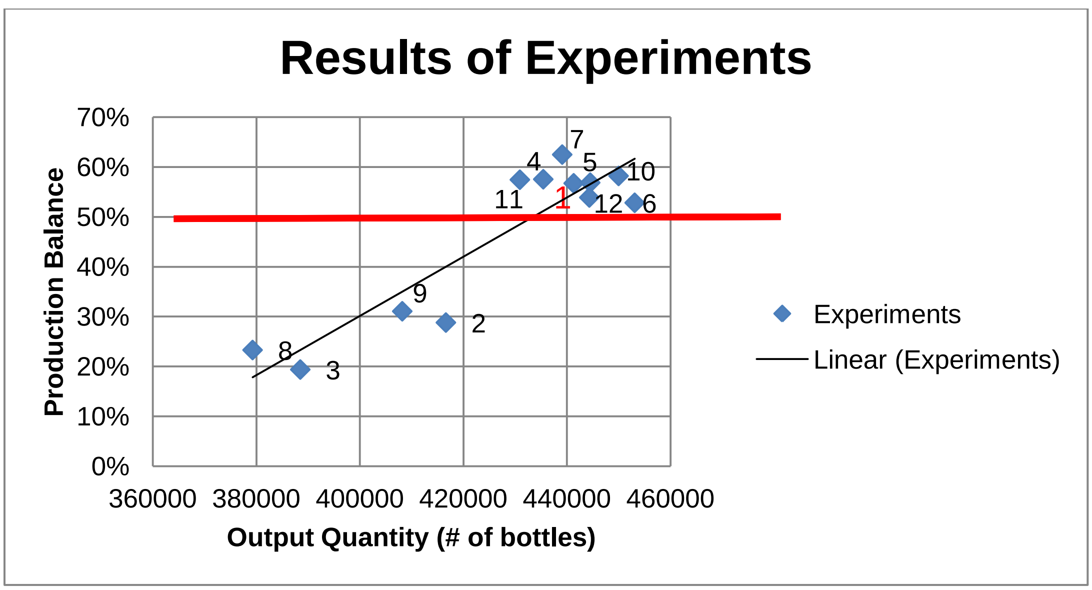

FIGURE 6.2: CORRELATION PRODUCTION BALANCE AND OUTPUT QUANTITY

When we consider all the experiments above the red line, which mean that the CPL111 produces more than the CPL112, we see no clear correlation. Nevertheless we see that all the experiments close to the red line have a higher output quantity. Overall this means that there is some correlation. Therefore we conclude that, over all experiments, an equal production balance (50/50) increases the output quantity. This means that we conclude that an equal production balance improves the output quantity, and therefore the line performance.

In order to determine if there is a correlation between the starvation and output, we consider Figure 6.3.

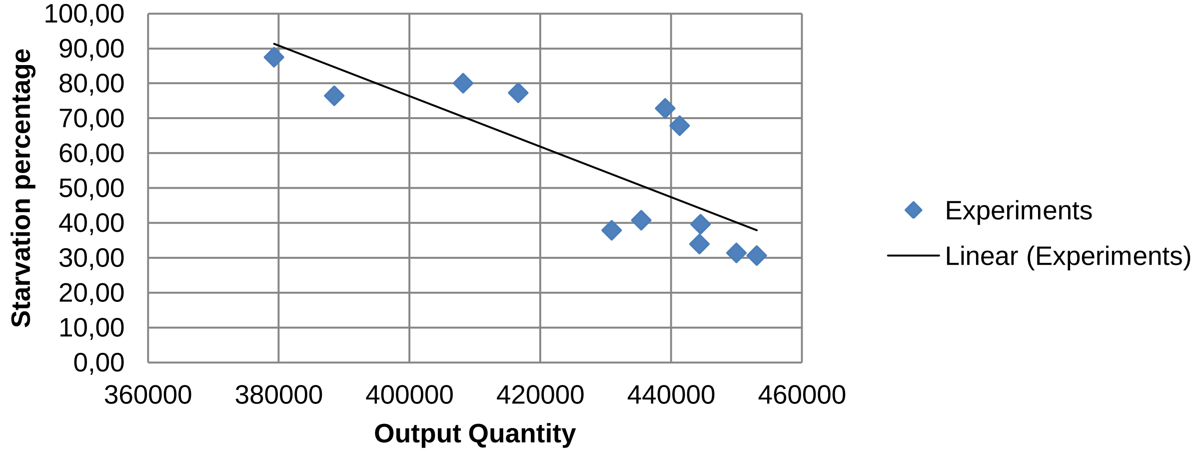

FIGURE 6.3: CORRELATION STARVATION PERCENTAGE AND OUTPUT QUANTITY

In Figure 6.3, we weigh the starvation percentage with the output quantity. We can conclude that there is a negative correlation between the two performance indicators. This means that when the starvation percentage decreases, the output quantity increases. This is obvious because when a CPLs in starvation, it cannot produce.

The next correlation that we check is the starvation percentage with the production balance. These performance indicators are shown in Figure 6.4.

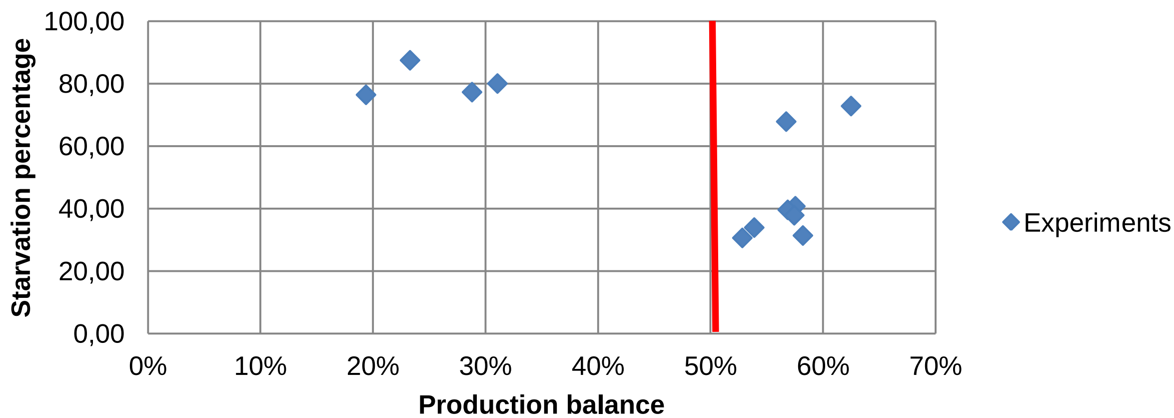

FIGURE 6.4: CORRELATION STARVATION PERCENTAGE AND PRODUCTION BALANCE

In this figure there is no obvious correlation between the starvation percentage and the production balance. Nevertheless we see that the experiments with a production balance around the 50/50 (60/40) have a lower starvation percentage. This conclusion fits the explanation in Section 3.2, where the bend conveyor in part I is described. The conclusion from this section was that when a shift has a starvation percentage above average, the CPL111 produced more bottles than CPL112. This was because the SBs have the tendency to transfer to the outer of the bend. This matches with the results from our experiments. Nevertheless, when considering the best experiments regarding the production balance, we see no correlation with the starvation percentage.

Experiment	CPL112 + low speed	CPL111 - low speed	CPL111 <> nominal speed	CPL111 <> high speed
Current	NOSPEED	O4	M4	L11
6	NOSPEED	NOSPEED	I8	E51
10	J4	NOSPEED	M4	L11
12	J4	NOSPEED	I8	E51

6.4: SENSOR POSITIONS TOP 3 ALTERNATIVE SOLUTIONS

Remarkable on Table 6.4 is that experiment 10 is close to the current situation and experiment 6 and 12 are different in almost every setting. It is remarkable because this proves that the combination of sensors is far more important the sensors itself. Furthermore we can conclude that the amount of speed levels at CPL111 decreases at all the three alternative solutions. In experiment 10 and 12, the amount of speed levels on the CPL112 increases to three.6.4: Sensor positions top 3 alternative solutions

6.3 Risk analysis

In our simulation model we assumed a constant input from the pasteurizer because these numbers are not available at HEINEKEN. Nevertheless, it is important to have a critical view on the performance of the pasteurizer when we want to implement our new experiment. When an experiment creates a higher risk for the blockage of the pasteurizer for any reason, the experiment will not be implemented. Factors as fallen bottles are not taken into account because these are very unpredictable, not measurable and hard to include. The blockage of the pasteurizer should be measured and therefore we will compare the current situation (experiment 1) with the best alternative solution (experiment 6).

When we implement experiment 6, this means that during a starvation on the CPLs, the buffer comes closer to the pasteurizer. In Figure 6.5 the difference in buffer capacity between the two experiments is shown. The left figure shows the current situation and the right figure shows the new alternative.

