INDUSTRIAL ENGINEERING & MANAGEMENT
MASTER THESIS

Bright Beer Cellar planning and scheduling at Heineken

A thesis submitted in fulfillment of the requirements for the degree of Master of Science in the field of:

Production & Logistic Management

Supply Chain & Transport Management

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UNIVERSITY OF TWENTE.

HEINEKEN

Preface

This master thesis represents the last phase of my time as a student at the University of Twente. My time as a student in Enschede has been a true pleasure. A time where academic and personal growth go hand in hand. A time to never forget. Of course, I couldn't have done it by myself, and therefore I would like to take this opportunity to thank a few people who have been a part of this journey.

First of all, I want to thank Heineken for giving me the opportunity to write my thesis at their company. My special thanks go to Siebe Brinkhof for being my internal supervisor. In a time where I was only able to go to the breweries of Heineken once and the technical drawings of the breweries were my best friend, you made me feel welcome in an online environment. Next to that, you were always willing to help me and learned me a lot about the world of planning. I would also like to thank my colleagues at Heineken for being very welcoming and helpful while doing my research at Heineken.

Secondly, I would like to thank Marco Schutten for being my first supervisor at the University of Twente. With the extensive feedback and nudges in the right direction, I could bring this graduation project to a satisfying end. Furthermore, I would like to thank Engin Topan for being my second supervisor and for providing feedback in the final phase of writing my thesis.

Last and certainly not least, I want to thank my friends and family who helped and supported me during the writing of this thesis and gave me a student time I can proudly look back on.

I hope you enjoy reading this thesis!

Siete Dijkstra
Utrecht
April 2021

Management Summary

This thesis is about assessing the Bright Beer Cellar capacity on long-term planning horizons and improving the scheduling process.

Heineken is the world's most international beer brewer. The Heineken brands are sold in more than 190 countries with an annual total over 200 million HL. In order to produce and sell those HL, Heineken employs more than 85,000 people divided over different operating companies. We conduct this research at Heineken Netherlands Supply (HNS) in the supply chain planning department. HNS is responsible for the Heineken breweries in Zoeterwoude, Den Bosch and Wijlre. This research focuses on the Den Bosch brewery.

Heineken experiences difficulties with the scheduling of the Bright Beer Cellar (BBC) in Den Bosch. The Bright Beer Cellar is an intermediate buffer in production, before packaging and after filtration, and is supposed to be an enabling part in production. Due to the fact that the BBC should be enabling, it has not been something that is taken into account in capacity calculations at strategic and tactical level. Nevertheless, the operational scheduling department creates a schedule from day to day and experiences the BBC to be a bottleneck, not enabling but limiting other crucial productions steps. The need arose to create quantitative capacity assessment of the BBC and the question if the current gross capacity can be used more efficiently. Therefore, we define the objective of this research with two questions:

1. *'How can the net capacity of the bright beer cellar be determined?'*

2. *'How can the net capacity of the bright beer cellar be increased?'*

To answer this research question, we divide our research in several phases. During the first phase, we analyze the current situation of the scheduling and production process. Next, we evaluate available literature relevant to our research and use the literature to find a solution direction. The literature review focuses on long-term capacity planning and the scheduling of production systems with buffers. In the review we find that Rough-Cut Capacity Planning (RCCP) methods can be used for capacity planning on the long-term and is able to bridge the gap between the short-term and long-term planning. In combination with the loading/allocation problem the RCCP procedures look promising for the problem of the BBC. A MILP describing the allocation of beer batches to specific BBC blocks can be used to solve the allocation problem in reasonable time. The MILP can be used in the RCCP methods, but also in the allocation in the short-term scheduling.

To improve the current planning process, we design a RCCP method that's able to asses the BBC capacity on a long-term planning horizon. We create a RCCP method that is a combination of multiple different methods, namely, capacity planning using overall planning factors (CPOPF), capacity bills and the MILP of the allocation problem. This model can be used for a capacity assessment of the future production plans based on the expected packaging volumes. We use the model to assess the annual plan of 2021, an investment in the piping of the 0.0 beer process and the impact of adding more volume.

Consequently, we conclude that the BBC cannot handle the 0.0 volume that is planned in the annual plan. The other volumes of the annual plan of 2021 fit the capacity of the BBC, although there are some critical weeks. An investment in the production of

0.0 beer, removing one production step, can remove the problems for the 0.0 beers in the BBC. This would also make the process of 0.0 beers ready for the future where a growth of 0.0 volumes is expected. When adding more volume to the annual plan we conclude that problems in the BBC arise at around a certain production volume in combination with more than 20 different types of beer.

Next, we extend the allocation model of the RCCP approach to be used in operational scheduling. The allocation model already shows promising results in the RCCP method and short calculation times. With some relatively small changes, the allocation model can be used in helping operational schedulers to create a schedule for the BBC. This removes manual activities from the scheduling process and saves time for the schedulers. When creating the allocation model it becomes clear that in creating a BBC schedule many factors are fixed and dependent on other more important production steps. Therefore, it is difficult to improve the BBC performance without changing, for example, the packaging schedule, which is out of scope of this research. Still, in the allocation of batches to BBC blocks, scheduling freedom exists. With the allocation model we find a feasible allocation in seconds. Figure 1 shows an example of the allocation graph helping the schedulers with the allocation.

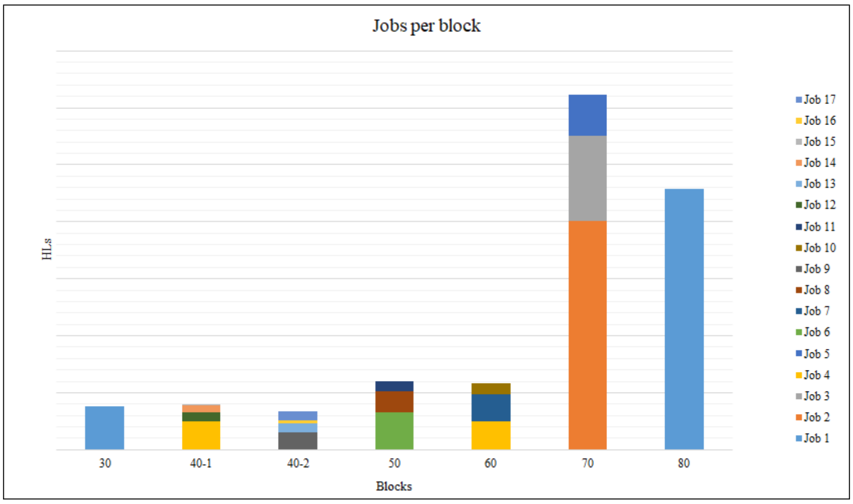

FIGURE 1: Output operational model: Example allocation of 17 jobs to BBC blocks to help schedulers

In conclusion, we found a new way to assess net buffer capacity in a complex and highly connected system using planning factors and an allocation model. With this model Heineken can identify bottlenecks in the BBC in an early stage and initiate interventions to prevent the bottleneck from actually occurring. Furthermore, we constructed an allocation model that can help operational scheduling in finding a feasible schedule in less time by reducing the manual work.

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List of Abbreviations

BBC Bright Beer Cellar

BBT Bright Beer Tank

CPOPF Capacity Planning using Overall Planning Factors

HL Hecto Litres

HNS Heineken Netherlands Supply

OS Operational Scheduling

SCP Supply Chain Planning

SCD Supply Chain Development

TSCP Tactical Supply Chain Planning

RCCP Rough-Cut Capacity Planning

Chapter 1

Introduction

This work describes the findings and ideas resulting from research conducted at Heineken Netherlands Supply (HNS). We conduct this research in the context of a graduation assignment for completion of the masters degree in Industrial Engineering and Management. This chapter introduces the problem, company, and describes the structure of this research. Section 1.1 presents a short company description, Section 1.2 describes the research motivation, Section 1.3 describes the research scope, Section 1.4 describes the research questions and structure of the research and Section 1.5 mentions the desired research deliverables.

1.1 Company description

Section 1.1.1 shortly introduces the company Heineken and Section 1.1.2 discusses the accompanying brewing process superficially. Chapter 2 provides more in depth information on the production process.

1.1.1 Heineken

Heineken is the world's most international beer brewer. The Heineken brands are sold in more than 190 countries with an annual total over 200 million Hecto Litres (HL). In order to produce and sell those HL, Heineken employs more than 85,000 people divided over different operating companies.

We conduct this research at HNS and specifically at Supply Chain Development (SCD), which is part of the supply chain planning department. HNS is responsible for the Heineken breweries in Zoeterwoude, Den Bosch and Wijlre. Together these breweries produce around 17 million HL for export and domestic consumption. The brewery in Zoeterwoude is mainly focused on cost efficiency and bulk production, where Den Bosch has more focus on innovation and smaller production batches. Wijlre is considered as 'The Craft Brewery', where specialty beers are produced.

1.1.2 Production process

Figure 1.1 shows a simplified schematic overview of the production process. The brewing involves grained barley (malt), water, heat and hops. The brewing is finished in several hours, depending on the beer type. After the brewing, yeast is added and sugars are transformed in alcohol and CO_2, this is called fermentation and lagering. This process step is the most time consuming. Depending on the beer this can take days to weeks. To create bright beer, that is ready for packaging, a last filtration step is done. For simplicity reasons we refer to the beer as 'wort' before filtration and

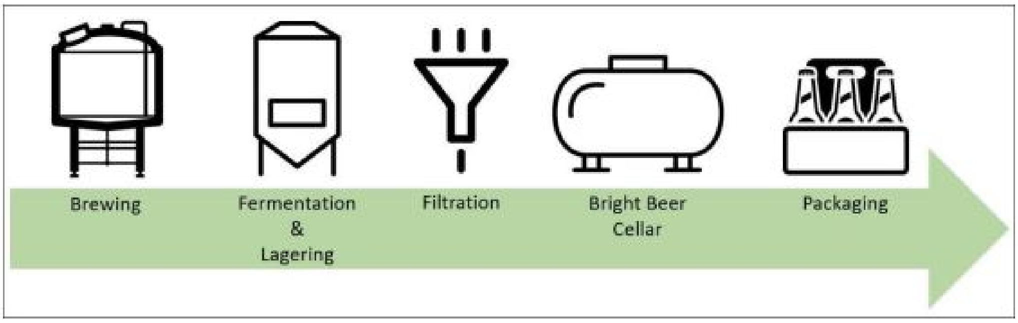

FIGURE 1.1: Schematic overview of the production process (Heineken, 2020)

after the filtration as 'bright beer'. In the filtration process, among others, alcohol and CO_2 levels can also be corrected or some flavour can be added. After filtration the beer is stored in a Bright Beer Tank (BBT). All BBTs together are called the Bright Beer Cellar (BBC). In the BBT a beer is waiting to be packaged at a packaging line. After packaging the beer can be distributed to the market.

This process is planned by the supply chain planning department. The production planning is divided in three different departments: strategic, tactical and operational. Each planning department plans or schedules on a different planning horizon. Strategic planning focuses on the long-term planning. Tactical planning focuses on a horizon of 13 weeks and plans the production in week buckets. Operational scheduling (OS) is responsible for creating the schedule inside the week buckets from day to hour. The strategic department is the problem owner of this research.

1.2 Research motivation

Heineken wants to maximize the output of the breweries. To do so, Heineken makes sure that the most capital intensive step in production, packaging, is the bottleneck and that other production parts follow the needs of packaging. However, due to changes in the product portfolio in the breweries, e.g. new types of beer or volume changes, HNS increasingly experiences filtration and/or BBC to be a bottleneck for the supply chain planning. The essence and causes of the bottleneck differs per brewery due to differences in the structure, size and capabilities. Due to the larger product portfolio and therefore increased complexity of the production process, the BBC bottleneck is the most pressing in the Den Bosch brewery.

The operational scheduling department experiences the problem, because the tactical and strategic department do not consider the capacity of filtration and the BBC. These departments assume sufficient capacity at the filtration and BBC. The BBC functions as a buffer in the production process and does not add value to the product. Such a buffer should have overcapacity and be an enabling part in the production process and not limit other production steps. In practice, the BBC can limit, for example, the most efficient packaging schedule. The operational scheduling department is not always able to find a feasible schedule for the BBC. The capacity of the BBC can be a limiting factor, constraining other production steps and creating a

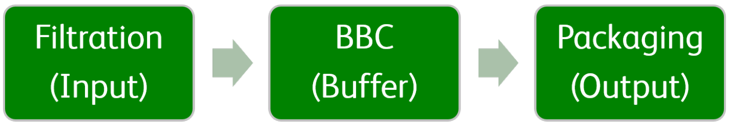

FIGURE 1.2: Schematic overview of the research production scope

schedule for the BBC also takes much time of the schedulers. The operational limitations of the BBC are unknown to the tactical and strategic planning and mostly based on qualitative arguments, which makes it hard to include for the strategic and tactical planning.

Furthermore, without a clear quantitative assessment on the BBC it is hard to substantiate if investments are needed to remove the bottleneck and create enough overcapacity to not limit other production steps. It is also not clear what is causing the BBC to be a limiting factor in the production. Research is needed to be able to properly asses the BBC capacity and how this capacity can be used in the most effective manner. With a quantitative capacity assessment the impact of investments, increasing production volumes and new product introductions can and should be evaluated.

1.3 Scope

The BBC as bottleneck is experienced the most in the Den Bosch Brewery and therefore this research focuses on this brewery. Figure 1.2 shows the production scope. Obviously, this research mainly focuses on the BBC. Filtration is inextricably linked, because filtration is responsible for the inflow of beer in the BBC. The packaging lines are responsible for the outflow of beer from the BBC. Therefore, this research includes the packaging lines to a certain extent. For example, the planning and scheduling of packaging lines fall out of the scope of this research and the packaging plans and schedules are considered as fixed. The brewing and fermentation & lagering are also considered as out of the scope of this research. These production steps have limited influence on the performance of the BBC.

This research mainly focuses on the long-term capacity planning for the BBC, because of the fact that SCD is the problem owner and also focuses on the long-term planning horizon. However, the short-term scheduling is also an important factor in the performance of the BBC since the short-term scheduling has a positive or negative influence on the performance of the BBC. Next to the short-term scheduling effects. The tactical planning horizon is not explicitly included in this research, because there is limited time available for this research. Although, the strategic and tactical planning departments make decisions in the same time buckets and therefore models, conclusions and recommendations based on the strategic horizon might also be applicable to tactical planning horizons.