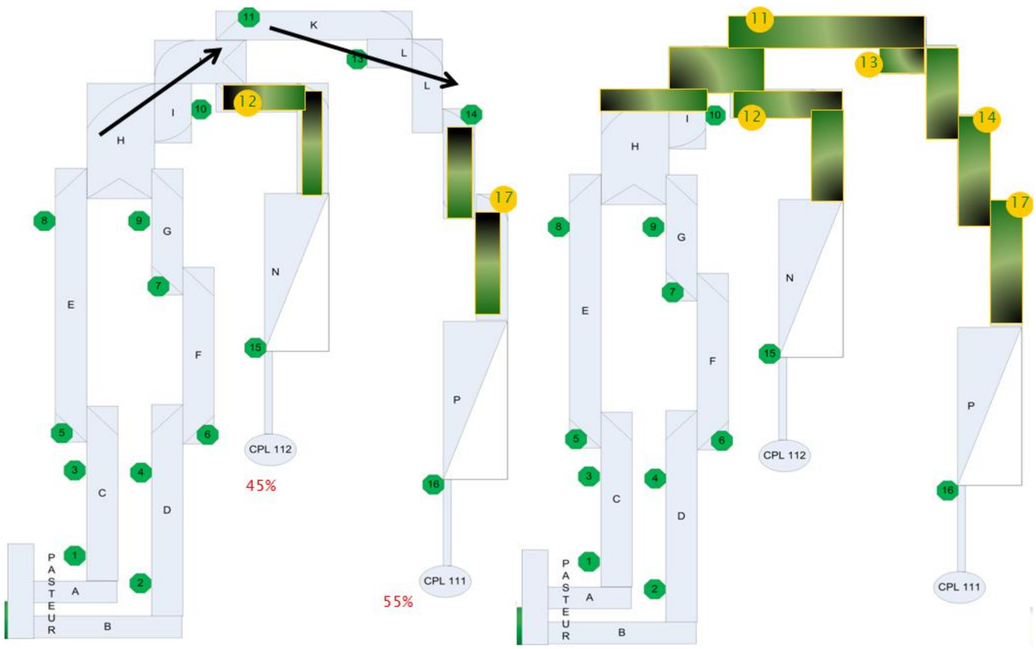

FIGURE 6.5: BUFFER POSITION – CURRENT (LEFT) AND NEW SITUATION (RIGHT)

The first positive result from the change in buffer capacity is that the problem with the bend is solved. At the current situation the problem arises that after a starvation all bottles move to CPL111 and assumed was that this was the reason for a production imbalance. With the use of the buffer before the bifurcation we solved this problem. Nevertheless, the change of buffer capacity also has negative effects. The buffer capacity during a starvation in the new alternative is lower than the capacity in the current situation. This means that the risk that the pasteurizer creates blockage increases when after a starvation period, a CPL fails. Despite the fact that the blockage of the pasteurizer is included in our simulation model, we want to exclude any contingencies.

Therefore we consider the capacity of the buffer in the new situation. In Figure 6.5 the difference in buffer size is shown with the red part. The capacity of the red part is 2517 SBs. This means that in the current setting, when the CPLs have starvation, CPL111 produces 2517 SBs more than CPL112. In addition, in the current situation the CPL111 starts at high speed when CPL112 is still down. On average this is 5 minutes, which means that another 3500 SBs are produced by CPL111 until CPL112 starts producing. When we combine these SBs, we can conclude that by every starvation, CPL111 produces 6017(=2517+3500) SBs more than CPL112. The calculations of the buffer capacity are explained in more detail in Appendix I.

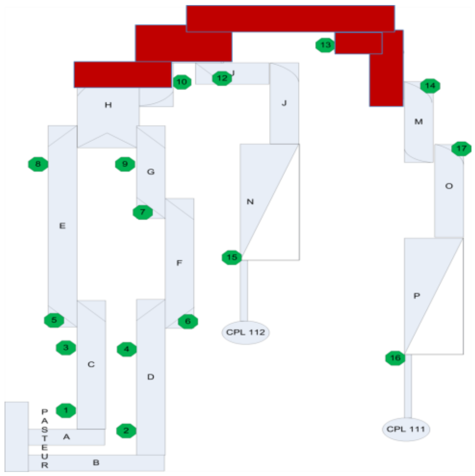

FIGURE 6.6: BUFFER ENLARGEMENT - CURRENT VS NEW ALTERNATIVE

Considering the new alternative solution, both effects will be solved. In the new situation CPL111 and CPL112 will start and end simultaneously on sensor 10. This means that the buffer stops before the bifurcation. The negative result of the change in buffer capacity is, as mentioned before, that the risk increases that the pasteurizer will create blockage. In order to consider this risk we consider Figure 6.7 The capacity from the pasteurizer till the new buffer location is 7576 SBs. Consider Table 6.5.

		Speed pasteurizer	per	buffer	Time to fill with SBs
Cap. Pasteurizer		Bottles	minutes	bottles	minutes
Red part Figure 6.6	100%	80000	60	2517	1.38
Blue part Figure 6.7	100%	80000	60	7576	5.08

6.5: RISK ON PASTEURIZER IN MINUTES

As shown in this table, we see that it takes 1.38 minutes to fill the red part and 5.08 minutes to fill the lines from the pasteurizer till the buffer (blue part).

In the current situation the buffer is located at 6.36minutes from the pasteurizer and the new situation the buffer is 5.08minutes from the pasteurizer. This means that the risk on blockage at the pasteurizer is increased with 1.28 minutes.

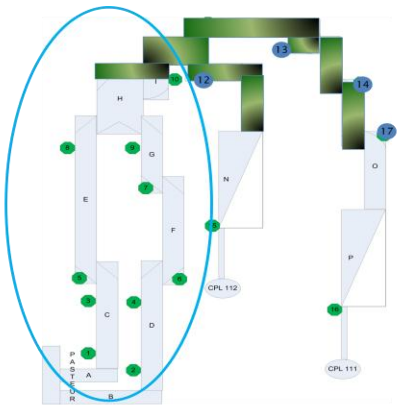

FIGURE 6.7: DETERMINING CAPACITY PASTEURIZER-BUFFER – BLUE PART

Nevertheless, there is a possibility to move the buffer closer towards the bifurcation. This is possible by implementing a delay of 30 seconds on sensor 10. The 30 seconds is determined by measuring the time it takes from sensor 10 to the bifurcation, which is done on the production line. This means that, according to the calculations in Appendix I, the risk on blockage at the pasteurizer is reduced with 30 seconds. The fact remains that the new solution still has a risk of 0.58 minutes more than the current situation.

Therefore we looked at the probability that a CPL is in failure for more than 5.38 (=5.08+0.30) minutes. Table 6.6 shows the amount of long failures in the month August. The whole table is shown in Figure 8.4, Appendix I.

	Long Failures (> 5 min)
CPL 112	46
CPL 111	36
total	82
2,928571429	per 24u
0,976190476	per shift
average less than 1x per shift	

6.6: NUMBER OF LONG FAILURES CPLS

We can conclude that the risk of implementing the new solution is that on average, one time per shift the pasteurizer creates a blockage of 0.58 seconds more than the current situation. In 0.58 seconds the pasteurizer produces approximately 1300SBs (80,000/60 = 1333 per minute).

Comparing this amount with the amount of SBs that experiment 6 yields over the current situation it is still the best solution to implement experiment 6, as one can see in Table 6.7. With an output of 452903 experiment 6 is still the best experiment. Even when we consider experiment 2, which does not change the location of the buffer, experiment 6 is the best solution.

Rank	Experiment	Output	Buffer	Real Ouput
		Average		Average
Current:	1	441313		441313
1st	6	453103	1300	452903
2nd	10	449990		449990
3rd	12	444338	1300	443038

6.7: CONCLUSION RISK ANALYSIS

Therefore we finally conclude that experiment 6 should be implemented on the SB production line at HEINEKEN.

6.4 Conclusions

The conclusion of all the experiments of is that the following experiments ranked 1st, 2nd en 3rd:

Rank	Experiment	Output	Production balance	
		Average	CPL111	CPL112
Current:	1	441313	57%	43%
1st	6	453103	53%	47%
2nd	10	449990	58%	42%
3rd	12	444338	54%	46%

6.8: BEST THREE ALTERNATIVE SOLUTIONS

This means that the current regulation should be changed into the settings of experiment 6. Translating the Table 6.4 into the different sensors will result in the following Table 6.9

Experiment	CPL112 + low speed	CPL111 - low speed	CPL111 <> nominal speed	CPL111 <> high speed
Current	NOSPEED	Sensor 17	Sensor 14	Sensor 13
6	NOSPEED	NOSPEED	Sensor 10	Sensor 8
10	Sensor 12	NOSPEED	Sensor 14	Sensor 13
12	Sensor 12	NOSPEED	Sensor 10	Sensor 8

6.9: SENSORS OF BEST ALTERNATIVES

The new regulation of sensors of experiment 6 is visualized in Figure 6.8 and Figure 6.9.
Furthermore we conclude that the amount of speed levels at CPL111 will reduce from three levels to two levels. This means that the amount of speed levels of the CPLs is the same in the new situation.

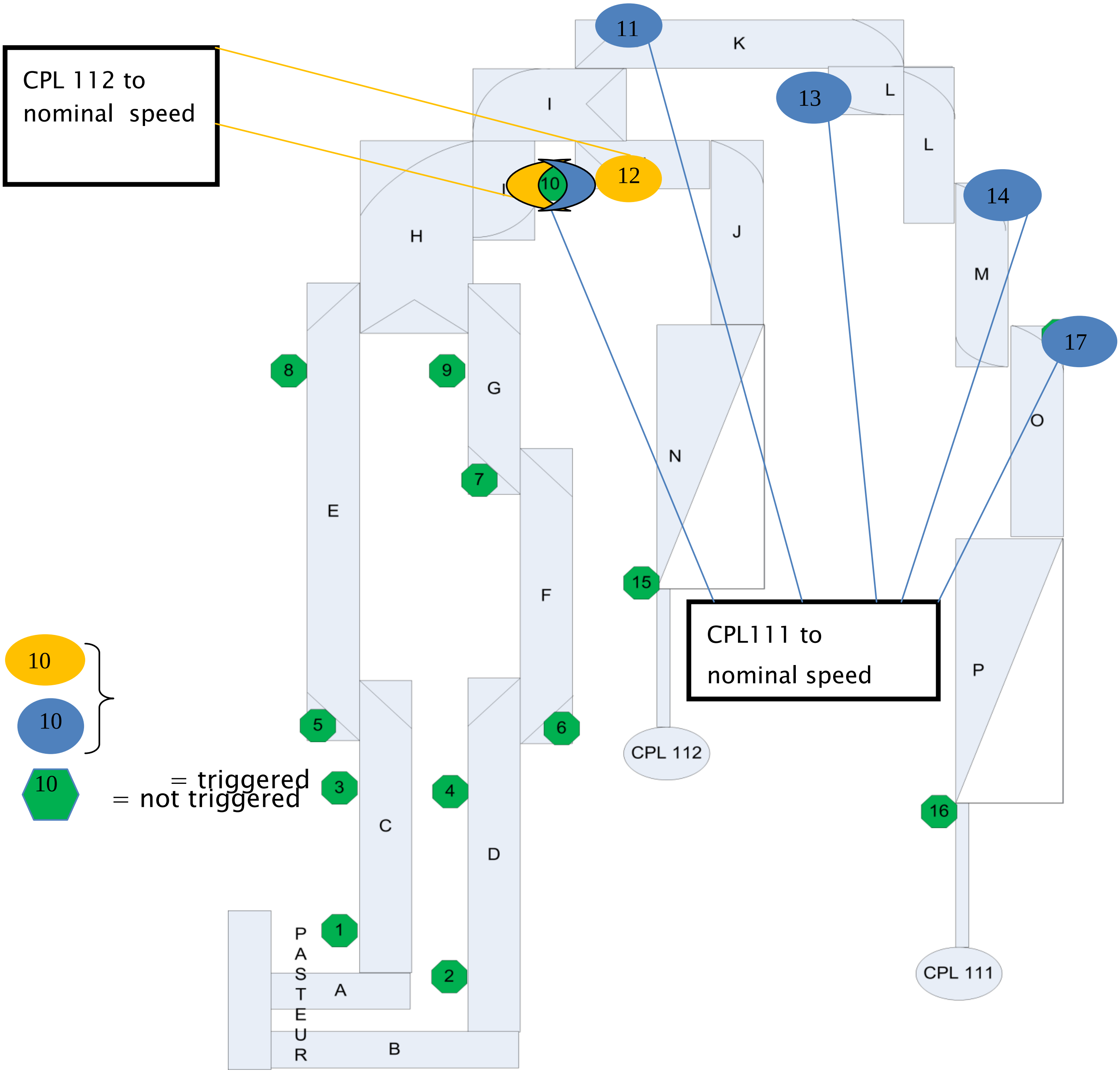

FIGURE 6.8: NEW SITUATION CPLS TO NOMINAL SPEED

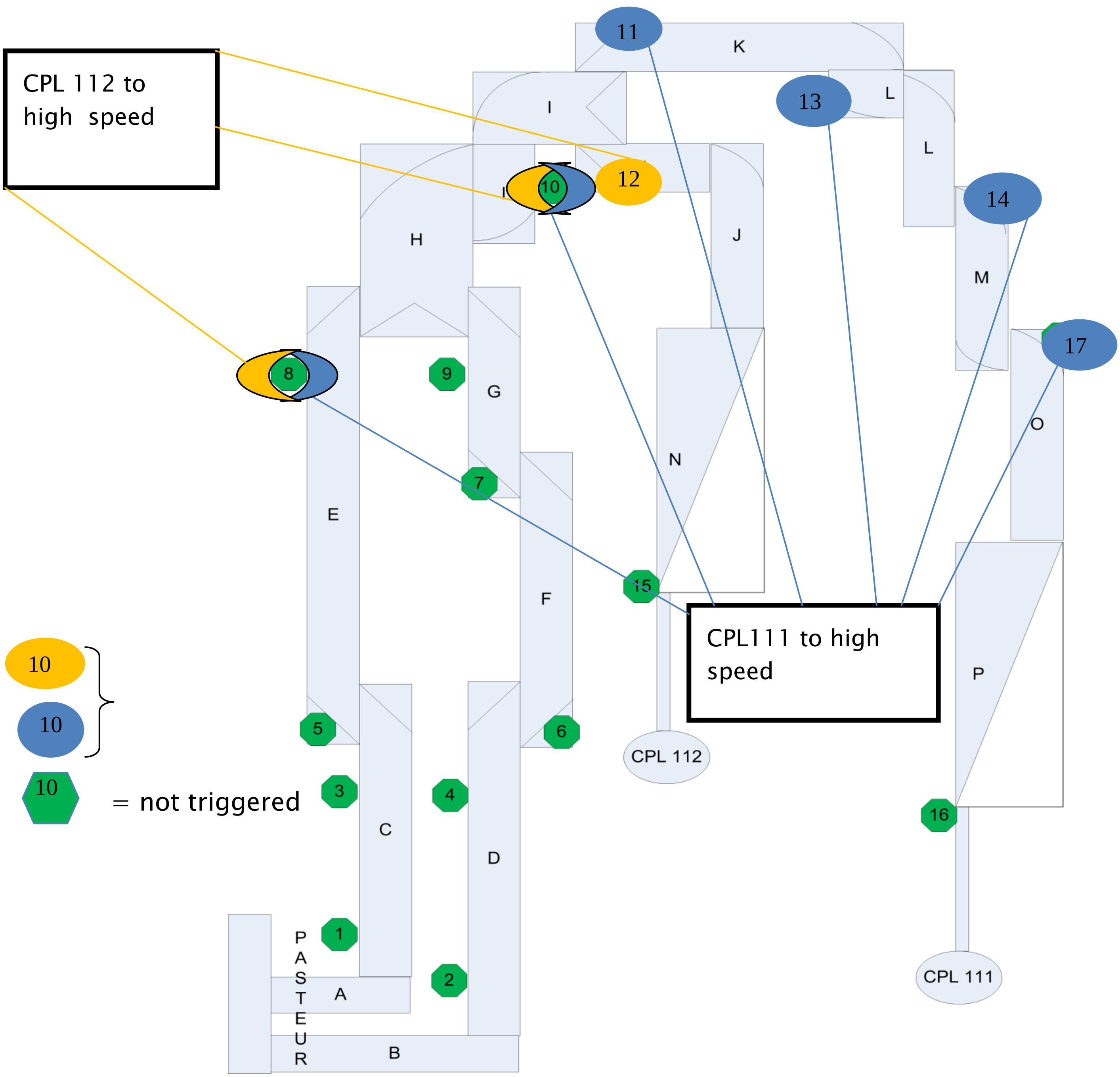

FIGURE 6.9: NEW SITUATION CPLS TO HIGH SPEED

7. Implementation

In this chapter, we discuss how the results from our experiments can be implemented at production line 11 at HEINEKEN. In Section 7.1 we describe the implementation procedure. In Section 7.2 we describe some preliminary results of a first implementation attempt. At last we formulate the savings of the implementation in Section 7.3.

7.1 Implementation Procedure

In order to implement experiment 6 we need one resource. This resource is an expert of PA-/PI engineering, the software department of HEINEKEN. Every conveyor part (in the simulation model shown as: A, B, .. , InlinerP) has its own regulation which is programmed in the software. Also the different sensors with their actions are programmed. For example, *if sensor 10 is triggered than the processing speed of CPL111 & CPL111 move to 30,000 bottles per hour*, is programmed in a code. This programming langue differs from the language we use in our simulation program, and therefore we need an expert to implement our solutions. These programming skills are out of scope for this research.

Nevertheless, the experts implemented our solution and therefore it is possible to check if the results have a positive influence on the line regulation, as we expected beforehand. This is done in the next section.

7.2 First results after implementation – 8hr shift

After the PA-/PI engineer implemented our solution, the modification is tested for 8 hours (1 work shift). Actually we should test the modification for several weeks, but this cannot be realized in this research. Therefore we show the results after an 8hr work shift.

The first improvement is that the problem described in Section 3.2 is solved. The situation of this problem is shown at the left in Figure 7.1 and was the result of a bad line regulation. After a failure on CPL111, the sensor before the bending conveyor was not hit by SBs, but after our modification this was solved and is shown at the right. We moved the buffer before the bifurcation as described in the previous chapter and therefore we assured that the sensor is hit.

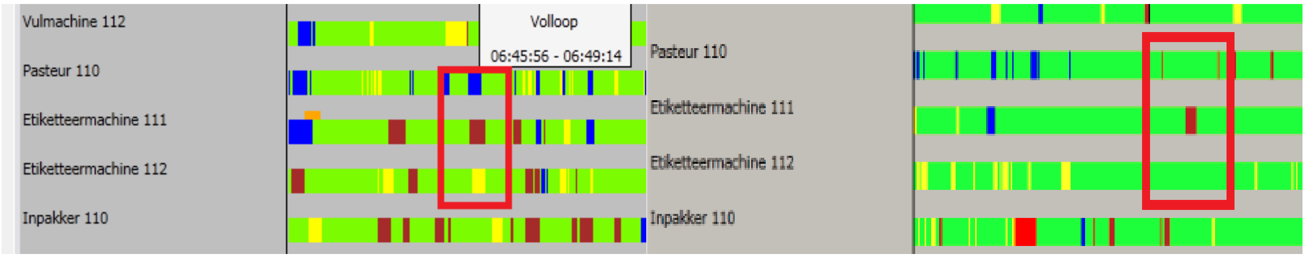

FIGURE 7.1: BEFORE (*LEFT*) AND AFTER (*RIGHT*) THE IMPLEMENTATION OF MODIFICATION

In Section 3.2 we stated that these inefficiencies take 5 minutes per shift, which are solved now. More examples of the DNA strands *before* the implementation are shown in Appendix A.

The second improvement is on the CILT activities. As described in Section 3.1 the CILT activities on CPL111 were higher than those of CPL112. CILT is described in Section 4.1 and consists of operator tasks such as, **C**leaning, **I**nspection, **L**ubrication and **T**ightening. The CILT activities are scheduled by the maintenance department equally over both CPLs, which means that they both get the same attention regarding maintenance. Due to the effect that *before* the implementation, CPL111 produces many more products than the CPL112, also more CILT activities were needed on the CPL111 and less on CPL112. Therefore **extra** activities need to be performed by operators on CPL111, which increases the costs. At the moment we can conclude that the production balance is around **52% (CPL111) and 48% (CPL112).** Therefore we asked operators, if extra CILT activities occur during or after this work shift. This was not the case and therefore we conclude that the extra CILT activities on CPL111 are reduced and the CILT activities on CPL112 are still below the scheduled amount. Note, that in order to validate this conclusion, we should run the test for several weeks longer. In Appendix J, some pictures are shown where operators report the differences in CILT activities, thus extra activities on CPL111. After the implementation, an operator does not have to do extra activities and therefore the lists in Appendix J have no extra information, so it is hard to show the results on the CILT-forms (no text is added by the operator). If the production balance approaches the 50/50 balance, then the CILT-activities fits with the maintenance schedule, so costs are reduced. Considering these CILT-activities we can conclude that these will decrease with **10 minutes** per shift, according to the operator lists.