1.4 Goal & research questions

The goal of this research is to find a suitable way of assessing BBC capacity and how this assessment can be used to investigate the impact of changes in the BBC process, mainly focused on the long-term planning horizon. With a suitable capacity

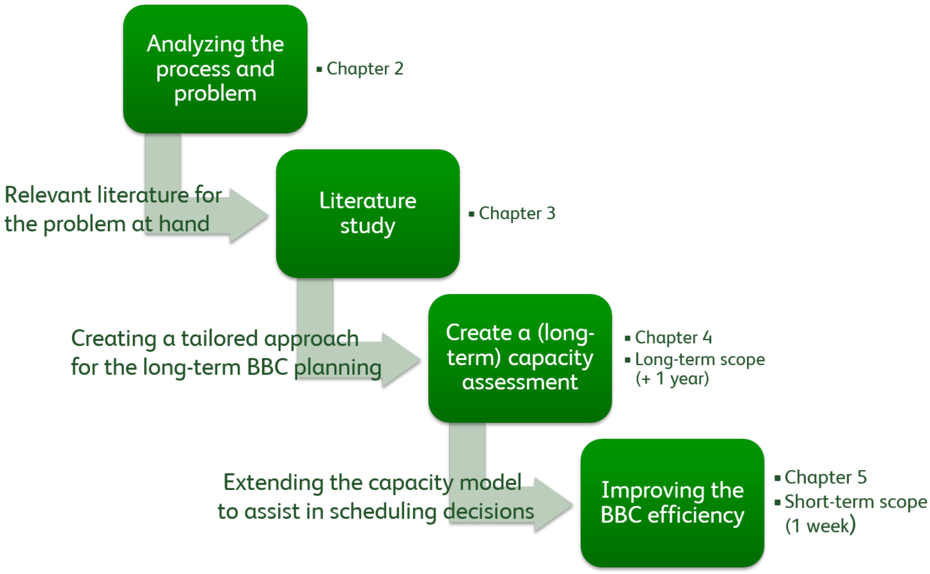

FIGURE 1.3: Research and thesis structure

assessment, the gap between tactical/strategical planning and operational scheduling should be removed and prevent the BBC from being a bottleneck. On the other hand we want to investigate if other filtration and BBC scheduling strategies can be used to improve the performance of the BBC. This results in the following two research problems:

1. How can the net capacity of the bright beer cellar be determined?

This problem mainly focuses on finding a quantitative way to assess the BBC capacity. In this research the net capacity is the capacity that is actually usable. Where we define the net capacity as the gross capacity multiplied with some efficiency factor. The gross capacity is easy to determine because the number of available tanks is known. How efficient the tanks can be used in practice is unknown. Furthermore, this first question focuses on the long-term planning horizon and how the capacity of the BBC can be quantified.

2. How can the net capacity of the bright beer cellar be increased?

This problem mainly focuses on opportunities to use the BBC gross capacity more efficiently to improve the net capacity. To more efficiently use the BBC we look into the short-term scheduling of the BBC.

To structure the research and finding a suitable answer, we break the research down into multiple sub-questions. Figure 1.3 shows the structure and how the chapters are connected. The sub-questions are stated below:

1. *How is the BBC currently used and planned and what is the current performance?*
   - *What does the BBC process look like?*
   - *How is the production currently planned?*

- *What production constraints need to be considered?*
- *What is the current performance of the BBC?*
- *What are qualitative and quantitative factors causing the BBC to be a bottleneck?*

Chapter 2 answers these questions and analyses the current situation of the BBC through available data and interviews with involved stakeholders. The BBC process has a high level of complexity and many different factors need to be considered.

2. *What literature is available to support capacity assessment and planning/scheduling of the BBC?*
   - *What is currently known about planning and scheduling on different horizons?*
   - *How can the purpose of buffer tanks in production be defined?*
   - *How could the BBC planning problem be classified?*
   - *How can such a classified planning/scheduling problem be solved?*

   Chapter 3 answers these questions and provides an overview of existing literature and what is considered to be a gap in the existing literature.

3. *How do we model the BBC process to be able to assess the capacity?*

   Chapter 4 describes how the BBC is modelled and how the capacity assessment can be used to research impact of investments, increasing production volumes and new product introductions. In this chapter we focus mainly on the long-term planning horizon.

4. *How can we improve the BBC planning/scheduling process?*

   Chapter 5 describes how the Bright Beer Cellar scheduling could be improved using the models of the BBC described in Chapter 4. Chapter 4 focuses on a longer term planning horizon and in Chapter 5 zooms in on the short-term scheduling to investigate more efficient scheduling.

1.5 Research deliverables

The deliverables of this research are:

- An overview of important factors causing the BBC capacity to be a bottleneck
- A model that can be used to asses the BBC capacity on a strategic level
- An improved and automated BBC planning strategy
- Impact of possible investments on the BBC capacity

Chapter 2

Context Analysis

This chapter aims to provide more context about the BBC and identify the most important factors to be considered in this research. This chapter focuses on the first research question: *"How is the bright beer cellar currently used and planned and what is the current performance?"* To answer the research question, Section 2.1 discusses the BBC and the planning process in more detail. Section 2.2 discusses a qualitative analysis based on interviews and Section 2.3 discusses the quantitative analysis based on the available data. The chapter concludes with Section 2.5.

2.1 Bright Beer Cellar

The first research question is divided in multiple sub-questions. This section focuses on the sub-questions:

- *What does the BBC process look like?*
- *How is the production currently planned?*
- *What production constraints need to be considered?*

Subsection 2.1.1 describes the BBC process and the most important process constraints and subsection 2.1.2 describes the currently used method of planning for the BBC.

2.1.1 Process

In Section 1.1 we mentioned that the BBC is the buffer between filtration and packaging. When beer is stored in the BBC the beer is ready to be packaged. Figure 2.1 portrays the flow of beer through the BBC. The flow starts with the filtration lines filling a dedicated BBT, which is located in a block with multiple tanks. Table 2.1 shows the corresponding number of tanks and volumes per block. Tanks in each block share filling and emptying pipes and every block has limited pipes available, thus not all tanks can be filled or emptied simultaneously. Table 2.2 displays the corresponding number of filling and emptying pipes per block. The emptying and filling of the BBC is handled by the emptying and filling matrices, respectively. These matrices are automated and ensure the correct beer is placed in the correct tank or brought to the correct packaging line. The filling matrix distributes beer from the filters to BBC blocks. The emptying matrix is not completely flexible, i.e. not all blocks are connected to every packaging line. Table 2.3 illustrates this and shows the connections per block to each of the packaging lines. One emptying pipe of block 10 is connected to an emptying pipe of block 50, because block 10 was reconnected

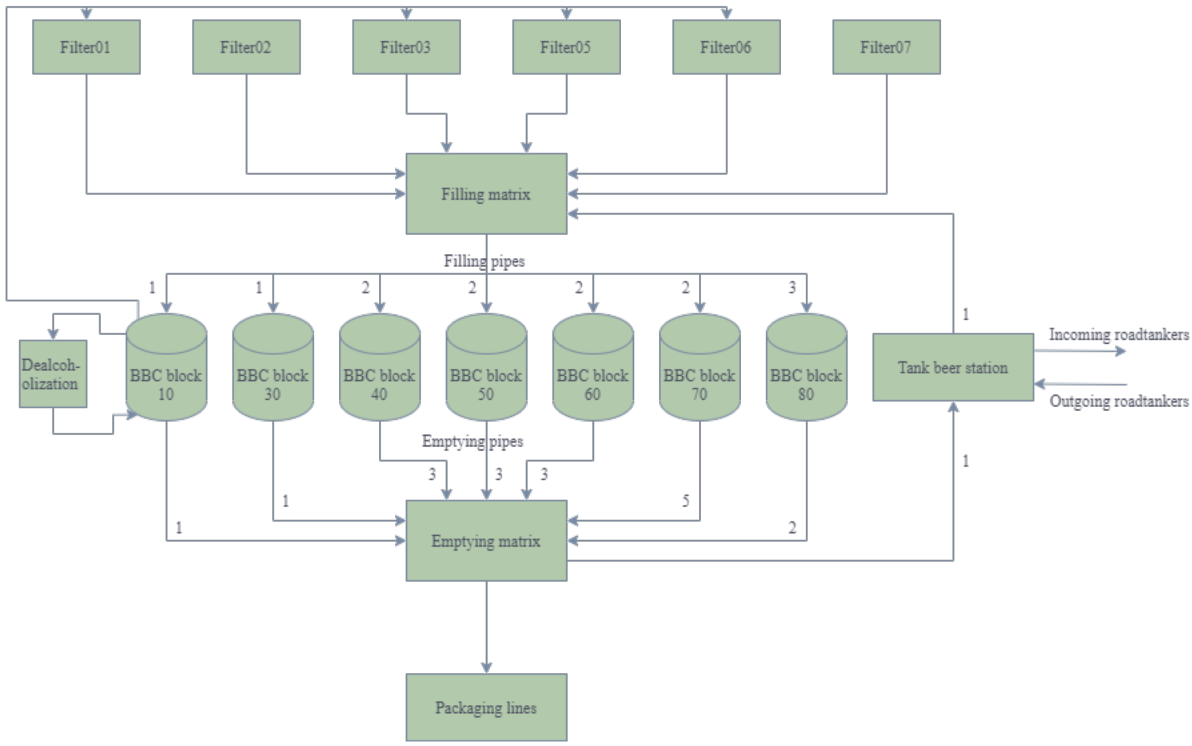

FIGURE 2.1: Schematic overview of the BBC flow in Den Bosch

to the emptying matrix in a later stadium and combining the emptying with a pipe of block 50 was a cost efficient solution. A disadvantage of this solution is that the pipes cannot be used simultaneously.

TABLE 2.1: Tanks and volumes for the BBC blocks

BBC Block	Nr. Tanks	Tank volume
10	6	Small
30	5	Small
40	6	Small & Medium
50	6	Small
60	6	Small
70	8	Large
80	4	Large

Due to different capabilities of the breweries, beer can be brewed at one brewery and packaged at another using road tankers. This causes the breweries to have incoming and outgoing road tanker streams. This process is not completely flexible, because not all filling or emptying pipes can be used in combination with the road tanker station, see Table 2.4 and Table 2.5. A road tanker can be emptied directly or indirectly. Indirect emptying happens when the beer is transported as high-gravity beer. The high-gravity beer is concentrated beer, where water has to be added to create the consumable product. Via indirect emptying of the road tankers water is added to high-gravity beer. As a result, the transported volume is less and therefore

TABLE 2.2: Filling and emptying pipes per block

BBC Block	Nr. filling pipes	Nr. Emptying pipes
10	1	2
30	1	1
40	2	3
50	2	3
60	2	3
70	3	5
80	2	2

TABLE 2.3: Connection BBC blocks and packaging lines, 1 if a block is connected, 0 otherwise.

BBC Block	16A	16B	8A	8B	15A	15B	24	17	14
10	1	1	1	1	1	1	1	1	1
30	0	0	0	0	0	0	1	1	0
40	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1
60	1	1	1	1	1	1	1	1	1
70	1	1	1	1	1	1	1	1	1
80	1	1	1	1	1	1	1	1	1

the transportation is more efficient. Loading docks also have different capabilities in the ability to fill or empty a road tanker, see Table 2.6.

TABLE 2.4: Emptying pipes that can be used to empty road tankers

BBC Block	Emptying pipes
10	2
30	-
40	3
50	3
60	1
70	5
80	1

Figure 2.1 also shows the use of the dealcoholization equipment. The dealcoholization equipment is used to remove alcohol and to produce Heineken 0.0 and other 0.0 beers. Block 10 is the only block connected to the dealcoholization equipment.

Over the years many investments have been done in the production network of the brewery in Den Bosch. For example, re-connection of blocks, adding more emptying/filling pipes or the addition of more BBTs. To provide an example what could change in the flow of the network with an investment, Figure 2.2 shows a possible change in the BBC flow. This portrays an investment in the piping of the dealcoholization equipment, where the dealcoholization equipment is connected to the

TABLE 2.5: Filling pipes that can be used to fill road tankers

BBC Block	Filling pipes indirect	Filling pipes direct
10	1	1
30	1	0
40	1	1
50	1	2
60	2	1
70	0	0
80	0	1

TABLE 2.6: Connection of road tanker docks to the filling or emptying matrix

Matrix	Dock 5	Dock 6	Dock 7
Filling	1	1	0
Emptying	0	1	1

filling matrix.

Overall we conclude that the BBC process has grown to be quite complex over the years. A multitude of changes and investments cause the process to have many constraints.

2.1.2 Planning

HNS plans the production on different levels (strategic, tactical and operational). The BBC is only taken into account on an operational level. The strategic and tactical planning departments do not include the capacity of the BBC in their planning models.

The planning of the BBC is a result of the brew plan and the packaging plan. Every week the tactical planning department provides a brew and packaging plan to the operational scheduling department. Based on the tactical plan, the operational scheduling creates a feasible packaging schedule to fulfill the tactical plan and how to use the available resources as efficient as possible. In the tactical plan, the brewing of beer is based on when the packaged beer should be ready for distribution. This can be 4 weeks in advance, due to long production times in the fermentation and lagering. The operational scheduling department is responsible for the availability of beer in the BBC prior to packaging. The moment of filtration can be scheduled, from the point that the beer is ready with fermenting and lagering. The moment of filtration determines when a BBT is filled. Thus, the beer is pushed to the BBC and the packaging lines are responsible for emptying the BBC.

Figure 2.3 shows the planning process considering the eventual BBC schedule. The operational scheduling department consists of multiple schedulers, each responsible for their own part of the total production schedule. First the packaging scheduler creates the packaging schedule based on the plan provided by the tactical planning department, e.g. how much bottles and cans there have to be produced. The

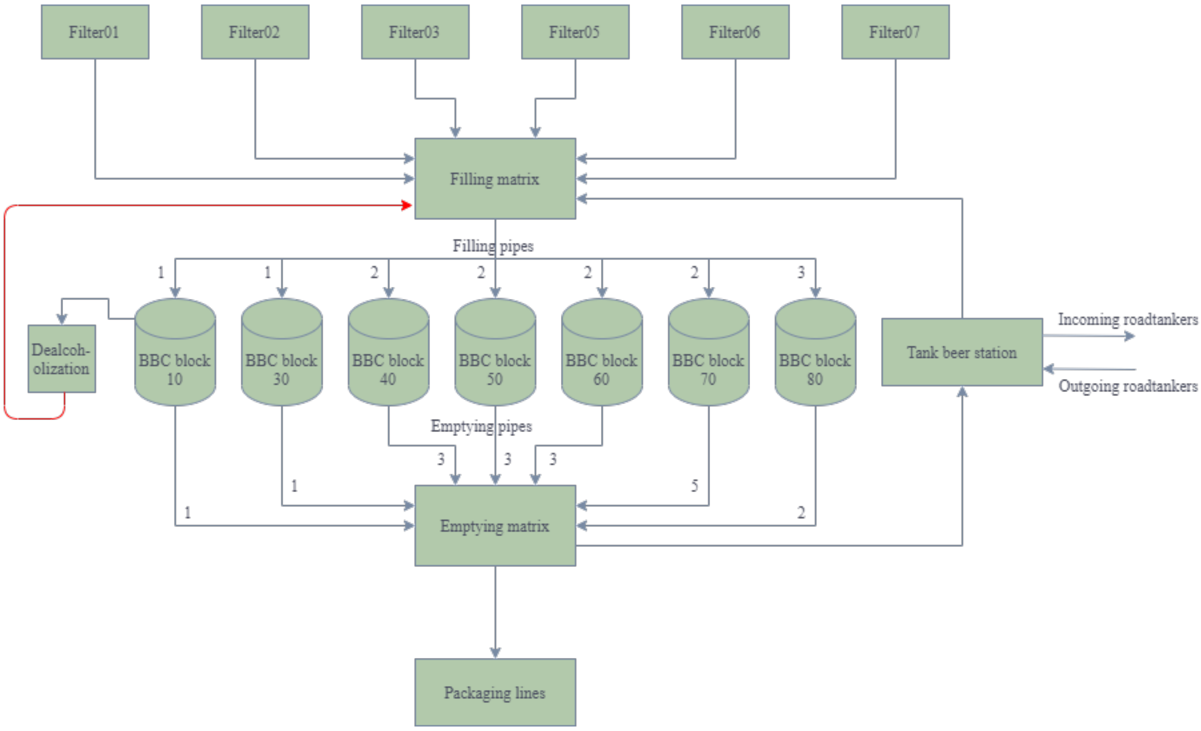

FIGURE 2.2: Schematic overview of the BBC flow with an investment in the 0.0 beer process indicated with the red line

packaging schedule is communicated to the filtration and BBC scheduler. With the scheduling of filtration and BBC the scheduler is responsible for the fulfillment of the demand needed for the packaging schedule. If the scheduler is not able to fulfill all demand on time, the packaging scheduler has to change the packaging schedule to be able to create a feasible schedule for both packaging and the BBC. The brewing schedule is created from the provided tactical brew plan and is considered as out of the scope of this research.