The output quantity is not improved as expected, but this depends on a lot of variables. Therefore a larger testing period is needed.

7.3 Savings

To determine the savings we again consider the results between the current situation and experiment 6. The savings are based on the results of the simulation study, because we believe that only 8-hours testing are not enough to support our savings. Nevertheless, we can confirm that the results of our implementation closely match with those of our simulation study as we consider Table 7.1, where REAL test show the results in **real life** after our implementation.

Situation	Output	Production balance		Difference on CPLs
	Average	CPL111	CPL112	
Current (simulation)	441313	57%	43%	14%
Alternative (simulation)	453103	53%	47%	6%
Difference (simulation)	**11790**	**4%**	**4%**	**8%**
Average(real life *before* modification)	420193	57%	43%	14%
REAL test (real life *after* modification)	447480	52%	48%	4%
Difference (reallife)	**27287**	**5%**	**5%**	**10%**

7.1: DIFFERENCE CURRENT, NEW ALTERNATIVE AND REAL LIFE

This table shows the differences between the current and alternative situations of both our simulation as real life. We show that the modification has a positive effect on the output **and** production balance.

Furthermore, based on the 8-hour test, we support our statement mentioned before that our *simulation model is valid*. Namely, also after the implementation the values are close and reliable. Besides, the production balance moves towards the 50/50 which was a constraint for a validated model, explained in

Section 5.4. Nevertheless, in order to *validate our modification* further we should run the modification for several weeks more. Now the 8-hour work shift has an output with **27287 SBs more** than the current situation. It is not realistic to compare *one* shift with an average over three quarters, therefore we base our savings on the difference between the current situation in our simulation model with the alternative situation, colored *yellow*. We believe this is a realistic comparison because the model is valid and all values of the model are comparable with real life.

Furthermore, this table shows that the output per shift increases with an average of **11790 SBs** and the production difference between the CPLs is reduced from 14% to 6%, with a total of **8%**.

Now we consider what these results yield for HEINEKEN. Unfortunately we cannot say that the output of the production line increases with 11790 SBs, because HEINEKEN produces on order. This means that we can state that an order is finished 11790 SBs *earlier*. Therefore we calculate with *reducing costs of employees,* because employees that are paid to complete this order can do other activities instead. We base the savings of the throughput on the salary of the employees. This means that the production of an order is **8.42 minutes** finished earlier, as calculated in Table 7.2. The savings per year are calculated in Table 7.3, in the column 'Higher throughput'.

	Output	Yield	
Star Bottles	80,000	11,790	SB
Per minutes	60	8.42	Min

7.2: REVENUE PER SHIFT – HIGHER OUTPUT

Furthermore the results of the blockage of the pasteurizer described in Section 7.3 results in 5 minutes less blockage per shifts. Remember that the pasteurizer is the bottleneck machine, and therefore this has a direct positive influence on the production output. Therefore we made a calculation for the savings per year, which is shown in Table 7.3 in the column 'Line regulation'. The determination of the OPI downtime per hour and operator costs per FTE (shown in the first column) is done by the financial department and is shown in Appendix K. As mentioned in the previous section, the CILT activities also contribute to the annual savings, and therefore these are also calculated in 7.3 in the column 'Decrease CILT'.

In Table 7.3 we define higher throughput, but as mentioned before this means that the production stops earlier at the end of a production week, because HEINEKEN produces on order. A production week at the SB production line consists of 5 production days instead of 7 production days, which means that *extra output* plays no role in our savings. Extra output plays a role if a line is producing for 24 hours a day and 7 days per week.

In the Table 7.3 the savings per year are calculated. This means that the total savings per year are **€X.**

	Higher throughput	Line regulation	Decrease CILT	Total
Reduction of blockage on pasteurizer per shift(8hr) in minutes	8.42	5		
Shifts per week	20	20		
Finished earlier per week (minutes)	168.4	100		
OPI downtime (per hour)	€	€		
Real OPI downtime per hour	€	€		
Production weeks per year				
Less CILT-activities per shift (minutes)			10	
Shifts per week			20	
Less CILT-activities per week (hours)			(200/60 =) 3,33	
Hours per work week				
Real reduction percentage				
Costs of 1 fte per year			€	
Savings per year	€	€	€	**€**

7.3: Savings per year

In order to support the table above, we developed three formulas in order to determine the savings per year:

Savings per year of higher throughput:

$$= \frac{Reduction\ blockage\ on\ pasteurizer * shifts\ p/week}{60\ (minutes\ to\ hours)} * OPI\ downtime\ (€) * production\ weeks\ p/y$$

Savings per year line regulation: *(same formula as higher throughput)*

Savings per year of decrease in CILT-activities:

$$= \frac{Reduction\ CILT\ activities\ (minutes) * shifts\ per\ week}{\frac{60\ (minutes\ to\ hours)}{hours\ per\ work\ week}} * costs\ of\ 1\ FTE\ per\ year$$

Total savings per year: **Savings per year of higher throughput + line regulation + CILT decrease = €X**

8. Conclusion and Recommendations

To finish our research, we describe the overall conclusion, recommendations and we propose ideas and insights for further research. This advice is at the same time the answer to our research question which is stated in Section 1.4, and is as follows:

"How to improve line performance at the regulated production line (line 11) at HEINEKEN Zoeterwoude?"

We summarize the conclusion of the previous chapters and answer our research question in Section 8.1. We describe the recommendations for the management of HEINEKEN in Section 8.2. In Section 8.3 we propose ideas and insights for further research.

8.1 Conclusions

The mission of this research was to improve the performance of the SB production line. However, the question was how to do this. Therefore we started with a process analysis in order to be sure that we consider every part of the production line. After describing the process, we continued with a data analysis to detect the bottleneck of the SB production line, the part that has the most negative influence on the line performance. The result from this process and data analysis was that we focused on the area from the pasteurizer to the CPLs. There are two main issues after these analyses, which are:

- *The pasteurizer creates blockage due to an inefficient regulation of the CPLs.* This results in an incorrect downtime of the CPL112.
- *The production balance between the CPLs was uneven (CPL111: 55% against CPL112: 45%).* This results in extra activities (CILT) of an operator, due to an incorrect maintenance schedule (which is based on a 50/50 balance).

These main issues arise due to inefficiencies of the regulation at the production line. This regulation is done by sensors and therefore we consider different solutions regarding this regulation.

In order to solve these two inefficiencies and therefore to improve the line performance, we developed a conceptual model. Review of theory helped us to substantiate ideas and decisions regarding interventions and possible improvements for this conceptual model. We translated this conceptual model into a simulation model in order to test possible changes on the production line. We run 12 different experiments, including the current situation, to determine the best solution. The best solution was experiment 6, which states that three out of four sensors settings have to be changed and that the speed level of CPL112 should be decreased from three to two levels. CPL111 & CPL112 are triggered on the same sensor, which means that they will start and stop at the same time.

The efficiency of the regulation between the pasteurizer and CPLs increases because a production week stops on average 168.4 minutes earlier, in the new situation. This is because the throughput of the production line is increased, and therefore more products can be produced at the same time. In addition, the two main issues described above are solved. The inefficiency of the blockage of the pasteurizer is corrected, which results that the production week stops 100 minutes earlier. In total this is **268.4 minutes** of the 9600 minutes per week. Furthermore the CILT tasks over the operators are reduced, because the production balance in the new situation is **CPL111: 53% against CPL112: 47%**. The reduction of these CILT tasks results in **10 minutes** less CILT-activities per shift. All these improvements lead to yearly savings of **€X**.

So, in order to improve the line performance on a regulated production line, the new changes should be implemented.

8.2 Recommendations

In addition to the recommendation to implement the new regulation settings, we found some other inefficiencies or possible improvements during this research. Below, we provide an overview of our recommendations:

- *Focus more on conveyors/lines.* On all packaging lines the focus is on the machines. Several teams focus on improving machine efficiencies. Mostly the thoughts at HEINEKEN consists, that the line performance is determined by all machine performances, which is understandable. Nevertheless, the conveyors and buffers also play an important role in the line performance. The conveyors between the machines can be seen as a machine itself, which is proven by this research. The implementation of the outcome of this research is relative small, but the results are relative large.
- *Create an overview of the functioning of sensors on the production line.* In order to improve the efficiency **between** machines, it is necessary to have a clear understanding of the function of the sensors. Then superficial inefficiencies can be solved directly and the rest can be completed with further research. This is also very useful to visualize the operation of the production line.
- *Improve data registration at MES.* The data registration at MES should be improved, especially for the SB production line. Due to the regulated production line, MES is not capable to measure all parameters. When a machine is producing at full or half speed, MES registers only ‘producing’ in a green DNA strand. Some tools presented in Section 3.1 will help to give an insight into the speed losses, but this should be done in MES. Furthermore, some PLCs measure wrong data. Not all machine states are registered correctly. This makes the data unreliable. For example, as described in Section 3.1. PLCs measure at CPL112 a starvation instead of a blockage. Overall, this recommendation is important, because a lot of decisions are based on data at MES.
- *Hire extra PA-/PI engineer.* When inefficiencies are noted by employees, they have to write a label. Different aspects on these labels are possible, from safety issues till machines issues. When such an aspect consists of technical issues these arrive on the desk of a PA-/PI engineer. Some filled in labels are on stack for six months. This slow response discourages the operators to help improving the line performance.
- *Improving the administration of changing small objects.* The exchange of small objects (e.g., Teflon cylinders, glue sprayer) and their location is not registered by the maintenance department. Known is the amount of spare parts changed, but not the destiny of it. Therefore it is not possible to determine the frequency and amount of small objects changed on parallel machines.
- *Visualization of inefficiencies for operators.* At the moment every machine has its own ‘light’ that visualizes the machine state. Nevertheless, not everything is visualized. For example, when on the bottle washer a couple of fallen bottles block the entrance, no light is shown. Sometimes these fallen bottles cause a machine inefficiency of 11,5% (6 out of 52 empty pockets). Therefore an operator should know if fallen bottles are present at the entrance of the bottle washer. This can be done with another light for ‘fallen bottles at entrance’ in order to prevent machine inefficiencies.