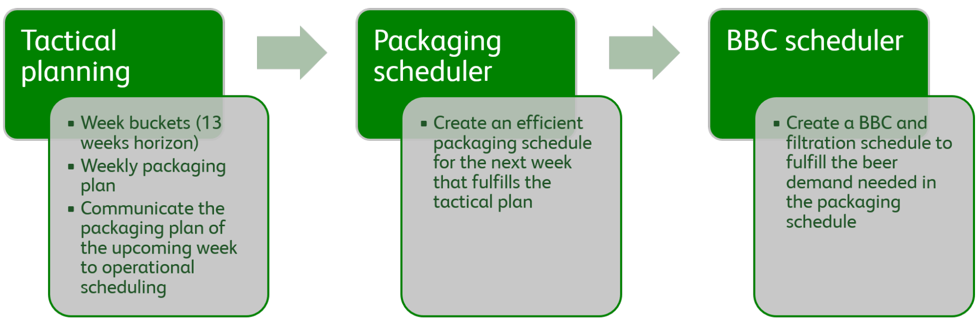

FIGURE 2.3: Schematic overview of the planning process

2.2 Product Portfolio

Not only the BBC itself has constraints, also the produced beers have constraints in how they flow through the process. This section discusses the different groups of beers considering constraints in the process.

In the current product portfolio some beers occupy a BBT more than once before being packaged. For example, the 0.0 beers have an extra dealcoholization step that causes the beer to occupy a BBT multiple times. In the current product portfolio a division can be made between one, two or three step BBC process. Figures 2.4, 2.5 and 2.6 illustrate the process of the one, two and three step process, respectively. The figures in this section are for illustrative purposes. Appendix A shows all the possible flows of beers based on constraints of filters and BBC blocks.

FIGURE 2.4: Schematic flow of a one step beer flow through the BBC

FIGURE 2.5: Schematic flow of a two step beer flow through the BBC

FIGURE 2.6: Schematic flow of a three step beer flow through the BBC

The number of steps refer to the number of times a beer flows through a BBT. Within the step division, beers can be grouped based on the constraints. The figures display the division of beers based on their constraints. Not every beer can be filtered on every filter and not every beer can be stored in all blocks. A beers falls within such a group that determines the possible routes a beer can have through the BBC. The one-step beers are only stored in the BBC once, the two-step beers twice and the three steps beers three times. Most beers only need one filtration run and will occupy a BBT once. The beers flowing through the BBC multiple times are the smaller volumes specialty and 0.0 beers.

2.3 Qualitative analysis

This section discusses the qualitative analysis based on interviews with different employees of Heineken. With this analysis this section also answers the qualitative part of the first research question:*"What are qualitative and quantitative factors causing the BBC to be a bottleneck?"* The occurrence of the BBC as bottleneck in the production process may have several causes. After the interviews multiple causes emerged. To create links and relationships between discovered problems we construct a problem cluster (Heerkens and Winden, 2012). Figure 2.7 shows the constructed problem cluster. The following subsections explain more about the mentioned problems in Figure 2.7.

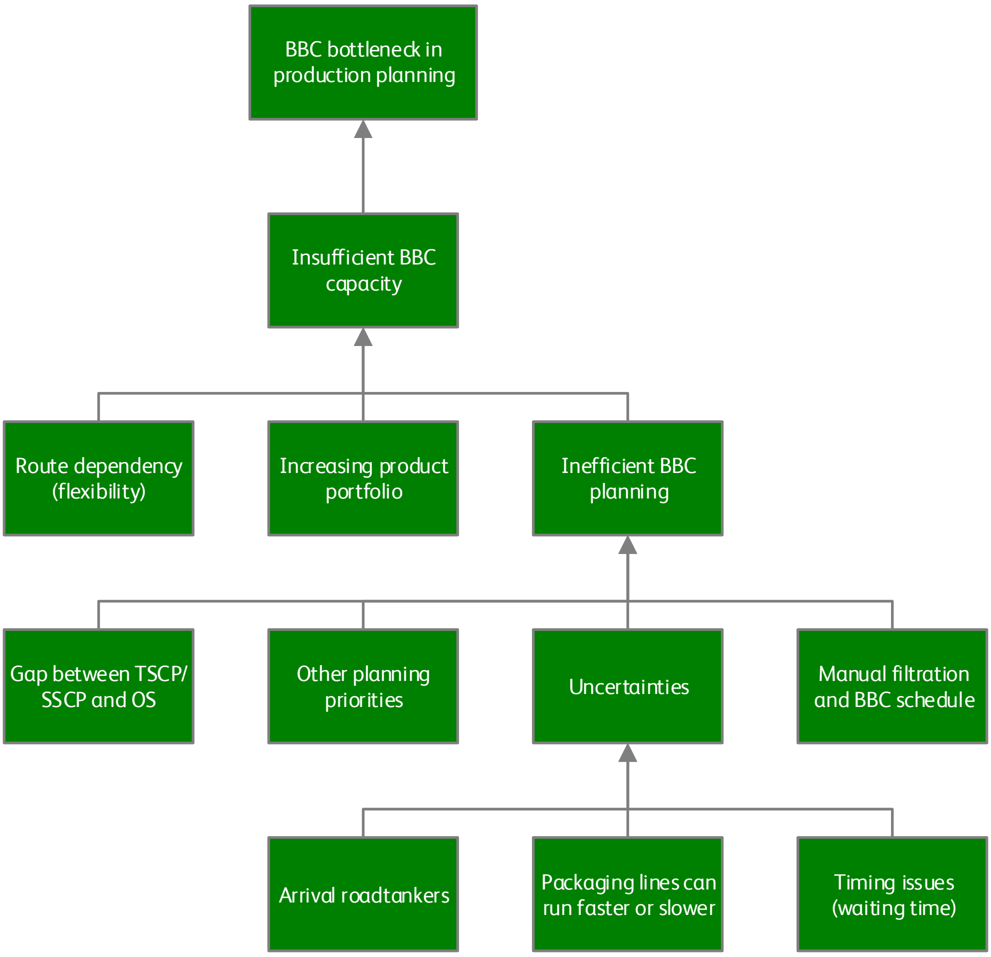

FIGURE 2.7: Problem cluster of the BBC as planning bottleneck

2.3.1 BBC bottleneck in the production planning

Figure 2.7 shows that at the top of the problem cluster we have the occurrence of the BBC as bottleneck in the production. The BBC is a so called decoupling point in the production process, that is, it decouples the output of the filters and the input for the packaging lines. It should always have overcapacity and never limit other production steps. In some cases the BBC cannot fulfill the packaging schedule and the packaging scheduler has to reschedule to be able to create a feasible overall schedule. However, this is not desirable, because the packaging lines are the most expensive assets and should be used in the most efficient way and should not be constrained by the BBC.

2.3.2 Insufficient BBC capacity

The underlying problem of the bottleneck to occur, is that there is not enough BBC capacity to be able to support the most efficient packaging schedule found by the packaging scheduler.

2.3.3 Route dependency (flexibility)

The insufficient BBC capacity is caused by route dependency. Not all filters and BBC blocks have the same capabilities. As explained in Section 2.1.1, when a beer is filtered on a certain filter, the beer can only flow to a limited number of blocks. After the beer reaches the BBC is has to be filled into for example bottles, cans or kegs. The different packaging lines all have their own capabilities and are not connected to all blocks. This makes the planning dependent on certain routes and decreases the flexibility in the planning. All the dependencies negatively influence the usable capacity of the BBC.

2.3.4 Increasing product portfolio

The insufficient BBC capacity is also caused by the production of more types of beer are produced, which makes the planning of the resources more complex. More product differentiation leads to more changeovers, cleaning, maintenance and complexity in the production process and planning. This puts pressure on the throughput capacity of especially the BBC. Before filtration the number of wort types is still relatively limited, but after the filtration these wort types split in multiple types of beer. Especially in the Den Bosch brewery this increased over the last years.

The increasing product portfolio decreases the net capacity of the BBC. Where the total volume of beer should easily fit in the number of tanks (gross capacity) this is different in practice. The utilization rates of the tanks decrease through the increasing number of produced beers.

2.3.5 Inefficient BBC planning

The capacity of the BBC is not always efficiently used, which decreases the usable capacity of the BBC. This inefficient planning has multiple underlying problems, the Subsections 2.3.6, 2.3.7, 2.3.8 and 2.3.9 discuss these problems in more detail.

2.3.6 Gap between TSCP/SSCP planning and OS

Tactical Supply Chain Planning (TSCP) and SCD do not take the filtration and BBC capacity into account for their planning. In a week it can occur that the proposed tactical plan is not feasible for the operational schedulers due to the filtration and BBC capacity. TSCP plans in week buckets. Overall the planning might seem feasible, but in the operational schedule simultaneity can occur. This can result in high peak moments on certain days and unused capacity on the other week days. In the worst case, the simultaneity can make a tactical plan infeasible for operational scheduling.

As a consequence, the tactical plan has to be adjusted to create a feasible plan for the BBC. This, however, is certainly not desirable. This causes rework for tactical planners and a possibility of inefficient plans.

For the strategic planning it is difficult to take the BBC capacity into account because it strongly depends on the operational scheduling. A proper capacity assessment of the BBC is missing to detect operational scheduling problems in the strategic planning phase. If these problems can be detected in an early stage SCD can take measures accordingly.

2.3.7 Other planning priorities

The packaging lines are the most expensive investments in the production process and have the priority in the production planning. The other production steps follow, which can lead to inefficient planning at these steps.

2.3.8 Manual filtration and BBC schedule

The operational scheduling is done manually. The operational schedulers seek feasible schedules, that fit in the time window. Feasible schedules are not always found, which can lead to a change in the packaging schedule to create a feasible BBC schedule. As the packaging lines should have the most efficient schedule possible, this not desirable. The schedulers do not use any optimization in this process, because this proves to be difficult in the current scheduling environment in combination with the high complexity of the process.

2.3.9 Uncertainties

Figure 2.7 also shows that uncertainties in the production process cause changes in the planning or the proposed planning to be inefficient. The process has multiple different uncertainties.

Arrival of road tankers

Due to different capabilities of the different HNS breweries, a road tanker flow emerges. Beer can ,for example, only be brewed in Wijlre but has to be packaged in Den Bosch. This results in incoming and outgoing road tankers flow at all breweries. The arrival of the road tankers is subject to uncertainty due to the dependency on the source and traffic. The planning of these flows proves to be difficult and causing long occupation times of the BBC.

Packaging lines can run faster or slower than planned

The planned production at the packaging lines is not always fulfilled. This can be caused by a break-down of the line or a stock-out in the packaging materials. In this case a BBT is not completely emptied and cannot be used for another type of beer. This can cause problems when a new beer is already scheduled to use a dedicated BBT. On the other hand, a packaging line can run faster. In this case a BBT is empty earlier than expected and is ready for a new batch. When the scheduler does not respond to the faster packaging lines, this results in unused capacity.

Timing issues (waiting time)

Before the beer can be packaged, it has to be produced. For example, for the production of Heineken, at least 28 days are needed before the beer is ready to be packaged.

Beer is not always ready to be packaged at the time it is needed, or is ready too early. These timing issues create inefficiencies in the use of the capacity of the BBC.

2.3.10 Conclusion qualitative analysis

From interviews we constructed a problem cluster and we conclude that the BBC is influenced by many factors, some controllable and some uncontrollable. In the problem cluster, there are two core problems that we can control: the gap between long-term planning and scheduling and the manual filtration and BBC schedule. Therefore, these are the core problems that we are trying to solve in this research.

2.4 Quantitative analysis

This section describes the quantitative analysis of the BBC process and answers the quantitative part of the sub-question: *"What are qualitative and quantitative factors causing the BBC to be a bottleneck?"* Based on data this section identifies what factors are the cause of the BBC to be a bottleneck. This section also answers the sub-question: *"What is the current performance of the BBC?"* We measure the performance of the BBC with the actual occupation of the BBC. The data used in the qualitative analysis is production data of 2019, because we want to exclude the influences of the pandemic and also want to use recent and relevant data.

2.4.1 Product portfolio and volume

Based on solely the produced volumes and number of beers produced, there is no clear relation between produced volume and produced beers. From the produced volumes and produced beers. see Table 2.7. We conclude that more different types of produced beer in a year does not necessarily reduce the produced volume. In 2019 and 2020 the number of produced beers declined, where the problem of the BBC to be a bottleneck increased. From this we also conclude that the volume alone is not a cause for the BBC to be a bottleneck.

TABLE 2.7: Number of produced beer types and produced volume per year

Year	Nr. of beers	Relative volume
2015	58	100%
2016	71	107%
2017	72	114%
2018	71	113%
2019	61	117%
2020	60	92%

Figure 2.8 shows the weekly average produced volume per number of produced beers. We expected that more produced different types of beer would reduce to total produced volume, because production of multiple different beer types includes more cleaning and setup times. On the contrary, Figure 2.8 shows that there is no clear relation between number of beers produced and the produced volume. More produced types of beer does not reduce the total produced HLs per definition. The

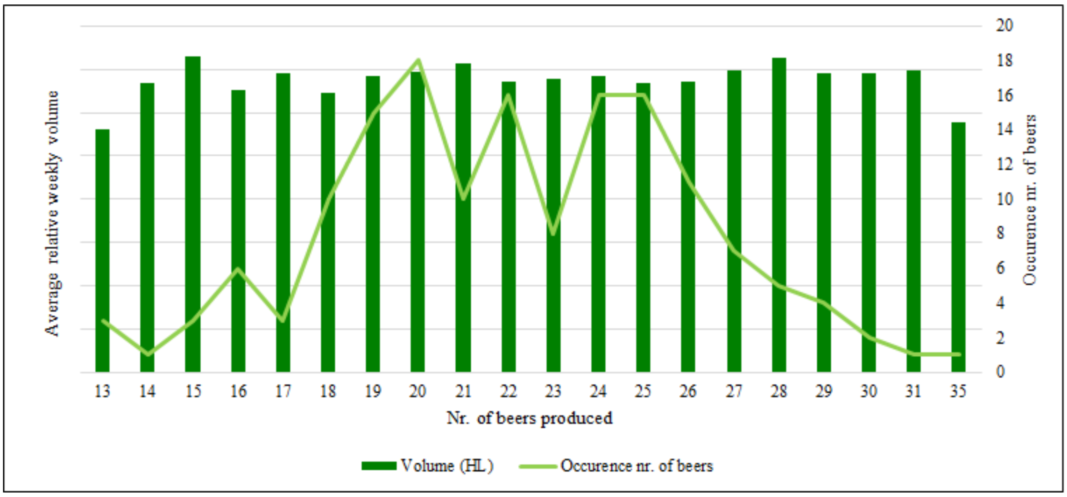

FIGURE 2.8: Average weekly volume per number of different types of beer produced.

figure also shows that a production of more than 28 beer types is not common. A week with a production of 31 and 35 beers only occurred once.

Table 2.8 provides more information about the composition of the product portfolio in the last years. The table only includes the ten biggest volume beers, to show the largest changes. The composition of the beers with the biggest volume over the years is more or less the same with one exception: Heineken 0.0. The production of Heineken 0.0 has increased greatly over the last few years and with the distinctive process of Heineken 0.0 this could indicate a pressure point. Heineken 0.0 currently lies within the 3-step process group.

TABLE 2.8: Top ten beers and cumulative volume per year. The red 0.0 beer shows the growing volume of dealcoholized beer.

2017		2018		2019		2020	
Top 10 beers	**Cum. total**	**Top 10 beers**	**Cum. total**	**Cum. total**	**Cum. total**	**Top 10 beers**	**Cum. total**
Beer 1	0,53	Beer 1	0,48	Beer 1	0,47	Beer 1	0,48
Beer 2	0,61	Beer 3	0,57	0.0 beer	0,57	0.0 beer	0,57
Beer 3	0,70	Beer 2	0,65	Beer 3	0,65	Beer 2	0,65
Beer 4	0,74	0.0 beer	0,71	Beer 5	0,72	Beer 5	0,72
Beer 5	0,78	Beer 5	0,75	Beer 2	0,78	Beer 4	0,77
Beer 6	0,82	Beer 4	0,80	Beer 4	0,81	Beer 3	0,80
Beer 7	0,84	Beer 6	0,83	Beer 9	0,84	Beer 9	0,83
Beer 8	0,86	Beer 9	0,85	Beer 6	0,86	Beer 6	0,85
0.0 beer	0,88	Beer 7	0,88	Beer 7	0,88	Beer 10	0,87
Beer 9	0,90	Beer 10	0,89	Beer 10	0,90	Beer 11	0,88

2.4.2 Bright Beer Cellar Occupancy

This section discusses the current performance of the BBC and answers the sub-question: *"What is the current performance of the BBC?"* With the available production data we construct different occupancy graphs. Appendix B shows four occupancy graphs of the BBC based on different types of BBTs as discussed in Section 2.1.1. This section only includes the graph for block 10.

Appendix B gives an in depth explanation of the graphs. An important insight in determining the BBC occupancy is the division of different occupancy types. A tank can be occupied with different actions: filling, buffering, emptying and the waiting time of the system. Filling occurs when a BBT is being filled with beer through a filtration run. Buffering occurs when the tank is filled and is waiting to be emptied. Emptying occurs when a tank is being emptied through a packaging run. Those first three actions are the actions considering the actual production of the packaged beer. The last action, Waiting time of the system, is considered as a gap in the schedule where a BBT is free but is unusable for a other batch of beer, due to the length of the gap. Hence, when a gap between two scheduled batches only has a span of hours, this cannot be considered as free capacity, as the tank cannot be used for other production batches. If a gap is bigger than the average of the total time a batch usually occupies the system, the gap can be considered as free capacity. When the gap is smaller than the average time, the gap is considered as waiting time of the system and thus unusable capacity for the BBC. We consider the waiting time of the system as planning inefficiency for the BBC.

From the graphs we conclude that all the tanks in the BBC are often completely occupied and maximum capacity is often reached. This corresponds with the qualitative analysis based in experiences of Heineken employees. The biggest contributors to the occupation of the BBC are emptying and buffering. The big tanks are mostly occupied with emptying and have less planning inefficiencies. The smaller tanks are more occupied with buffering and in the peak season, weeks 20 to 33, more small and unusable gaps between batches in the schedule occur. That is expected, because more batches have to flow through the system. However, this gives an idea in how the BBC is used and that there is a difference between gross and net capacity in the BBC. From the graphs we conclude that the small tanks are more sensitive to planning inefficiencies than the big tanks.

Section 2.4.1 shows the increasing volume of the Heineken 0.0. The production of Heineken 0.0 strongly depends on block 10, because the dealcoholization can only be done in block 10. Therefore, we consider this part of the BBC as a stand-alone block of tanks, because the 0.0 production does not influence the usage of the regular tanks and regular beer production has minor influence on the usage of block 10. Figure 2.9 shows the occupancy of block 10. From this figure we conclude that block 10 is often used to its maximum capacity in many occasions and is a bottleneck in the production.

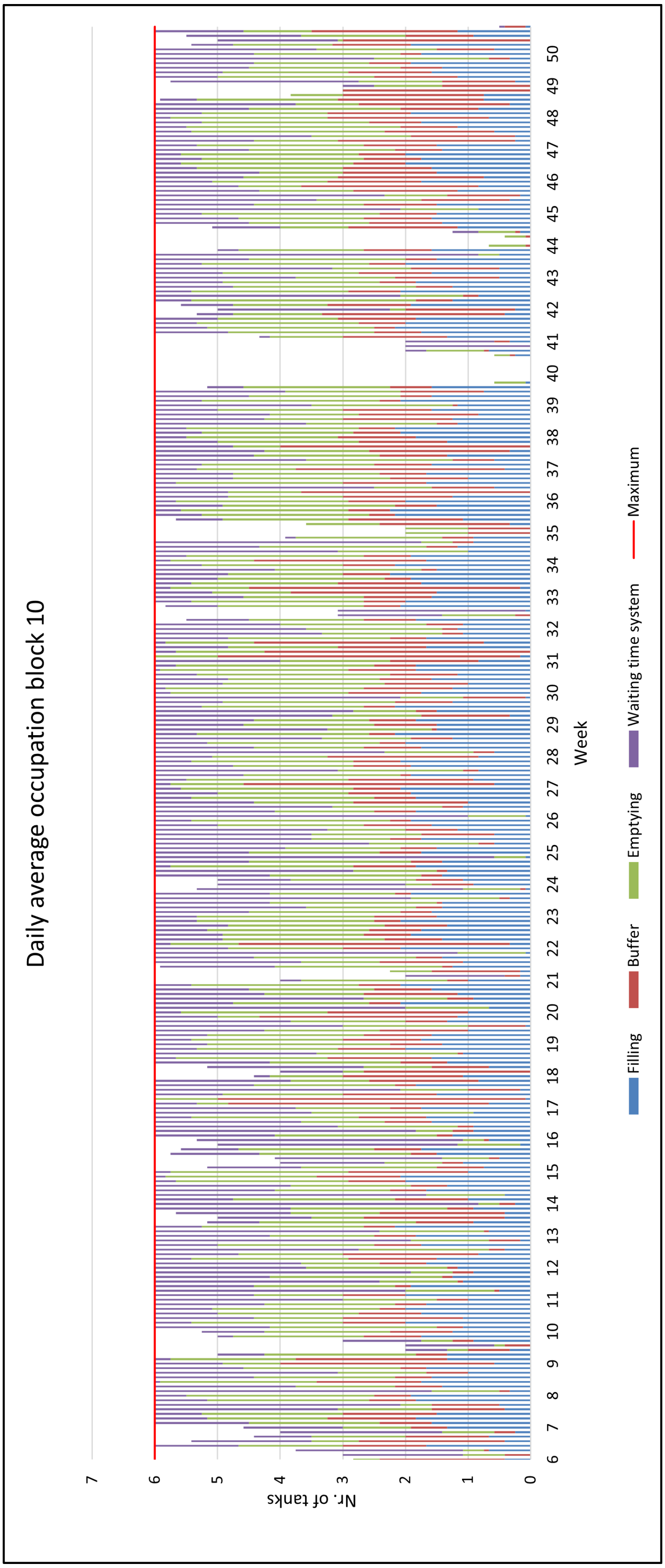

FIGURE 2.9: Average daily occupation of block 10

2.4.3 Cycle times per beer

This section reviews the filling, buffer and emptying times of the produced beers in 2019 to determine beers with above average cycle times and identify possible causes for the BBC to have a high occupation. Figure 2.10, Figure 2.11 and Figure 2.12 show the times of filling, buffering and emptying in a box plot. Box plots are a powerful way of summarizing distributions of data to allow visual comparisons of centers and spread through the five-number summary (minimum, lower quartile, median, upper quartile, maximum), which divides the data into four equally sized sections (Pfannkuch, 2006). A type of beer usually has constant batch sizes and is often allocated in big or small tanks and seldom both. Therefore, no distinction is made in batch sizes per type of beer.

The filling time of a BBT in comparison to the buffer and empty times is only a small part of the total cycle time, often not more than a half day. Figure 2.10 shows some outliers in filling times. The biggest outlier is a beer that is not produced anymore. The first box plot in Figure 2.10 also shows the longer filling time of dealcolized beer. This is caused by the use of the dealcoholization equipment. The box plots show a small average and spread in the filling times. We conclude that the type of beer has little influence on the filling times.

Figure 2.11 shows the buffer times. The buffer times have a higher average and more spread. The bigger spread is caused by the exposure of the buffer times to uncertainty. The buffer times can be negative when the emptying of the tanks starts before the filling is finished. There are no big outliers in the buffer times. Therefore, we conclude that the type of beer has little influence on the buffer times.

Figure 2.12 shows the emptying times. The emptying times mostly have a small spread with some beers as exceptions. The beer destined for catering sector (road tankers) have longer emptying times. A tank in the BBC has a bigger volume than the road tankers. Multiple road tankers are needed to competently empty a tank. In this case, there is often some time between the arrival of road tankers, which causes the emptying times to be longer. The packaging line for kegs also is a cause of longer empty times. The keg line demands a low amount of HLs per hour and needs more time to empty a tank.

Based on the box plots, we conclude that beers that are emptied into road tankers and kegs have a lengthier cycle time, through the long emptying times and exposure to uncertainties. Other beers are more or less equal considering their cycle times in the BBC. On the other hand, the volumes of those beers are small and therefore also the influence on the performance of the BBC is minor.

2.4.4 Cycle times per block

Section 2.4.3 investigated the impact of the beer types on the cycle times. This section zooms in on the different types of BBC blocks and their filling, buffer and emptying times, to investigate the influence of different types of tanks on the cycle times. Figures 2.13, 2.14 and 2.15 show the box plots of the production times per block.

Figure 2.13 shows a distinction in types of blocks. Block 10 requires more time to fill, because of the production rate of the dealcoholization equipment. Blocks 30, 40, 50 and 60 require less time because these blocks have tanks with smaller volumes. Therefore, blocks 70 and 80 require more time due to the bigger volume tanks. Block

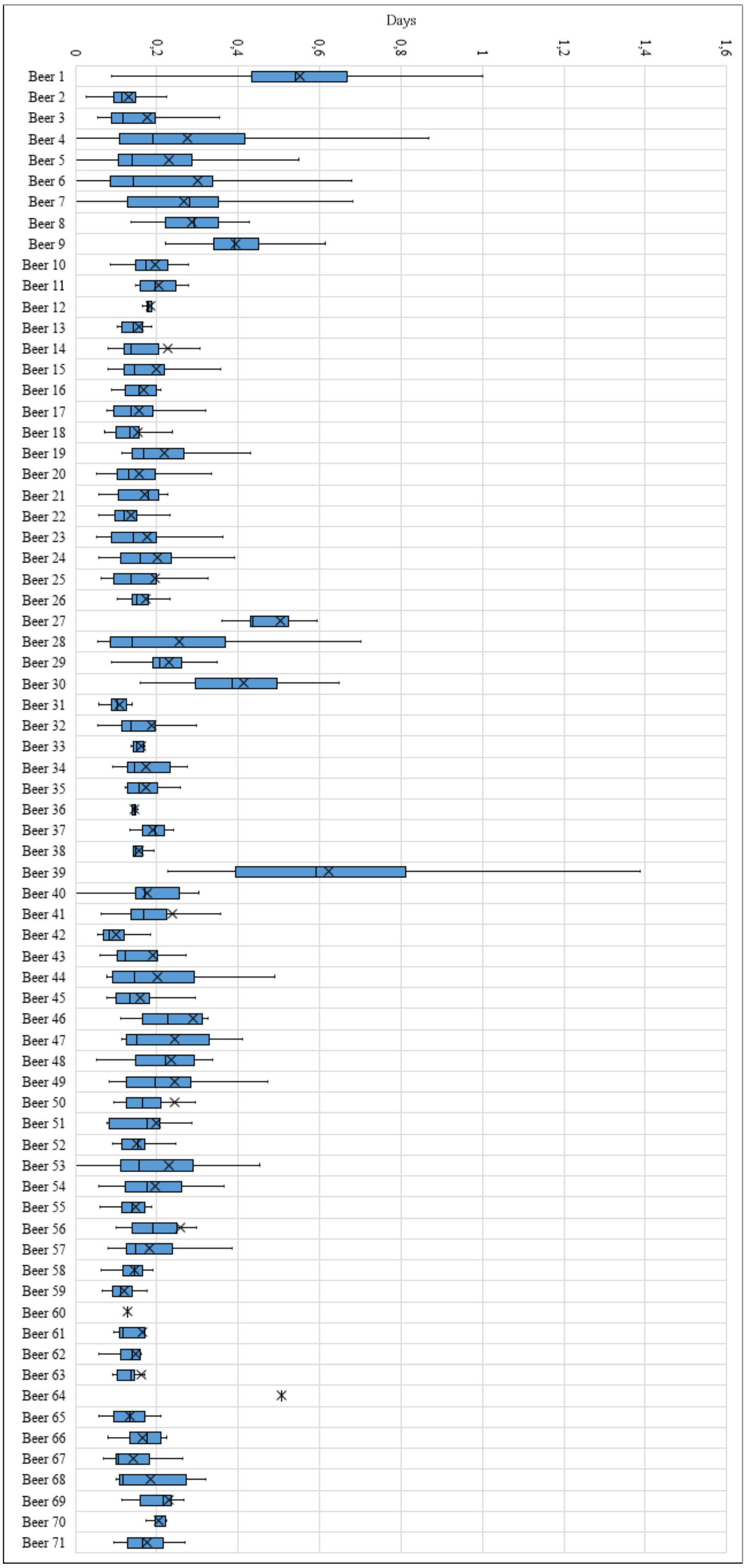

FIGURE 2.10: Box plot per beer of the filling times, with some beers types having long filling times