8.3 Further research

We finish our research with the proposition of ideas for further research. The ideas for further research are given below:

- *Optimizing all conveyors/lines between machines.* The subject will be the same as this research, but should consider every flow line between two consecutive machines. The part between the pasteurizer and CPLs which is done in this research is just one part. Multiple improvement steps can be made, when considering the whole production line.
- *Improving the use of the crate buffer.* At the moment operators choose when crates should be stored into the crate buffer or when crates should be pulled from this buffer. This means that when an operator is busy on another machine, he/she is not able to regulate the crate buffer. Further research should indicate whether if it is profitable to make this automatic and how this should be done.
- *Reducing downtime of the packaging machine.* The packaging machine has a high down time. This causes a blockage on the CPLs and therefore on the pasteurizer. This is a direct loss.
- *Visualization of inefficiencies for operators.* In the previous section an example is given. Nevertheless this should be researched for other machines.

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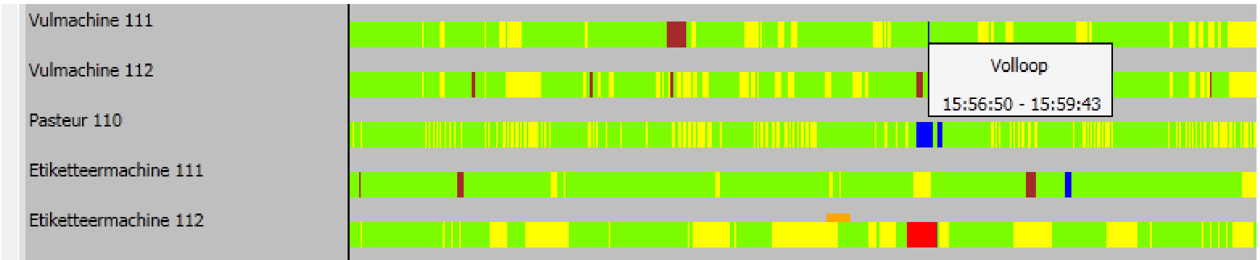
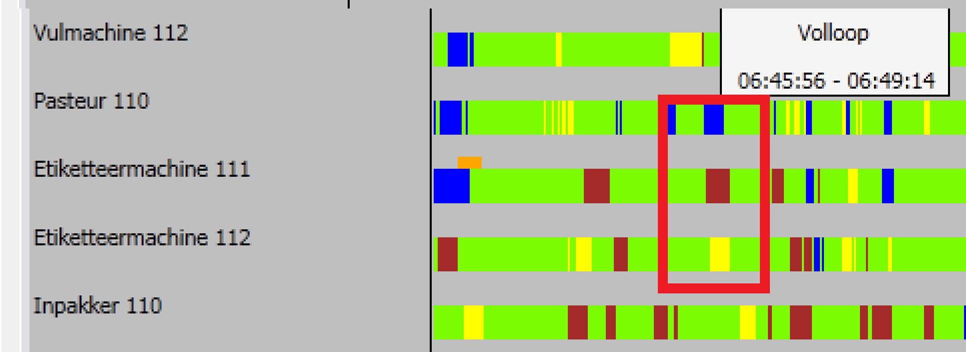
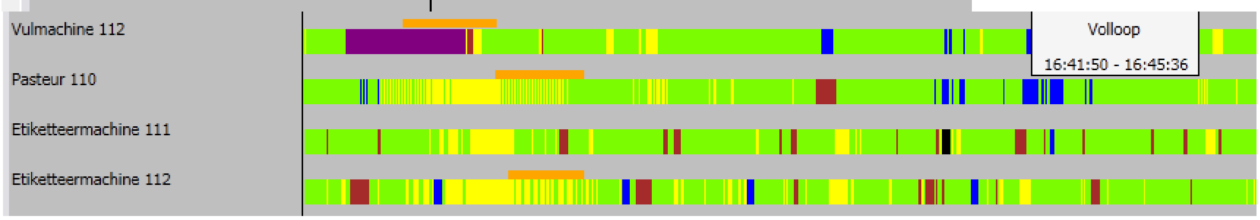
Appendices

Appendix A: Examples of MES DNA inefficiencies







APPENDIX B: FLOW LINE - SIMULATION MODEL

In Figure 8.1 the main frame of the simulation model is showed again.

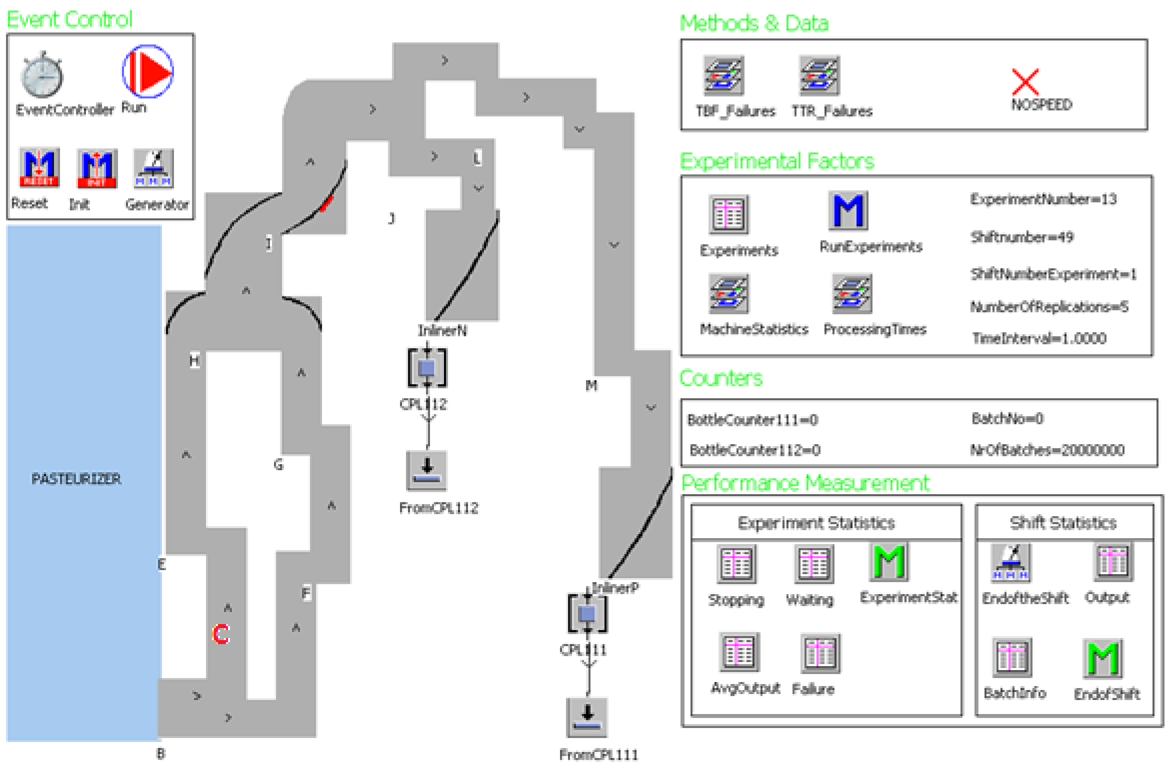


FIGURE 8.1: MAIN FRAME PLANT SIMULATION

The flow line of bottles is separated in multiple conveyors, because every conveyor has its own characteristics. Some characteristics are length, width, number of strokes and speed. We want to improve the understanding of the flow line, and therefore we consider conveyor. We choose conveyor C, which makes no difference because the regulation of all conveyors is the same. Only the destination tables and the characteristic will differ. In Figure 8.2, conveyor C is shown in more detail.

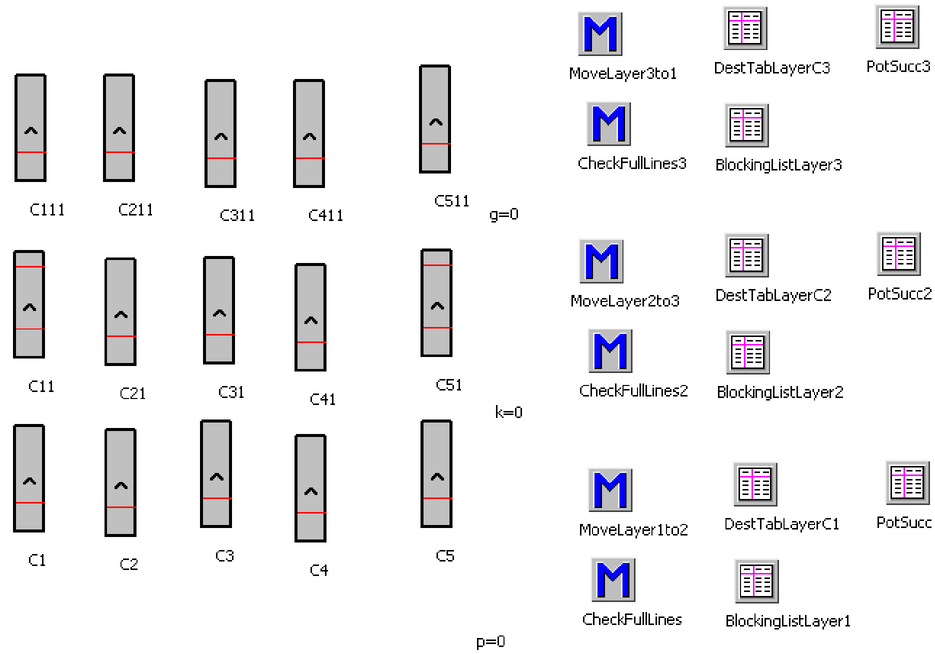


FIGURE 8.2: CONVEYOR C IN DETAIL

As one can see C has five different strokes. In real life these can move independently. Not every conveyor has the same amount of strokes. Therefore these are measured on the production line. The results are explained in *Calculation of capacity*.