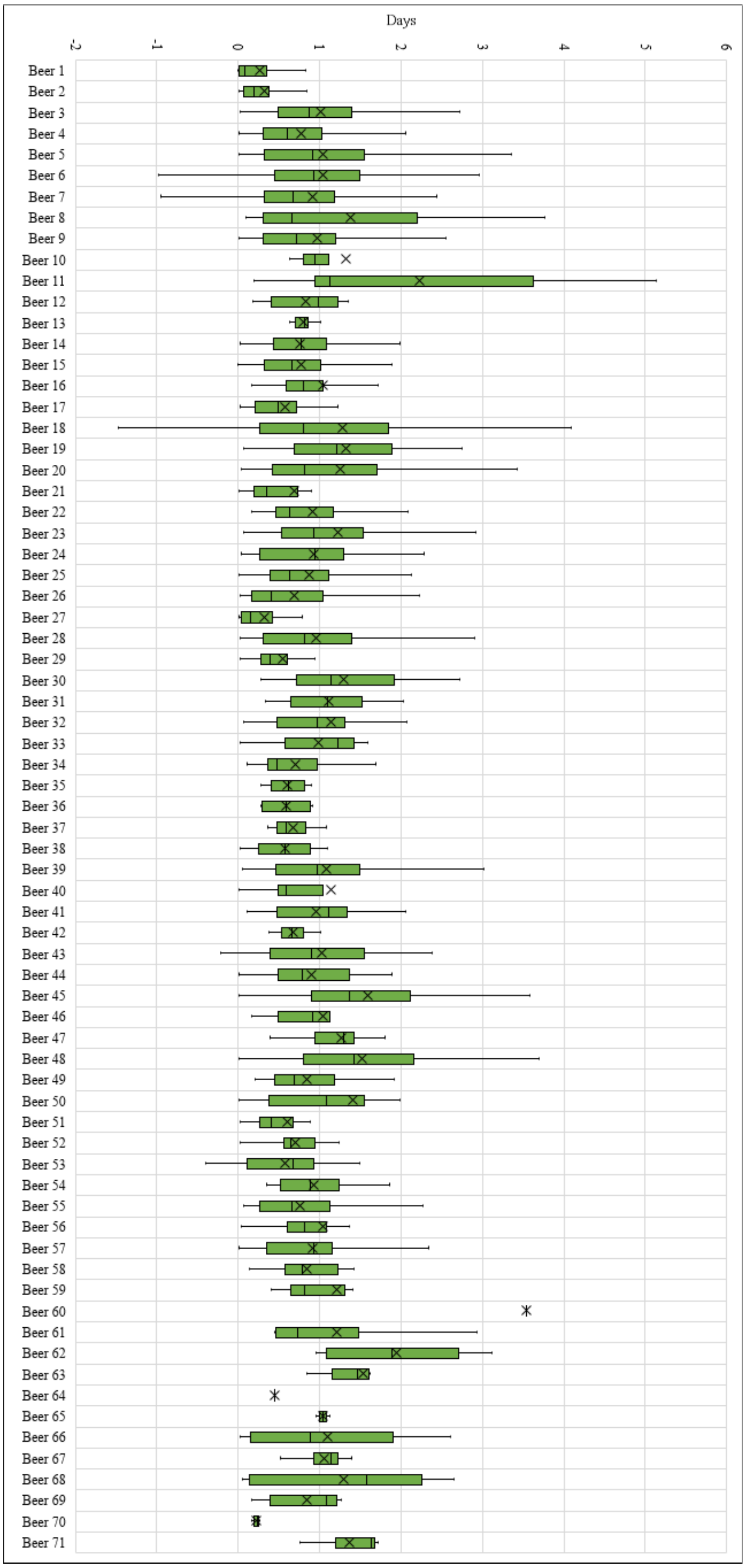

FIGURE 2.11: Box plot per beer type of the buffer times, with no big outliers

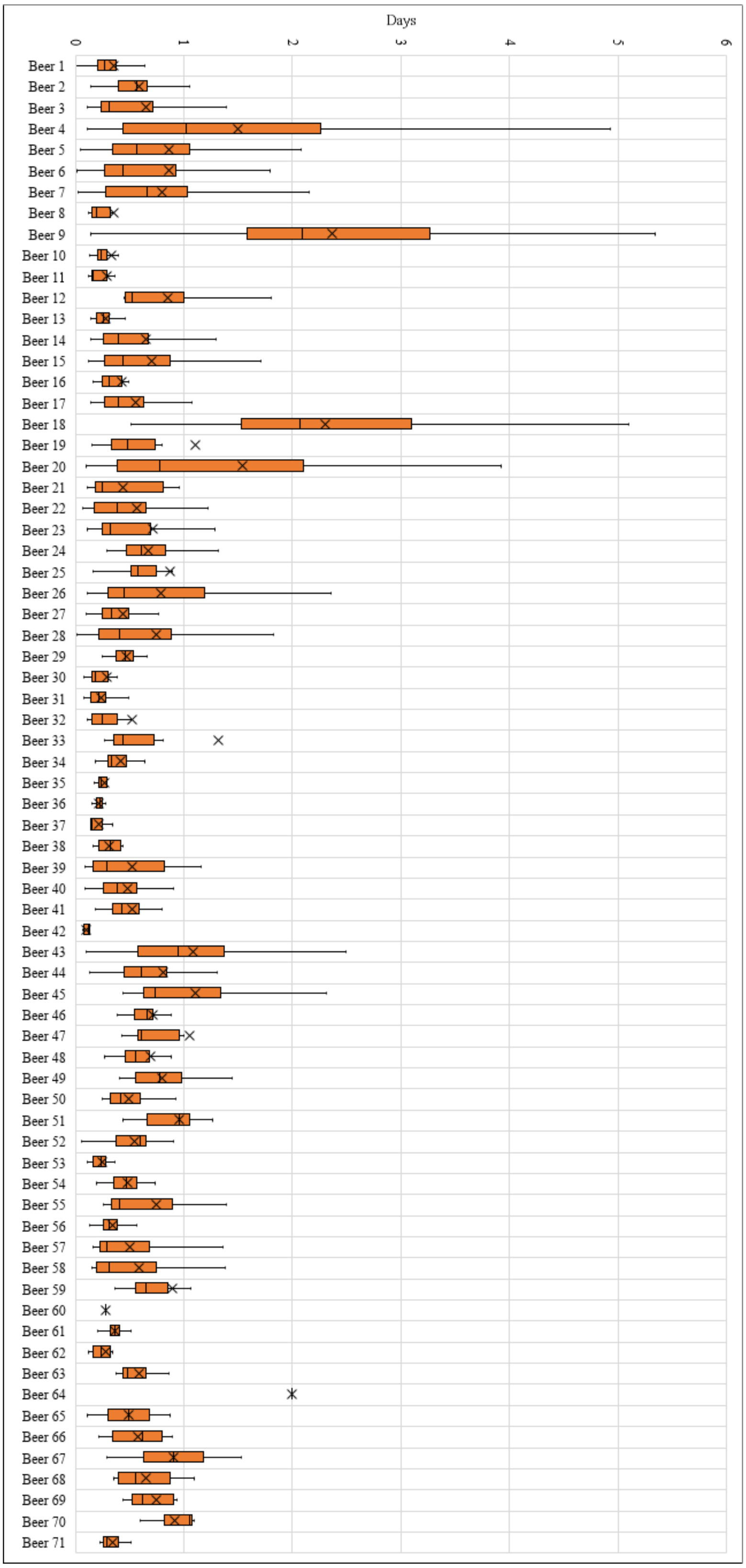

FIGURE 2.12: Box plot per beer of the emptying times, with some beers having long emptying times

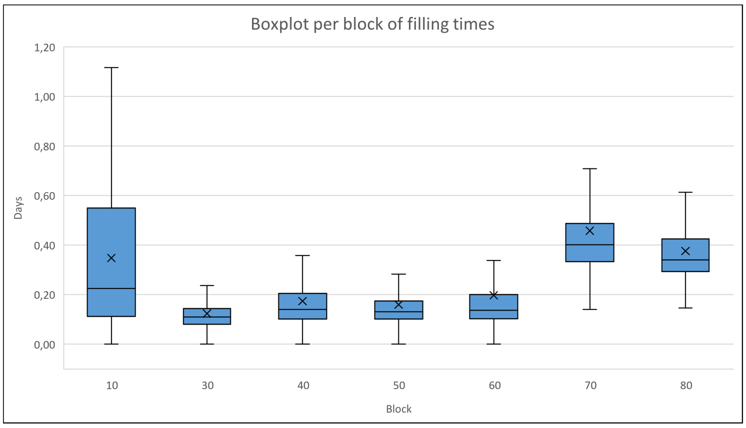

FIGURE 2.13: Boxplot per block of the filling times, where block 10, 70 and 80 have longer filling times

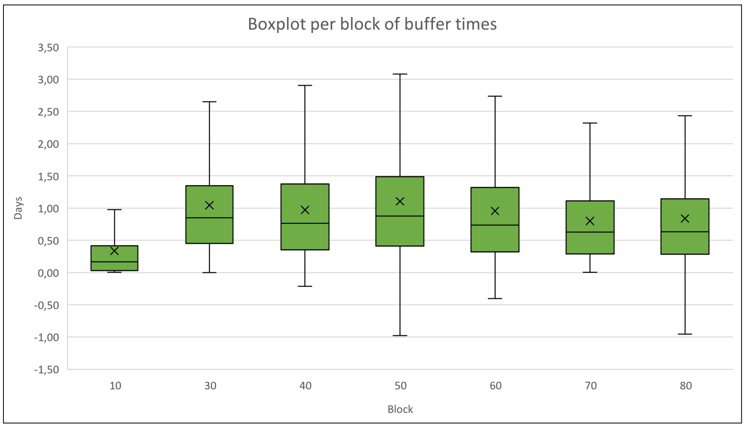

FIGURE 2.14: Boxplot per block of the buffer times, where block 10 has short buffer times

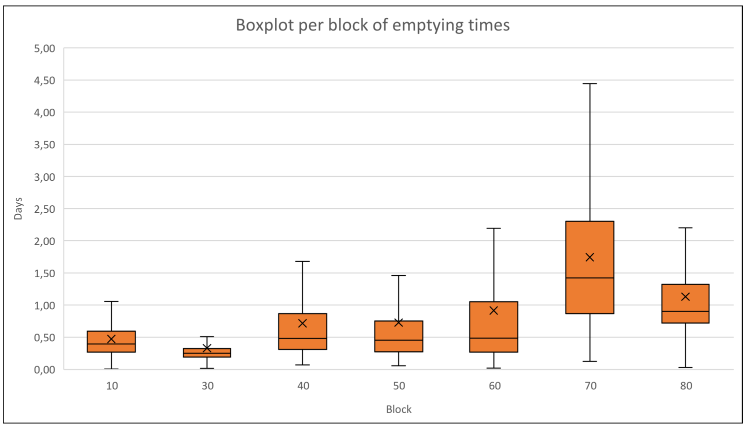

FIGURE 2.15: Boxplot per block of the emptying times, where block 70 has long emptying times and in constrast block 10 has short emptying times

40 uses slightly more time, because the medium volume tanks are included in this block.

In Figure 2.14 we see equal buffer times, except for block 10. Since, Block 10 is not used as decoupling point but for dealcoholized beer production. This gives block 10 a different nature as BBC block and therefore also smaller buffer times, because the scheduling process is more straightforward and less prone to the uncertainty of packaging lines.

Figure 2.15 shows the emptying times per block and we again see a distinction between the blocks. Block 30 has short empty times, because this block can only be emptied by the packaging lines used for canned beer. The emptying times are shorter because the can lines use more HLs per hour than other packaging lines and thus empty tanks faster. Block 70 and 80 require more time to empty through their bigger volumes.Block 80 is mainly used for the biggest volume beer, which often is required on many packaging lines at the same time, emptying the tanks faster than block 70. In block 70 we see a big spread in emptying times, this is due to the fact that different packaging runs with the same beer can lie on different days causing long emptying times.

Overall, we conclude that we can divide the BBC in several types of tanks. Blocks have different natures due to volume, usage and connection to packaging lines. Based on this analysis we divide the capacity of the BBC in five different types.

- Block 10, used for the 0.0 beer production
- Block 30, only emptied by the can packaging lines
- Block 40, 50 and 60 with the small volume tanks
- Block 40, with the medium volume tanks
- Block 70 and 80 with the large volume tanks

2.5 Conclusion

This chapter analyses the BBC process and answered the research question: *How is the BBC currently used and planned and what is the current performance?* With this research question we aim to gain more insight in the BBC production and planning process. Another important aim is to analyse the current performance of the BBC and identify the most important problems causing the BBC to be a problem in the operational scheduling of the Heineken production in Den Bosch.

Over the years, the BBC has grown to be a complex step in production with many constraints. The BBC is originally a buffer and should have sufficient capacity to be able to fulfill the desired packaging schedule. A buffer has a different nature as regular production steps and with this nature it is difficult to say something about the capacity because a buffer does not have standard production times to be used in capacity calculations. In combination with the great complexity of the BBC this makes the BBC a difficult part in the production process to perform a proper capacity assessment on.

Heineken plans their production in different departments, over different horizons, where the BBC is only included on the short-term horizon. The strategic and tactical planning do not take the BBC capacity into account in their planning models, because the BBC is expected to have sufficient capacity and the assessment of capacity is difficult. From the qualitative analysis multiple problems arise causing the BBC to be a scheduling bottleneck. The core problems that we want to solve in this research are: the gap between strategic/tactical planning and operational scheduling and the manual scheduling of the BBC. The assumption that the BBC has sufficient capacity to enable the other production steps appears to be incorrect. Therefore, on the longer planning horizons, operational limitations of the BBC should be considered.

Section 2.1.1 discusses the constraints in the BBC process and shows that the BBC is also highly flexible. Most of the tanks blocks can be reached by all filters and packaging lines. Inside the BBC there are different types of tank blocks with dedicated filling and emptying pipes. Based on the constraints of the process and data about the production times the BBC capacity is divided in different types.

Over the last few years the schedulers experience the BBC to be a difficult and limiting step to schedule. The production data of 2019 also shows that the BBC reaches its maximum capacity in many occasions. We conclude that with the introduction of the 0.0 beers the pressure on the BBC is higher than before, because 0.0 beers require multiple filling, buffering and emptying actions. On the contrast, we conclude that other types of beer have equal influence on the BBC performance.

We also conclude that the BBC is not used as efficiently as it could be, if it was the main planning focus. However, the BBC is not the main planning focus and has to enable the most efficient packaging schedule.

Chapter 3

Literature

This chapter answers the second research question: *"What literature is available to support capacity assessment and planning/scheduling of the BBC?"* Chapter 2 discusses the BBC process in detail and the aim of this is chapter to gain more insight in solution direction for such a planning and scheduling problem. The research question has multiple sub-questions that need to be answered:

- *What is currently known about planning and scheduling on different horizons?*
- *How can the purpose of buffer tanks in production be defined?*
- *How could the bright beer cellar planning problem be classified?*
- *How Can such a classified planning/scheduling problem be solved?*

Section 3.1 answers the first sub-question, Section 3.2 introduces a type of process similar to a brewery, Section 3.3 answers the second sub-question, Section 3.4 answers the last two sub-questions on a strategic level and Section 3.5 answers the last two sub-questions on a operational level. This chapter concludes with Section 3.6.

3.1 Manufacturing planning and control architecture

Planning and scheduling activities can be divided in different areas. Figure 3.1 shows a general architecture for manufacturing and control (Zijm, 2000). With the departmental structure of HNS, the modules can be assigned to the different planning departments (strategic, tactical and operational). This division is also portrayed in the figure. The areas differ in the moment of decision making and the decisions to be made. The strategic decisions are long-term decisions taken early in the planning process. the operational decisions are short-term decisions, which are decided late in the planning process. Zijm (2000) classifies the short-term decisions as 'scheduling' and the longer-term decisions as 'planning'. For example, long-term decisions can be about substantial investments and short-term decisions are about when to produce which product on what machine.

This research is restricted to on the one hand the facility and resource planning and on the other hand the shop floor scheduling. In the facility and resource planning long-term decisions are made about the available production equipment and decide if the equipment is sufficient to produce the forecasted volumes. If the equipment appears to be insufficient, investments in the equipment can be considered. In the shop floor scheduling the decisions are about when and where a job/product is produced. This can either be offline or online. Offline scheduling schedules the entire system before the system starts running. So, it needs a complete knowledge of all job parameters. Online scheduling is done during production. When something unexpected occurs, online scheduling can adapt to a change by changing the schedule accordingly (Phavorin et al., 2018).

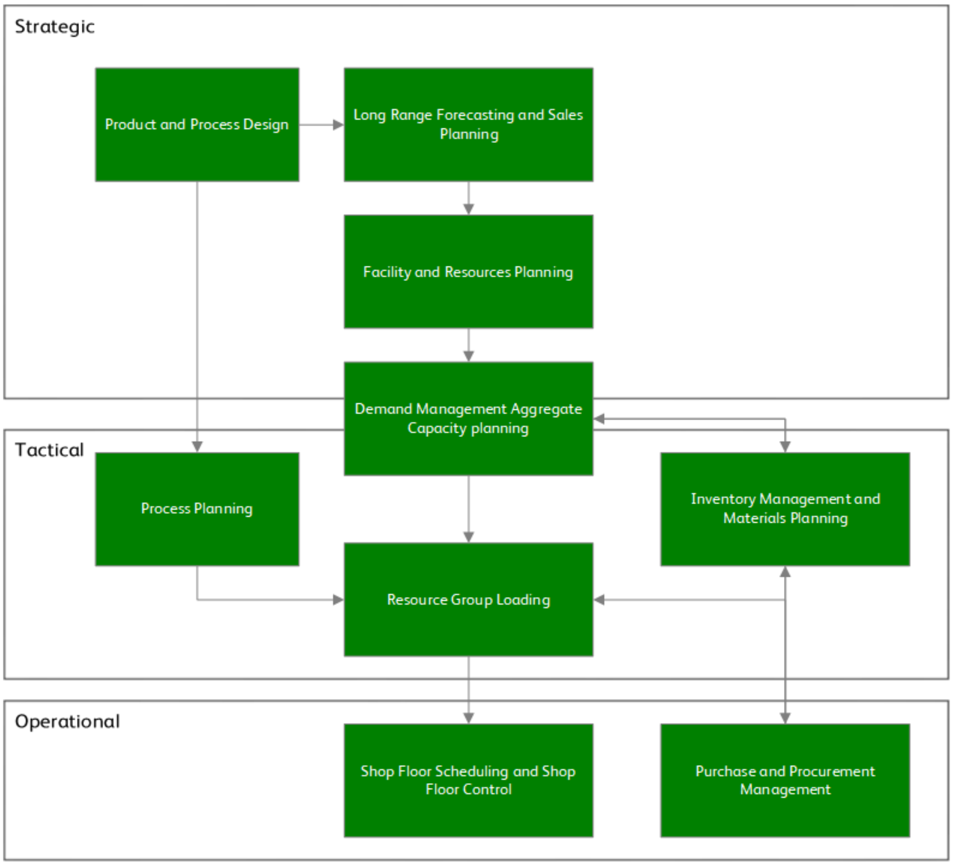

FIGURE 3.1: General architecture for manufacturing and control (Zijm, 2000)

3.2 Multiproduct, multipurpose batch process

Based on the analysis of the current situation in Chapter 2 and according to literature a process with more types of products, production equipment capable of producing multiple products and production batches, can be described as a multiproduct, multipurpose batch process with finite intermediate storage (Liu and Karimi, 2007). Compared to discrete parts manufacturing processes, in a brewery, there are more complex constraints on the possible schedules. When an operation is finished, the material cannot be stored on the floor for any period of time. It must be stored in some storage tank, which may be tanks used for production or in a buffer tank with limited capacity. In some cases intermediate storage is not allowed because this leads to a degradation of the material. In this case it is only permitted for a limited period of time (Engell et al., 2000).

3.3 Buffer tanks

In this research the main focus is on the tanks of the BBC. Those tanks function as buffer tanks between filtration and packaging. The use of buffer tanks is common in industry, under many different names such as intermediate storage vessels, holdup tanks, surge drums, accumulators, inventories, mixing tanks, continuous stirred tank reactors (CSTRs), and neutralization vessels (Faanes and Skogestad, 2003). Faanes and Skogestad also give a definition for buffer tanks:

A buffer tank is a unit where the holdup (volume) is exploited to provide smoother operation.

With this definition, buffer tanks can be divided in into two categories: for disturbance attenuation and independent operation.

Buffer tanks used for the disturbance attenuation are installed in a continuous process to avoid multiplication of disturbances in successive production steps. For the independent operation, buffer tanks are installed to ensure independent operation of two production stages, for example during a temporary shutdown. It can also ensure independent operation between continuous and batch processing units. In this category the design of the tank size for these types of buffer tanks is often fairly straightforward (typically equal to the batch volumes).

The decision regarding the allocation of buffer capacities to mitigate throughput losses from stochastic processing times and unreliable stations is known as the Buffer Allocation Problem (BAP) (Weiss, Schwarz, and Stolletz, 2019). In the BAP the choice where to place buffers in the process is the most important decision. In the situation of Heineken the decision of where the buffer should be placed in the process has already been made. Therefore, we do not include literature about the BAP and how to solve this problem.

3.4 Capacity Planning

Decisions concerning strategic capacity planning play a significant role in a company's performance and have been an important research topic in operations management. The decisions regarding capacity planning relate to determining the sizes, types, location and scheduling of capacity expansion, reduction and replacement of old or obsolete equipment. In the long term, capacity planning supports strategic business plans of new process technology and new products (Chou et al., 2007). This research focuses on the long-term capacity planning of the BBC, where it is important to take the operational limitations into account. When using capacity planning problems in the operational scheduling can be recognized in an early stage on the longer planning horizon. The earlier recognition enables Heineken to take actions to prevent the problem from actually occurring (For example, invest in more capacity, more flexibility or reallocate volumes to other breweries). This section provides literature over the capacity planning that can bridge the gap between the longer planning horizon and the operational scheduling.

Capacity can be defined as the maximum output rate that can be achieved by a facility. The facility may be an entire organization, a division, or only one machine. Available capacity needs to match the load. Insufficient capacity decreases the service levels, while too much capacity is associated with unnecessary costs. Although, the definition of capacity seems simple, there is no one way to measure it. There are different interpretations of what capacity means, and the units of measurement are often different as well. When determining the capacity of a facility, two types of information are important. First, available capacity, which will help to understand how much capacity a facility has. Second, effectiveness of capacity use, which will tell us how effectively the available capacity can be used (Reid and Sanders, 2016). Together these two types of information provide the load a facility or a resource of a facility can handle.

An approach to checking if the available capacity can match the planned load is Rough-Cut Capacity Planning (RCCP). On a long-term planning horizon, the planned production is mostly based on forecasts and not actual placed orders. To evaluate the feasibility of such a production plan, RCCP can be used. The process of RCCP is described as converting the planning into requirements for key resources such as direct labor and machine time (Reid and Sanders, 2016).

RCCP calculates an estimate of the workload placed on critical resources. This workload is compared against demonstrated capacity for a critical resource. This comparison enables the planner to spot a lack of capacity in an early stage and propose possible increase of capacity. In a planning situation there are various RCCP methods to choose from (capacity planning using overall factors (CPOPF), capacity bills, resource profiles and Capacity Requirement Planning (CRP)). Every method has its own advantages and disadvantages, depending on the planning environment. The choice of method can be a result of internal analysis to evaluate the appropriateness of the various approaches, or it can be based on intuition (Jonsson and Mattsson, 2002). Sections 3.4.1, 3.4.2, 3.4.3 and 3.4.4 discuss the mentioned RCCP approaches in more detail. Section 3.4.5 discusses the allocation problem found in the CPOPF procedure.

3.4.1 Capacity planning using overall factors (CPOPF)

The Capacity Planning Using Overall Factors (CPOPF) is an approach that applies historical ratios. With obtained data of production volumes in specific time periods a capacity prediction can be made for future work. Reid and Sanders (2016) provide a procedure for CPOPF in five steps:

1. Determine the appropriate planning factors using historical data.
2. Multiply the production quantities by the appropriate planning factor.
3. Sum capacity requirements by time period.
4. Allocate demand to individual work centers based on historical percentages.
5. Evaluate the workload at each resource to validate feasibility and identify resources with insufficient capacity.

In the CPOPF procedure Reid defines a planning factor as the amount of a resource needed for one completed unit.

3.4.2 Capacity bills

When using capacity bills for the capacity planning, more detailed product information such as its bill or material (BOM), routing information, and capacity requirements at each work center is required. This technique uses the bill of materials and parts produced along with the setup and run times to compute capacity. Here, capacity is calculated by multiplying the number of units required (demand) by the time required to produce each item/unit. The capacity bills technique provides a more direct linkage between individual end products and the capacity required at individual work centers than CPOPF does. The capacity bills technique also requires more data than CPOPF does. Bills of material, routing. and operation time standard data are all necessary inputs in order to develop the capacity plan using the capacity bills technique (Swamidass, 2000).

While this technique accounts for more details than capacity planning using overall factors by considering shifts in the product mix, it does not take into account lead times for production or the specific timing of each operation at each work center/resource.

3.4.3 Resource profiles

In resource profiles, production lead time data are added to the capacity bills in order to provide a time-phased projection of the capacity requirements for individual production facilities. The CPOPF and the capacity bills technique do not take into account the time-phasing of the projected work loads at individual work centers. For example, the production capacity required early in the production cycle for an end product, is offset by the amount of production lead time between these operations and the final assembly of the product. (Swamidass, 2000)

3.4.4 Capacity requirements planning (CRP)

The capacities requirement planning (CRP) technique requires detailed input for all components and assemblies, including: MRP planned order receipts, on-hand quantities, the current status of open shop orders at individual work centers, routing data, and time standard information. Implementing CRP requires both a far more detailed industrial engineering data base, e.g., work standards and routing files, but also formal systems for handling transactions on theshop-floor and in the storerooms (Swamidass, 2000)

3.4.5 Allocation problem

Martínez-costa et al. (2014) mention multiple strategic planning problems in an manufacturing environment. The mentioned allocation problem corresponds with the problem mentioned in step four of the CPOPF procedure. When a manufacturer produces multiple products, with products using the same resources, then the allocation problem describes how to best allocate the existing manufacturing resources among different products. It has to answer what product to produce on what resource (allocation problem). These problems are typically formulated as a mixed-integer linear programming (MILP) model. Allocation based on historical percentages can be replaced by such a MILP to create a feasible allocation, when this is not available.

Mazzola, Neebe, and Dunn (1989) also discuss the allocation problem. Given the total amount of work that has been planned into the time buckets, the objective of the problem is to determine the number of production runs, the loading of part operations to machines and the configuration of tool magazines. The principal objective is to find a feasible solution. On an aggregate basis, the system should have sufficient capacity to produce all parts assigned to it in each time bucket. The allocation problem is then concerned with the grouping of machines and the loading of parts onto machines such that the gross requirements of all parts for the time bucket are met.

Mazzola, Neebe, and Dunn (1989) also model this problem as an MILP. This model and problem also have similarities with step 4 in the CPOPF procedure and could be used in this step.

3.4.6 Conclusion Capacity Planning

The RCCP is a promising approach regarding the problem of the BBC. With including actual plannings factors the limitations of operational scheduling are included. The plannings factors express the actual possible throughput and implicitly include all constraints and complexity of the BBC process. The RCCP has multiple approaches with different degrees of detail, Chapter 4 discusses what degree of detail this research uses.

3.5 Operational Scheduling

The problem of production planning and scheduling has emerged as one of the most significant challenges in the field of industrial plant operations, especially when multipurpose and multiproduct batch processes are involved and when there is the potential for significant savings through the use of mathematical modeling techniques (Orçun, Altinel, and Hortaçsu, 2001). The scheduling task for batch processes consists of the choice of the types of batches produced and the batch sizes, the assignment of equipment to the batches and the timing of the operations (Engell et al., 2000). In this research the focus is on the assignment of equipment and timing of operations. Considering the filtration and BBC scheduling the main goal is to find a feasible schedule taking into account the already determined products and batch sizes based on the packaging schedule. Timing and allocation to equipment is the only degree of freedom in this specific scheduling problem. In this section we discuss the type of scheduling problem in this research and how this problem is typically solved. Although this research is mainly focused on the longer planning horizon, the problem occurs at the operational scheduling. Therefore we consider is useful to gain more insight in the processes and difficulties considering the operational scheduling.

3.5.1 Flexible flow lines

A flexible flow line, also referred to as hybrid flow shop, flow shop with parallel machines or multiprocessor flow shop, is a flow line with several parallel machines on some or all production stages. All products follow the same linear path through the system. They enter it on the first stage and leave it after the last. On each of the stages, one of the parallel machines has to be selected for production. Several units (jobs) have to be produced. A job consists of multiple operations, one for each production stage. The number of machines per stage may be different. Figure 3.2 shows a schematic view of a flexible flow line with L production stages and $M_{1,2,\dots,L}$ machines per stage. Buffers are located between stages to store intermediate products (Quadt and Kuhn, 2007).