Calculation of capacity

In Table 8.1 one can the information per line in more detail. The '% of line used' is the percentage that is efficiently used on a line, because on every line a SB is forced to move to another line. This is done by a fence that is positioned above the strokes. This means that the place behind those fences is not uses by the SBs, and is therefore excluded from the capacity. The capacity included the % of line used is the efficient capacity.

scale 1:100	in Simulation	Reality	1 line =			
	Length in cm	Length in m	# of strokes	capacity	% of line used	Eff capacity
Name Line						
A	2,6	2,60	5	343,2	99%	339,8
B	2,8	2,80	5	369,6	99%	365,9
C	11	11,00	5	1452	99%	1437,5
D	9	9,00	5	1188	99%	1176,1
E	12	12,00	5	1584	98%	1552,3
F	7	7,00	5	924	98%	905,5
G	9	9,00	5	1188	98%	1164,2

H			4,4	4,40	8	932,8	92%	858,2
I	Angle	1,10		1,10	8	233,1062	95%	221,5
	Straight	4,5		4,50	8	954	95%	906,3
			5,6	5,60		1187,106	95%	1127,8
J	Angle	0,55			4			
	Straight	4			4			
			4,5	4,55		477,7268	95%	453,8
Inliner N			4	4,00	12	1279,844	10%	128,0
K			4,25	4,25	4	446,25	98%	437,3
L	Angle	0,55			4			
	Straight	6			4			
			6,55	6,55		687,7268	95%	653,3
M			8	8,00	4	840	98%	823,2
O			4	4,00	4	420	98%	411,6
Inliner P			4	4,00	12	1279,844	10%	128,0
								SKUs
						15787	Total capacity:	13090

8.1: Line information

In Table 8.2 the translation from strokes to the capacity is shown.

Diameter SB	60	mm

Stroke		
82.5 mm	84	
# of strokes	Stroke width	Capacity (# of bottles) per meter stroke
1		24
2		51
3		78
4		105
5		132
6		159
7		186
8		212
9		239
10		266
11		293
12		320
13		347
14		374

8.2: Calculation of amount of bottles

APPENDIX C - DISTRIBUTIONS DATA SET

In this data set, we try to find a theoretical distribution. As mentioned before we try to find distributions for the processing time, the MTBF and the MTTR. Plant Simulation tests the data against twelve theoretical distributions which are listed below:

- Beta distribution
- Binomial distribution
- Erlang distribution
- Gamma distribution
- Geometric distribution
- Lognormal distribution
- Normal distribution
- Negative exponential distribution
- Poisson distribution
- Triangle distribution
- Uniform distribution
- Weibull distribution

According to Law (2006), these twelve distributions are the most promising to fit with our process and failure times. Furthermore there are three tests that can check if the data fits with a theoretical distribution. Law (2006) describes three different tests which are:

- Chi-squared test (CS). This is used to determine if a sample comes from a data set with a specific distribution. The test is applied to binned data, so the value of the test statistic depends on how the data is binned. There is no optimal choice of number of bins (k), which is determined by

$$k = 1 + \log_2 N$$

- Kolmogorov-Smirnov test (KS). This is used to decide if a sample comes from a hypothesized continuous distribution.
- Anderson-Darling procedure (AD) . This is a general test to compare the fit of an observed cumulative distribution function to an expected cumulative distribution. This test gives more weight to the tails than the Kolmogorov-Smirnov test.

In order to find a theoretical distribution function we will use a combination of the Chi-squared test and the Kolmogorov-Smirnov test. The Anderson-Darling test focuses more on tails, which is something that is not preferable in our model. We will use a level of significance of 5%, which is common in statistics.

Appendix D – Determining theoretical distribution: MTBF

In order to rank the different distributions we used two different tests. The first one is the Kolmogorov-Smirnov (KS) test and the second one is the Chi-Squared (CS) test. These tests are performed using Excel. Number 1 means that it ranked first and therefore the best. Number 2 ranks the second best and so on. In Table 8.3 one can find the different rankings on the two tests.

	CPL111		CPL112	
	KS	CS	KS	CS
Beta	4	-	1	-
Exponential	7	5	6	5
Gamma	2	2	2	3
Log normal	3	4	4	4
Normal	5	1	5	2
Uniform	6	-	7	-
Weibull	1	3	3	1

Table 8.3 – KS and Cs test for MTBF

For both CPLs the P- value is very close to zero or zero as one can see in Table 8.4. Considering a significance level of 5%, we can conclude there is no distribution that fits to the data, based on the two tables. Therefore we use empirical data in order to determine the MTBF for the simulation model.

This MTBF is stored in a table file and linked with the option ‘cEmp’ in Tecnomatix Plant Simulation.

		KS P-value	CS P-value
CPL 111	Weibull	0	0
	Normal	0	0
CPL112	Beta	0	0
	Weibull	0	0.038

Table 8.4 – P-value: MTBF

APPENDIX E - DETERMINING THEORETICAL DISTRIBUTION: MTTR

Determining the fit of data from the process with a theoretical distribution of the MTTR is done the same as described in Appendix B for the MTBF. The ranking of the distributions is also the same, which means that number 1 is the best, number 2 the second best and so on. In Table 8.5 we show that both test score the best on a Weibull distribution.

	CPL111		CPL112	
	KS	CS	KS	CS
Beta	5	4	5	5
Exponential	4	5	4	4
Gamma	2	2	2	2
Log normal	3	3	3	3
Normal	6	6	6	6
Uniform	-	7	-	7
Weibull	1	1	1	1

TABLE 8.5 – KS AND CS FOR MTTR

		KS P-value	CS P-value
CPL 111	Weibull	0	0.052
CPL112	Weibull	0.103	0.173

TABLE 8.6 – P-VALUE: MTTR

Considering the P-value in

		KS P-value	CS P-value
CPL 111	Weibull	0	0.052
CPL112	Weibull	0.103	0.173

Table 8.6 and a significance level of 5% we can conclude that a Weibull distribution satisfies. For CPL111 we see not fit the Kolmogorov-Smirnov test. The significance level of the Chi-squared test satisfies narrowly (5.2% > 5%). The P-values of the KS test and CS test on the CPL112 are convincing (10.3% and 17.3% respectively). This means that we use for the MTTR the Weibull distribution with the following parameters, shown in Table 8.7.

	Distribution	Parameters	
CPL111	**Weibull**	**α = 0.83029**	**β = 36.428**
CPL112	**Weibull**	**α = 0.78302**	**β = 28.755**

TABLE 8.7 – FIT WEIBULL DISTRIBUTION WITH CORRESPONDING PARAMETERS

The Weibull distribution with the corresponding parameters is implemented in Tecnomatix Plant Simulation. Furthermore one can see the interval of the duration of a failure, which contains the empirical data of the MTBF. A screenshot of the simulation is shown in Figure 8.3.