Flexible flow lines can be found in a large number of industries. They are especially common in the process industry.

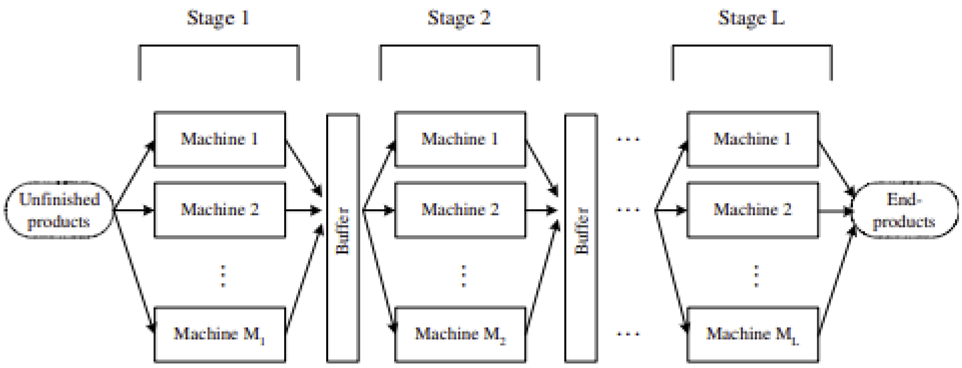

FIGURE 3.2: Schematic overview flexible flow line (Quadt and Kuhn, 2007)

3.5.2 Buffers and blocking

A product that has completed processing on a machine in some stage is transferred either directly to an available machine in the next stage (or another downstream stage depending on the product processing route) or to a buffer ahead of that stage. Storage or buffer capacities between successive machines in flow shop problems may be unlimited, limited or null. The last two cases can lead to blocking situations. The product may remain on the machine and block it until a downstream machine becomes available. This, however, prevents another product from being processed on the blocked machine. In flow shop scheduling literature, many studies have been performed about flow shop problems with blocking constraints. Figure 3.3 portrays the overview of the flexible flow line without intermediate buffers and routing constraints.

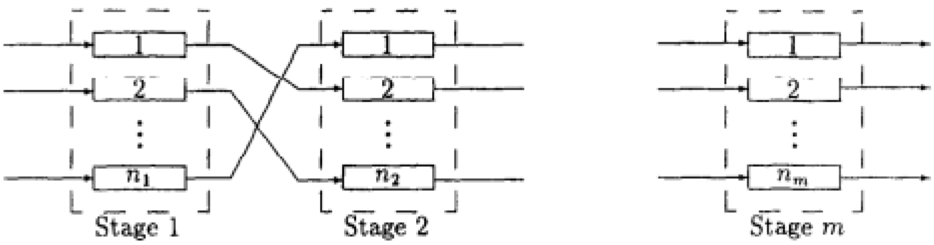

FIGURE 3.3: Schematic overview flexible flow line with no intermediate buffers (Sawik, 2000)

Trabelsi, Sauvey, and Sauer (2012) consider four different types of blocking in the flow shop problem: Unlimited buffers without blocking (Wb), Release when started blocking (RSb) and two Release when completing blocking types (RCb* and RCb). The difference between RCb* and RCb blocking is that in an RCb* blocking problem, a machine remains blocked by a job until its following operation on the next machine is finished, whereas in RCb problem, blocking time is bigger since the first machine will only be available when its following operation is completed and actually leaves the following machine. Figure 3.4 illustrates the different blocking constraints.

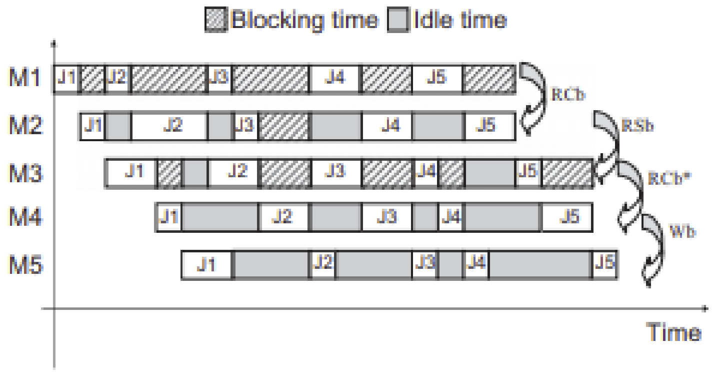

FIGURE 3.4: Flow shop problem with mixed blocking constraints (Trabelsi, Sauvey, and Sauer, 2012)

3.5.3 Solution approaches

For the scheduling of the flexible flow line many different procedures exist. The problem is NP-hard for all traditional optimality criteria, even when setup times are negligible (Garey, Johnson, and Sethi, 1976). Thus, the computation time of optimal solution procedures is too long when medium-sized or large instances are considered.

Quadt and Kuhn (2007) categorize the solution approaches to the flexible flow line scheduling problem as depicted in Figure 3.5. The first division is between optimal and heuristic procedures. We will focus on the heuristics as the problem is NP-hard and a optimal solution is not necessarily needed in this research. Heuristic procedures may be segmented into holistic and decomposition approaches. Decomposition approaches divide the problem with respect to the individual jobs, the production stages, or sub-problems (batching, loading and sequencing).

Heuristics are usually faster than optimal procedures but do not necessarily find an optimal solution. The holistic approaches consider the complete scheduling problem in an integrated way. Therefore, holistic procedures often include local search methods or metaheuristics. The decomposition approaches divide the overall scheduling problem into easier to solve problems that are considered consecutively. This allows simplification but neglects the interdependencies between the smaller problems.

The stage-oriented decomposition divides the flexible flow line along the production stages. This creates parallel machine scheduling problems with reduced complexity compared to the overall problem. The stages can be scheduled in the flow sequence or for example start with the bottleneck production stage.

Job-oriented decomposition procedures consider jobs subsequently. Per iteration a job is selected and loaded on a machine in every production stage. Sequencing decisions can be made simultaneously.

Problem oriented-decomposition is based on the sub-problems: batching, loading and sequencing. Batching occurs when setup times are involved in the scheduling problem. The loading problem refers to the allocation of operations to the machines, after loading the sequencing problem remains. The production sequence has to be determined. These problems can be solved consecutively and thereby reducing the overall complexity, but sacrificing the consideration of inter dependencies.

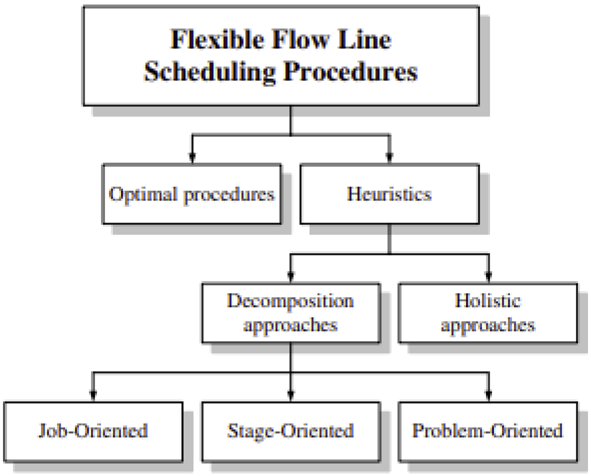

FIGURE 3.5: Overview of solution approaches to the flexible flow line scheduling problem (Quadt and Kuhn, 2007)

3.5.4 Fixed-time-assignment problem

Belaid, T'Kindt, and Esswein (2012) introduces the fixed-time-assignment problem, where the goal is to determine an assignment of the batches on the tanks and to fix the starting time and not lateness is allowed. The solution to this problem can be infeasible in reality, but is it interesting because this problem is solvable in polynomial time. In an industry where the schedule can change per day a fast calculation is desirable. This problem also has some overlap with the allocation problem that we discuss in Section 3.4.5.

3.5.5 Conclusion Operational Scheduling

From literature we learn that the scheduling problem considering the complete flexible flow is a complex problem that is not solvable in polynomial time and many approaches to this scheduling problem exist. When comparing the scheduling approach of Heineken with the literature we see that Heineken decomposes the production steps to reduce the complexity of the total scheduling problem. As a result, Heineken has multiple smaller scheduling problems, where the disadvantage is that inter dependencies between the problems are sacrificed. The scope of this research is only on the already decomposed problem of the BBC and therefore the total system is not included. Belaid, T'Kindt, and Esswein (2012) discuss a solution to an assignment problem solvable in polynomial time, due to the overlap with the already discussed allocation models for the capacity planning we consider this as a promising solution in helping the operational schedulers at Heineken to create a BBC schedule in less time.

3.6 Conclusion

This chapter discussed multiple subjects considered relevant to this research based on literature. First, a framework for general manufacturing and control, dividing the planning and scheduling decisions, is discussed. Second, a description of a multiproduct, multipurpose batch process is given to gain more insight in the process at hand. Third, a description of buffer tanks is given to provide more information about why and when buffer tanks are used. From literature we discovered buffer tanks can be used for two purposes: disturbance attenuation and independent operation. Next, the strategic capacity planning is discussed. In literature we found multiple Rough-Cut Capacity Planning (RCCP) methods that can be used for capacity planning. Chapter 4 will discuss what method can be used in this research. In combination with the loading/allocation problem the CPOPF and capacity bills procedures appear to be promising for the long-term BBC planning. After the strategic planning we zoomed in on the operational scheduling of a multiproduct, multipurpose batch process. In literature this problem has many names, for example a flexible flow line. This problem has various types, with differences in for example buffers and routes. Therefore the problem also has many different solution approaches.

In literature most articles assess the complete system in the planning and scheduling problem. In this research we are limited to the part of the BBC in the brewing process. Thus, complete system has already been decomposed into a smaller problem. The biggest difference with the problem in this research and the problems in literature is that the literature has the main focus on actual processing stages and in this research the focus is on the intermediate buffers. To the best of our knowledge, literature does not discuss the scheduling and capacity planning of the intermediate buffers. Especially a problem were the buffer space is shared between different production routes and great complexity exists. Buffer spaces are seldom mentioned as a bottleneck because in most production environments this is not an limiting resource, most of the time even unlimited. Therefore, we recognize this as a gap in literature.

Chapter 4 discusses the capacity planning using RCCP to close the gap between the strategic/tactical planning and operational scheduling and Chapter 5 discusses the assignment/allocation model to help operational scheduling in creating a schedule in less time and possibly improving the plannings factors used and thereby increasing the net capacity.

Chapter 4

Solution Design

This chapter answers the research question:*"How do we model the BBC process to be able to assess the capacity?"* In this chapter we use the theories found in literature and transform them to theories that are applicable to the problem in this research.

To be able to say something about the capacity of the BBC, we define the unit of measurement in Section 4.1. Chapter 3 mentions the Rough-Cut Capacity Planning (RCCP) as a promising method for the long-term capacity assessment to bridge the gap between long-term planning and operational scheduling. The RCCP has multiple types of approaches in assessing capacity. The types differ in how much data and information is needed as input for the procedure. Section 4.2 describes the choice for the RCCP method. Section 4.3 describes important modelling decisions. Then, Section 4.4 describes the model and needed inputs. After the construction of the model, Section 4.5 discusses the validation of the model. Section 4.6 uses the model for analysis of the BBC capacity and finally, this chapter concludes with Section 4.7.

4.1 BBC Capacity

Chapter 2 discusses the BBC and what actions a batch performs when flowing through the BBC, namely: filling, buffering and emptying. Those actions have to be completed before the batch leaves a BBT and the BBT becomes available for a new batch. In this research we decide to group the three BBC actions and create one 'tank action'. Thus, a tank action is the complete cycle of a batch entering and leaving the BBC system. This is for the reason to create an easy and simple unit of measurement for the BBC capacity that can be used in the RCCP approach. In Chapter 3 we discussed that the RCCP approaches use a planning factor, that we defined as: "the amount of a resource needed for one completed unit." With the creation of the tank action, we create a planning factor that includes the volatility of the times a batch needs to flow through the BBC and also include all factors influencing the BBC and create realistic capacity assessments. The available tank actions in a week also includes the planning gaps that Chapter 2 discusses. Including the planning gaps is an important part in choosing the tank actions as unit of measurement and closing the gap between operational scheduling and long-term planning.

To clarify, Chapter 2 discusses beers with multiple 'steps' in the BBC, those beers need multiple tank actions before being packaged. Based on the tank actions we can determine how many tank actions the BBC can handle in a period of time.

4.2 RCCP method

Chapter 3 describes multiple approaches to the RCCP, with various levels of detail. The approaches include: capacity planning using overall factors (CPOPF), capacity bills, resource profiles and Capacity Requirement Planning (CRP). This sections describes the choice of method for the capacity assessment of the BBC. Figure 4.1 shows the methods in a schematic overview based on the level of detail.

CPOPF is a Rough-Cut Capacity Planning technique that requires inputs based directly on planned production rather than detailed time-phased records from a, for example, material requirements system. The CPOPF technique is based on planning factors involving direct labor standards for end products. When these planning factors are applied to the planned production, overall capacity requirements are estimated. This overall estimate is allocated to individual work centers on the basis of historical data of shop work loads. CPOPF plans are usually stated in terms of weekly or monthly time periods.

In comparison to CPOPF, the capacity bills technique provides more linkage between individual end products in the planned production and the capacity required at dedicated work stations. To create more links between the actual planned products and capacity requirements at the dedicated work centers, the capacity bills method needs more input data, for example, bills of material, routing and operation time standards.

Resource profiles also includes the time-phasing of the planned production. CRP requires even more data, also based on actual orders in the production system.

When comparing these methods to the problem at hand, we conclude a combination of CPOPF and capacity bills is the most useful and applicable to the long-term planning horizon and BBC.

CRP is not applicable due to the detailed input that it needs. The input is based on short term information which is not available yet on the long term planning horizon. The time-phasing of the resource profiles is also not applicable due to the scope of this research. We focus solely on the BBC and do not include predecessors in the production process. A more holistic planning approach is needed to include the resource profiles.

With the exclusion of this methods, the CPOPF and capacity bills remain as viable options. CPOPF uses historic production data of used resources for the production of an end product. In the case of the BBC this is an interesting approach, because the BBC is a buffer and the actual time a beer requires to flow through the BBC is not easy to grasp and is exposed to many factors, e.g. planning inefficiency, waiting for available filling/ emptying pipes, availability of beer and disturbances in the packaging lines. Using planning factors, an estimation can be made of what the system can handle in reality, including all factors influencing BBC performance.

Chapter 2 proposed a division in the BBC based on those constraints. The division creates individual work centers to be assessed with the CPOPF method. Chapter 2 also discusses that the BBC has grown to be a complex part of production with many constraints and production routes. Given the constraints, we also include routing data as proposed in the capacity bills method. Not every beer can be stored in every type of BBC. Therefore it is important to include the routing and operation time standards of the beer types.