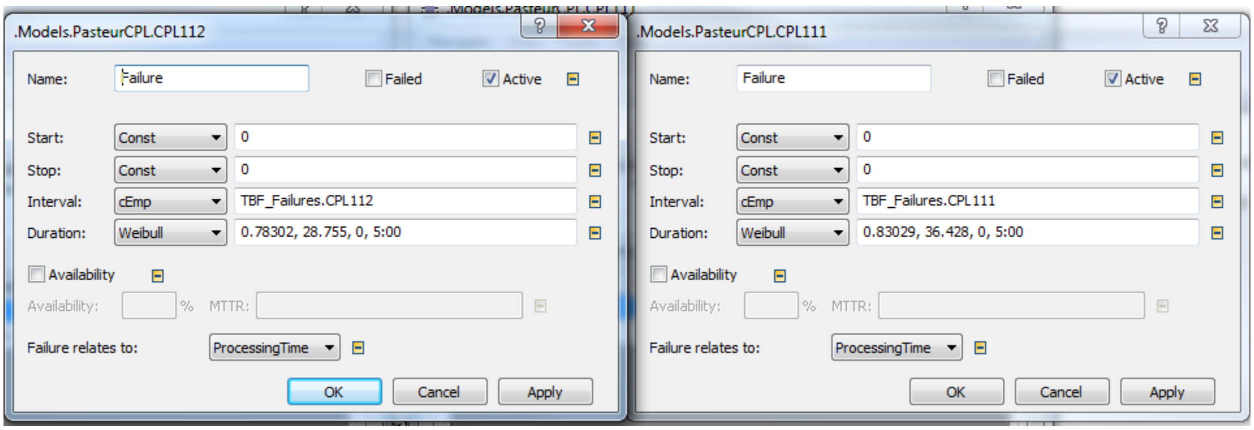
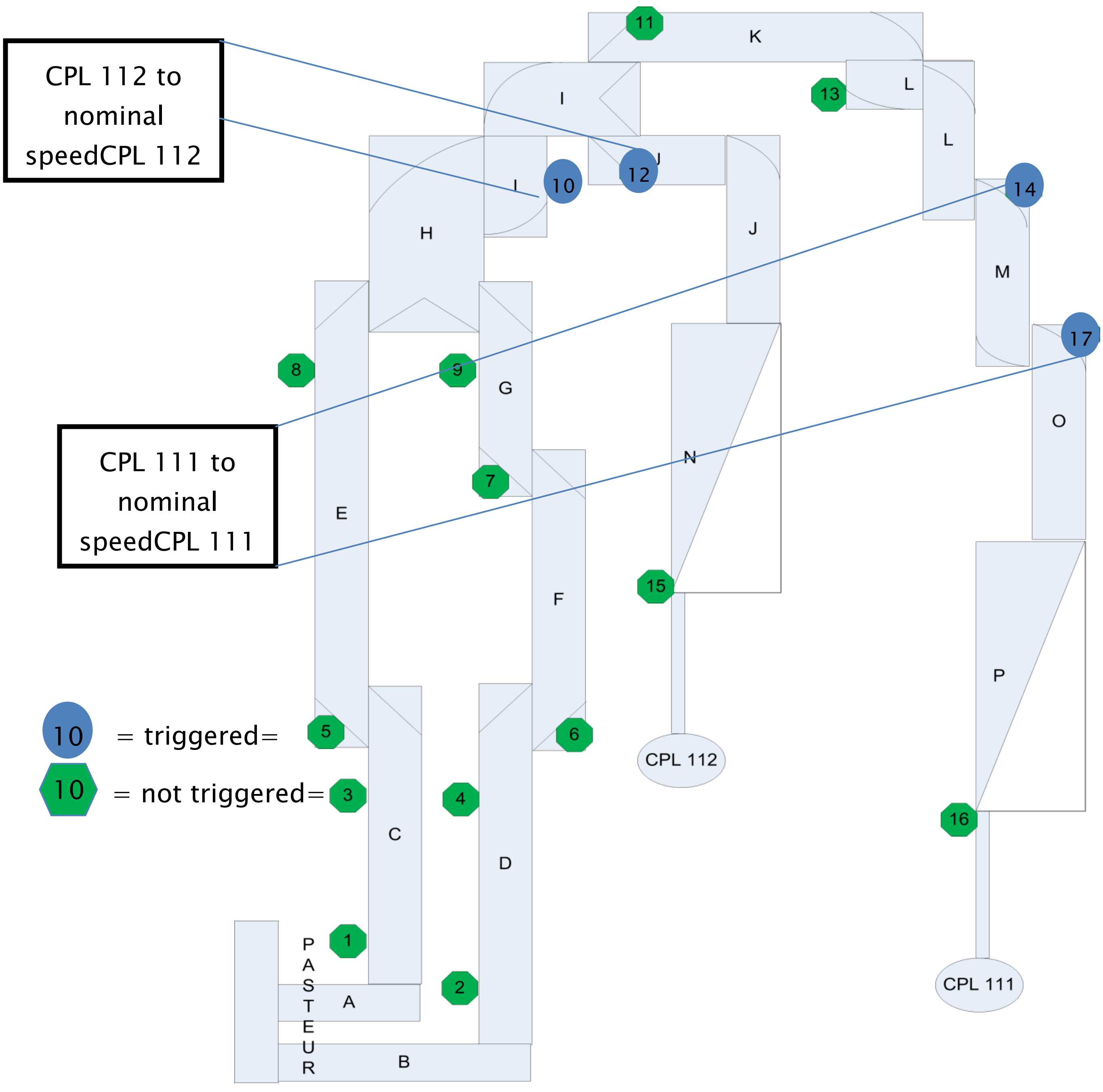
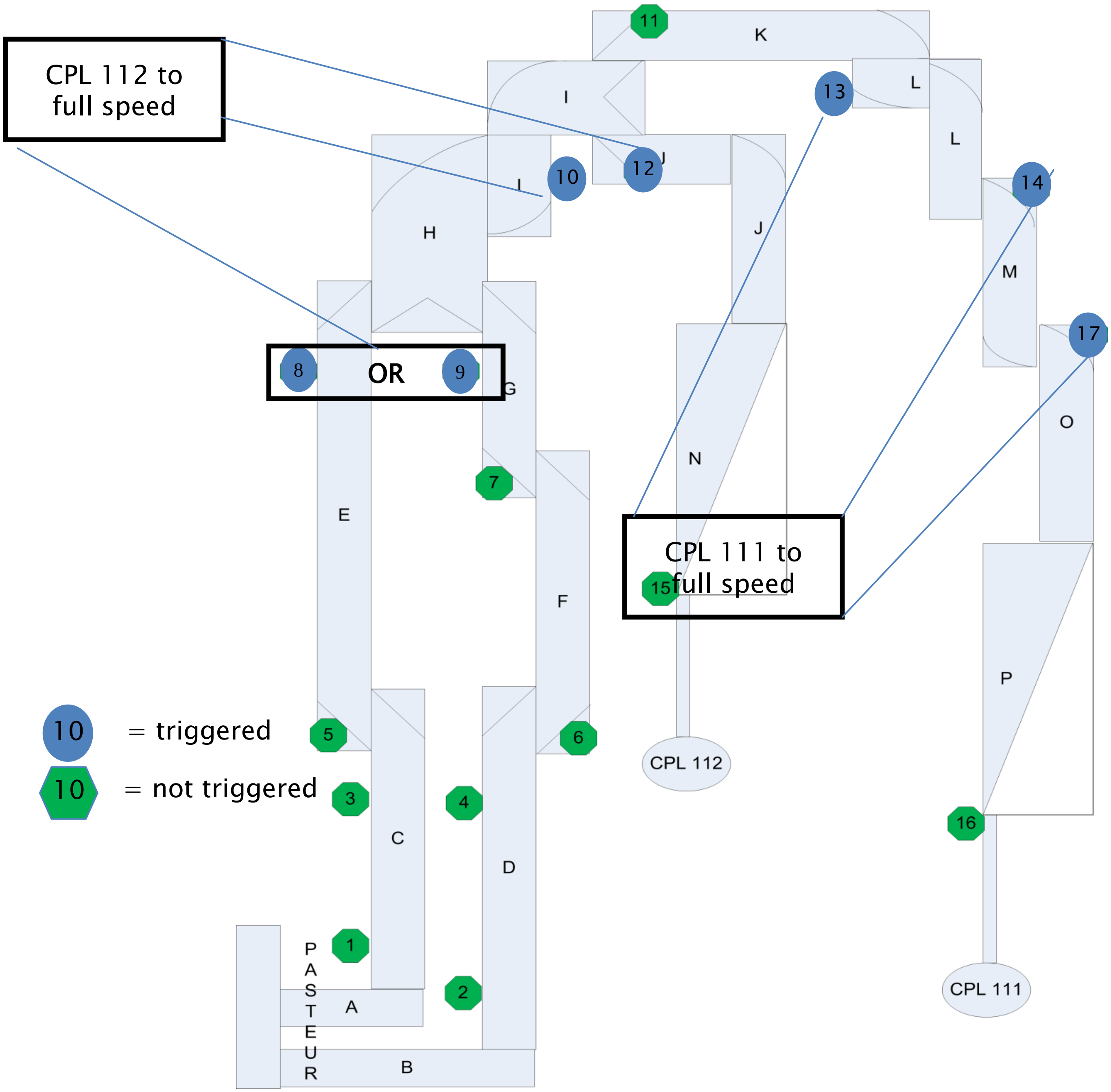


FIGURE 8.3: PRINT SCREEN OF WEIBULL DISTRIBUTIONS OF MTBF AND MTTR

APPENDIX F: CPLS TO NOMINAL SPEED



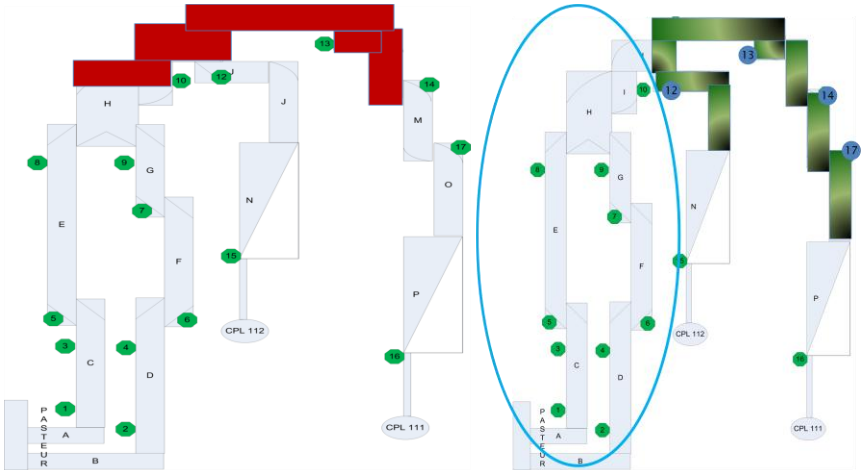
APPENDIX G: CPLS TO HIGH SPEED



Appendix H: Results experiments 1 till 12

Experiment	Output	Production balance		Waiting		Stopping		Starvation			Failure	
	Average	CPL111	CPL112	CPL111	CPL112	CPL111	CPL112	CPL111	CPL112	Total	CPL111	CPL112
1	441313	57%	43%	0,78	38,08	28,99	0,00	29,77	38,08	67,85	2,22	0,85
2	416625	29%	71%	0,05	9,51	67,71	0,00	67,77	9,51	77,28	0,43	1,33
3	388495	19%	81%	0,00	7,03	69,40	0,00	69,40	7,03	76,42	1,03	0,24
4	435440	58%	42%	1,72	39,03	0,00	0,00	1,72	39,03	40,75	1,65	0,54
5	444508	57%	43%	0,82	38,79	0,00	0,00	0,82	38,79	39,61	1,20	0,18
6	453103	53%	47%	0,01	30,61	0,00	0,00	0,01	30,61	30,62	1,42	0,04
7	439100	62%	38%	2,45	0,00	22,20	48,17	24,65	48,17	72,82	0,84	0,13
8	379278	23%	77%	0,03	1,39	76,64	9,41	76,67	10,80	87,47	0,46	1,36
9	408198	31%	69%	0,00	1,34	66,44	12,25	66,44	13,59	80,03	0,39	1,06
10	449990	58%	42%	2,90	8,77	0,00	19,71	2,90	18,48	31,38	1,99	1,03
11	430915	57%	43%	0,78	34,63	0,00	2,46	0,78	37,09	37,86	2,83	0,86
12	444338	54%	46%	0,08	33,33	0,00	0,51	0,08	33,84	33,92	0,78	0,80

APPENDIX I: RISK ANALYSIS - BLOCKAGE ON PASTEURIZER



In Table 8.8 one can find the capacities per line.

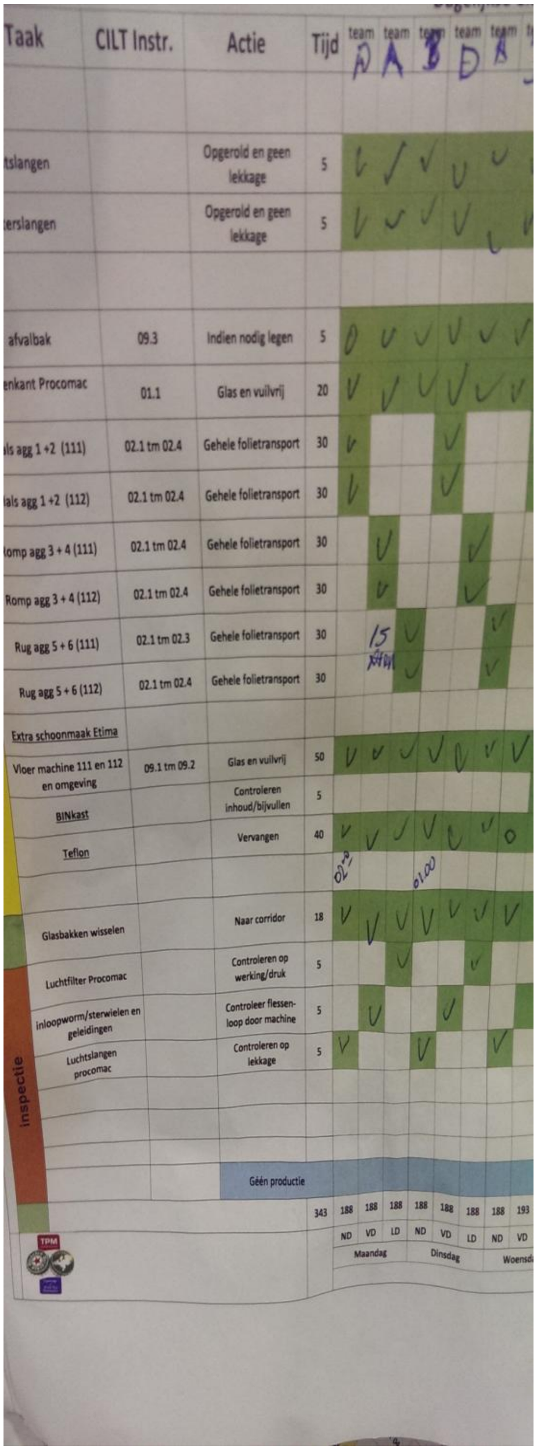
	Length	Number of strokes	capacity	% of stroke used	Eff capacity	
Name line	m					
A	2,60	5	343,2	99%	339,8	
B	2,80	5	369,6	99%	365,9	
C	11,00	5	1452	99%	1437,5	
D	9,00	5	1188	99%	1176,1	
E	12,00	5	1584	98%	1552,3	
F	7,00	5	924	98%	905,5	
G	9,00	5	1188	98%	1164,2	
H	4,40	8	932,8	32% or 68%	373.1 or 559.7	
I	5,60		1187,106	95%	1127,8	
J	4,55		477,7268	95%	453,8	
Inliner N	4,00	12	1279,844	10%	128,0	
K	4,25	4	446,25	98%	437,3	
L	6,55		687,7268	95%	653,3	
M	8,00	4	840	98%	823,2	
O	4,00	4	420	98%	411,6	
Inliner P	4,00	12	1279,844	10%	128,0	
		Capacity	14600	Total eff capacity:	13090	SBs
				Total eff capacity:	2517	SBs
				Total eff capacity:	7576	SBs

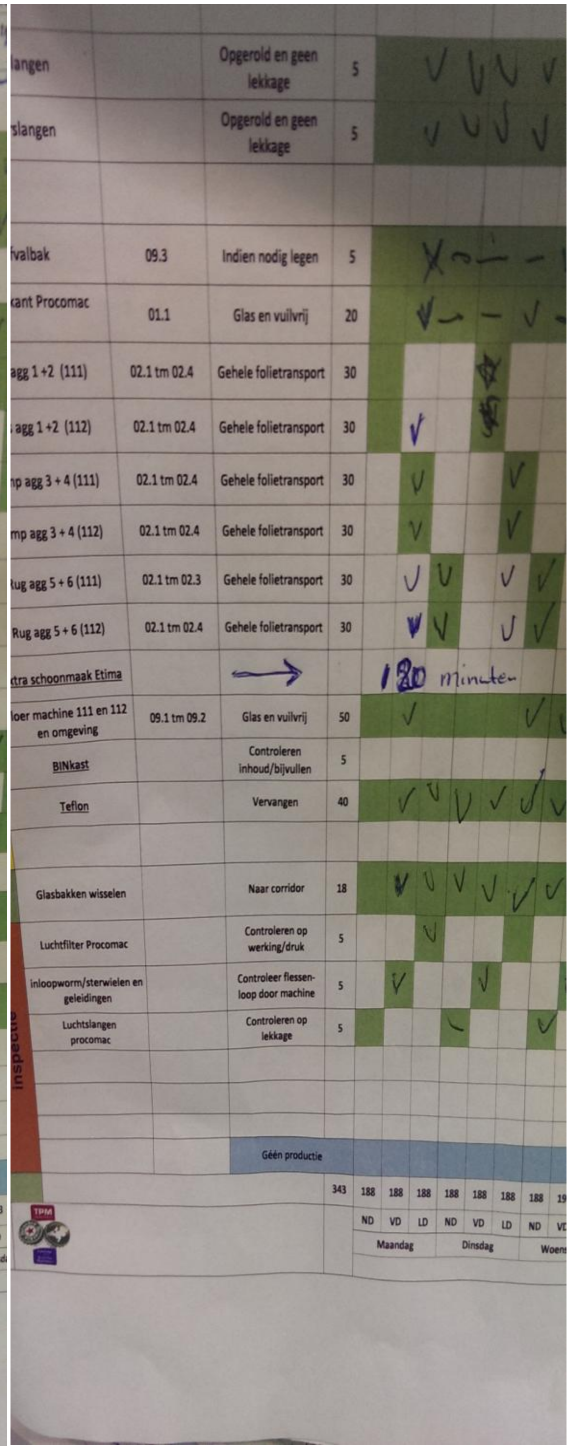
8.8: DETERMINING BUFFER CAPACITY

	MA		DI		WO		DO		VR		ZA		ZO			
31	28 Jul 14		29 Jul 14		30 Jul 14		31 Jul 14		01 Aug 14		02 Aug 14		03 Aug 14		Total	
	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal
Etiketteermachine 112	16,2	2	5,2	1	6,1	1					26,5	1	69,8	3	123,8	9
Etiketteermachine 111	42,0	4	5,7	1	7,0	1							39,9	2	94,6	8
32	04 Aug 14		05 Aug 14		06 Aug 14		07 Aug 14		08 Aug 14		09 Aug 14		10 Aug 14		Total	
	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal
Etiketteermachine 112			5,5	1			7,7	1	37,8	4	12,9	2	45,6	4	109,5	12
Etiketteermachine 111	5,1	1	47,9	5	5,1	1	28,0	2	6,0	1			10,3	1	102,4	11
33	11 Aug 14		12 Aug 14		13 Aug 14		14 Aug 14		15 Aug 14		16 Aug 14		17 Aug 14		Total	
	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal
Etiketteermachine 112	12,7	1	31,7	3	12,4	1	48,7	2	58,7	8	6,6	1				17
Etiketteermachine 111	21,9	2			19,5	1	131,4	4	39,2	3	25,1	1			237,0	13
34	18 Aug 14		19 Aug 14		20 Aug 14		21 Aug 14		22 Aug 14		23 Aug 14		24 Aug 14		Total	
	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal	Duur	Aantal
Etiketteermachine 112	20,7	2	13,5	2	17,9	2	7,1	1	14,9	2			6,4	1	80,5	10
Etiketteermachine 111			6,7	1			39,9	3	5,1	1			10,2	1	61,9	6
tot aantal		12		14		7		13		19		5		12		82 = storingen in 1 month

FIGURE 8.4: NUMBER OF FAILURES OF CPLS

APPENDIX J: EXTRA CILT ACTIVITIES ON CPL111





Appendix K: OPI downtime per hour and Operator costs

Machine Verliezen

OPI non cash savings per col		Per 1 % OPI
OPI NONA 11	€	22.233
OPI NONA 12	€	15.091
OPI NONA 2	€	21.969
OPI NONA 3	€	26.604
OPI NONA 41	€	8.223
OPI NONA 42	€	8.142
OPI NONA 43	€	6.053
OPI NONA 5	€	20.238
OPI NONA 6	€	26.900
OPI NONA 7	€	34.217
OPI NONA 81	€	15.620
OPI NONA 82	€	15.172
OPI NONA 9	€	5.380

OPI Stilstandtarief		Per uur
OPI NONA 11	€	327
OPI NONA 12	€	377
OPI NONA 2	€	366
OPI NONA 3	€	443

Verpakk
One-way
Retour fl
Blik (leeg
Cluster (
Tray
Carrier
Carton (l
Tapvat 5
Griptop
Extractv
Extractv
Extractv
Energie
Water (€
Water (€

Arbeids Verliezen

Personeelskosten operator		
1 fte op jaarbasis (3pl.)	€	77.837
Gem. Uurloon	€	28,00
Overwerk 150%	€	38,00
Overwerk 200%	€	50,00
Overwerk 300%	€	75,00

HEINEKEN

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