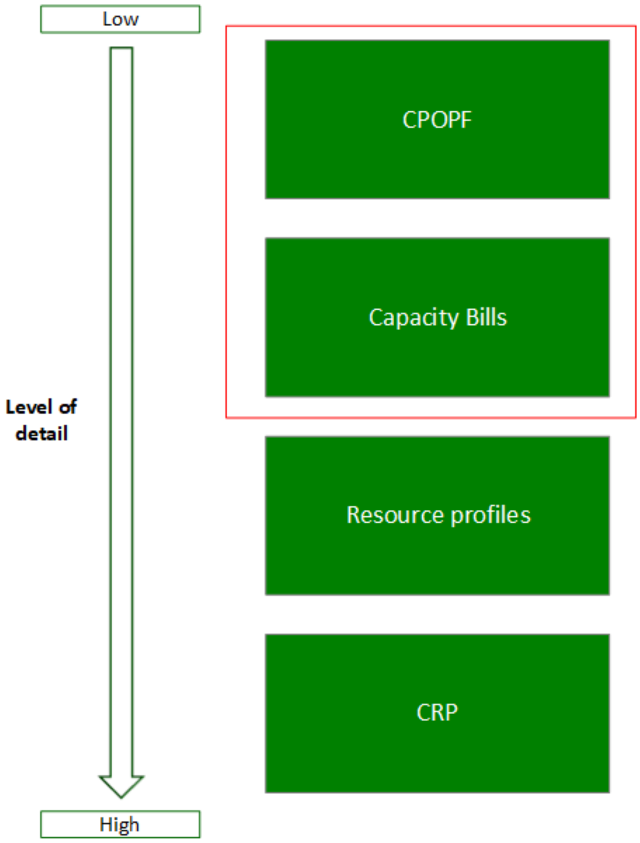

FIGURE 4.1: Schematic overview RCCP methods, where the arrow corresponds with the level of detail of the method and the red box indicates the methods used in this research

4.3 Modelling decisions

In assessing the BBC capacity based on the CPOPF and capacity bills methods, we have to make some modelling decisions for different aspects: the division of BBC types, the definition of tank actions, the choice of time buckets, the independence between the time buckets and the modelling of the allocation to the BBC types.

4.3.1 BBC types

Chapter 2 already recognizes that inside the BBC there exist blocks with a different nature and capabilities. Based on the different nature and capabilities we split the BBC in different work centers. Table 4.1 gives a recapitulation of the division.

With this division we create individual work centers that include multiple of the same BBTs. Due to the longer planning horizon we decide to aggregate the capacity of the same types of BBTs to create a better estimation and not include a too great level of detail. Through aggregating the same types of BBTs we still can add routing constraints to the model and check the capacity of all types in combination with multiple production weeks.

TABLE 4.1: BBC types included in the RCCP model

Tanks type	Tanks
Small	15
Block 10 small	6
Block 30 small	6
Medium	2
Large	12

4.3.2 Planning factor

The RCCP methods require a defined planning factor. Chapter 3 defines a planning factor as: "the amount of a resource needed for one completed unit." Here we define a planning factor as a tank action, as discussed in Section 4.1. Using tank actions as planning factors allows us to include the volatile times that a batch occupies a BBT, and therefore include influences of external factors. Including these factors is important to create a realistic capacity assessment corresponding with the operational limitations.

4.3.3 Time buckets

An important decision in modelling is the choice of time buckets, e.g. a week or month. With the use of time buckets we can compare the total capacity in the bucket with the planned production in the corresponding bucket. Comparing the both will give an idea of the feasibility of the planned production. A bigger time bucket means more aggregation and on average, a better estimation. On contrary, smaller time buckets offer a higher level of detail on the timeline. The tactical and strategic planning department both use week buckets in their planning models and most of the data are arranged for this type of time bucket. Therefore, we choose to use time buckets of a week in this model because it is compatible with the organisation. Also, for assessing the capacity of the BBC too much aggregation is not desirable as the BBC can be a bottleneck in one week and not be a bottleneck in another week.

4.3.4 Independent time buckets

In reality the time is continuous and weeks do not have a strict separation. With the use of time buckets we assume that the capacities and demands in time buckets are independent. So, capacity in one week cannot be used in other weeks and demand cannot be produced in another week. In essence, every week is an independent capacity assessment. Where the overall view of the planning horizon will say something about the sufficiency of the available capacity.

4.3.5 Resource allocation

To properly asses the capacity of all BBC types, the planned production has to be allocated to a BBC type. Most beers do not have a standard allocation due to the flexibility of the BBC. On the other hand, some beers have a standard allocation and have no flexibility, e.g. 0.0 beers. Per week the allocation can differ depending on the total product mix planned in the week. Therefore, to create a feasible allocation we need a realistic allocation to the BBC types. This corresponds with practice as the operational schedulers also make smart allocations depending on the product mix. For this reason, determining allocation based on historic percentages leads to infeasible allocations and an irrelevant capacity assessment. So, for the resource allocation we deviate from the CPOPF procedure and not use historic percentages but use a MILP for resource allocation. In Chapter 3 we learned that an allocation problem can be solved with a MILP in polynomial time. Section 4.4.4 discusses the MILP in detail.

4.4 The model

Section 4.2 discusses the choice for capacity planning using overall factors (CPOPF) in combination with capacity bills for assessing capacity. This sections constructs the model for the BBC based on the theory of these methods. Chapter 3 mentions five steps for the CPOPF method:

1. Determine the appropriate planning factors using historical data.
2. Multiply the production quantities by the appropriate planning factor.
3. Sum capacity requirements by time period.
4. Allocate demand to individual work centers based on historical percentages.
5. Evaluate the workload at each resource to validate feasibility and identify resources with insufficient capacity.

As discussed in Chapter 3, in the five steps of the CPOPF we change the 4th step. We do not use historical percentage of production, because this leads to infeasible solutions. For the 4th step we use the allocation model of Section 4.4.4. The allocation model comes with routing constraints, corresponding with the described method of capacity bills in Section 4.2. The approach of the capacity bills allows for including the impact of the multiple step beers that require more capacity. The five steps of the procedure come down to Figure 4.2, where we transform the five steps to the input, an allocation model and the output. This section explains the factors mentioned in the figure.

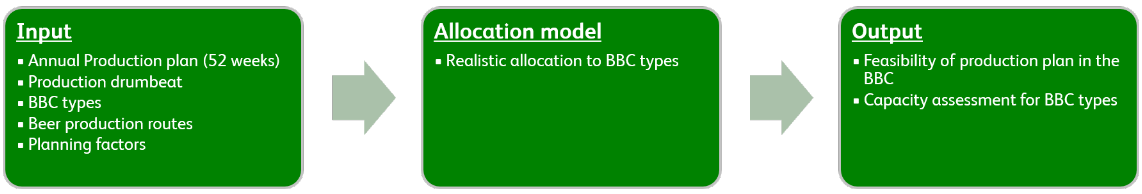

FIGURE 4.2: Model structure

Section 4.4.1 introduces the planning factors according to step 1 and 3 of the CPOPF. This section determines the number of tank actions a BBC type can handle based on historical data. Section 4.4.2 introduces the planned production quantities to be used according to step 2. Section 4.4.4 discusses the allocation of the production quantities corresponding with step 4 and Section 4.4.5 discusses limitations of the model.

4.4.1 Planning factors

This section explains the used planning factors in the model. Where, the planning factors include the available tank actions per BBC type.

Using production data of 2019 we determine the maximum number of tank actions available for a type of BBC. In determining the maximum capacity per week we use the number of tank actions that the BBC was able to complete in the the bottleneck weeks. Those weeks are the weeks were the maximum capacity is reached and that is why we consider the number of tank actions in this week as the maximum capacity. Table 4.2 shows the maximum number of tank actions per BBC type. This planning factor is an average over multiple weeks where the maximum of tank actions can differ and therefore, the output figures also include a deviation to see worst and best case scenarios.

TABLE 4.2: Maximum number of tank actions per BBC type

Type	Max tank actions
Small	40.5
Block 10 small	24
Block 30 small	13.5
Medium	4.8
Large	26.4

4.4.2 Production quantities

The long-term production quantities are based on the annual plan of Heineken created by the strategic planning department. The annual plan is a yearly plan of 52 week buckets, calculated for the production of all the packaging lines. In determining the annual plan the capacity of the packaging lines is, again, leading. The strategic department also decomposed their planning problem into multiple smaller problems.

The keep the model linear and calculation times within reasonable calculation times, no cyclicity is added to the model calculating the annual plan. Thus, batching is ignored in this model and the production quantities per week don't correspond with reality. In reality, beer is produced in batches and not every beer is produced every week. In this manner efficient batch sizes are used, reducing setup times and using the tanks volumes as efficient as possible. What beer is produced in what week, is known and determined by a drumbeat of production. The drumbeat is used to create a production plan fitting the current capacity but also for transparency to the suppliers of materials.

To create realistic production quantities for the capacity assessment we combine the drumbeat and the annual plan. Tables 4.3, 4.4 and 4.5 illustrate the combining of the annual plan with the production drumbeat. Table 4.3 shows an illustration of the annual plan with production of the beers in every week. Table 4.4 shows the production drumbeat, where a 1 corresponds with a production week and 0 corresponds with no production. A week with production, produces all upcoming demand until the next production week. Table 4.5 combines the drumbeat and annual plan according to this principle. With the combination of the drumbeat and annual

TABLE 4.3: Illustrational table of the annual plan

	Demand per week (HL)							
	1	2	3	4	5	6	7	8
Beer 1	46	705	211	34	27	27	28	29
Beer 2	226	340	282	460	398	318	570	734
Beer 3	276	262	388	389	414	267	291	526
Beer 4	138	32	30	115	279	223	79	165
Beer 5	195	147	72	178	168	163	384	391

TABLE 4.4: Illustrational table of the production drum beat, where 1 corresponds with a production week and 0 otherwise

	Production per week							
	1	2	3	4	5	6	7	8
Beer 1	0	1	0	0	0	1	0	1
Beer 2	1	0	0	0	1	0	0	1
Beer 3	0	0	0	1	0	0	0	1
Beer 4	0	0	1	0	0	0	1	1
Beer 5	1	0	0	0	1	0	0	1

TABLE 4.5: Illustrational table for the combination of the drum beat and the annual plan

	Demand per week (HL)							
	1	2	3	4	5	6	7	8
Beer 1		977				55		X
Beer 2	1307				1286			X
Beer 3				1361				X
Beer 4			647				79	X
Beer 5	593				715			X

plan we create realistic production quantities. The numbers in the tables are merely for illustration purposes.

4.4.3 Transforming the production quantities to tank actions

With the cyclic annual plan we can calculate the tank actions needed for every beer in every week. The number of tank actions a beer needs to be produced is based on the production quantities and the number of steps a beer needs (1, 2 or 3). For every type of BBC, in every week, for every production quantity the tank needed tank actions can be calculated with the formula:

$$Tankactions = Productionsteps\left(\frac{Productionquantity}{VolumeTank}\right)$$

In the calculation, tank actions have to be rounded up. Whenever a tank is filled, completely full or not, 1 complete tank action is needed. The quantities and tank volumes are in HLs and the tank volumes have three options based on the BBC types (small, medium and large). Table 4.6 gives an illustration of the transformation of production quantities to tank actions.

TABLE 4.6: Illustrational table of transforming production quantities to tank actions

		Tank actions		
Beer	**Production quantity (HL)**	Small	Medium	Large
1	9946	12	6	3
2	7169	9	5	2
3	6618	8	4	2
4	4795	6	3	2
5	3634	5	3	1

4.4.4 Allocation model

This section discusses the allocation model in more detail. The tank actions, coming from the production quantities, are parameters for the allocation model. Section 4.4.1 determined the maximum tank actions available in every BBC type and the maxima also important parameters for the allocation because a BBC type has a limited amount of tank actions available. To properly assess if the load of the proposed production quantities are feasible, the quantities need to be allocated in to the BBC types in a realistic manner. Every BBC type only has a limited amount of tank actions and in allocation of the production quantities this should not be exceeded.

The model allocates all productions quantities to a BBC type while minimizing the exceedance of capacity and the used tank actions for all BBC types. Soft constraints are used so the model can exceed the capacity to find a feasible solution in high demand weeks. The exceeding of capacity gives an idea what weeks will cause problems, then the model cannot find a solution without exceeding the available capacity. The annual (cyclic) production plan, BBC types, beer production routes and the maximum available tank actions are the input for the allocation model.

Constraints

In the model three constraints exist:

1. A production quantity of a type of beer can be allocated to only one BBC type.
2. A soft constraint penalizing exceeding the maximum capacity or rest capacity for Block 30.
3. The connectivity constraint.

The soft constraint penalizes the exceedance of the maximum of tank batches available, this creates the realistic allocation. On the other hand, for Block 30 the model penalizes rest capacity, because block 30 is only connected to packaging lines for cans and therefore enough can capacity should be allocated to smaller tanks. Otherwise, the block 30 capacity cannot be used to its full capacity. The connectivity constraint makes sure that for example, the beers that can only flow through small tanks cannot be allocated to bigger tanks, or that 0.0 volumes can only be allocated to block 10

Objective function

In the model we use binary allocation variable for all beer types that have to be allocated to a BBC type. With the soft constraint exceeding capacity is penalized, we want to minimize the penalties of exceeding capacity to create a feasible and realistic allocation. To simulate the behaviour of the operational schedulers, the objective function also contains the minimizing of the number of tank actions used. In reality the schedulers also makes decisions in logically allocating the volumes to the BBC types. Also, minimizing the tank actions gives a better view of the rest capacity in the output figures. This makes the tank actions both a constraint in the capacity but also something that has to be minimized to get to most out of the available capacity.

The allocation model:

Indices

Beer types $i = 1,..., I$

BBC types $j = 1,..., J$

Parameters

b_{ij} = Number of required tank actions for beer type i in BBC type j

m_j = Maximum number of tank actions per week in BBC type j

$$c_{ij} = \begin{cases} 1 & \text{if beer i can be allocated to type j} \\ 0 & \text{otherwise} \end{cases}$$

I = Number of beer types

J = Number of BBC types

z_j = Penalty for exceeding capacity in type j

s_j = Penalty for rest capacity in type j

Decision variables

$$x_{ij} = \begin{cases} 1 & \text{if beer type i is allocated to BBC type j} \\ 0 & \text{otherwise} \end{cases}$$

$R_j =$ Rest capacity in BBC type j

$E_j =$ Exceeding capacity in BBC type j

Objective function

$$\begin{aligned} \text{Min} \ & \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}b_{ij} + \sum_{j=1}^{J}(E_j * z_j + R_j * s_j) & \\ \text{S.t.} \ & \sum_{j=1}^{J} x_{ij} = 1 & \forall i \\ & \sum_{i=1}^{I} x_{ij}b_{ij} + R_j - E_j = m_j & \forall j \\ & x_{ij} \leq c_{ij} & \forall i,j \end{aligned} \tag{4.1}$$

4.4.5 Limitations

With the RCCP procedure and the allocation of production quantities some limitations have to be considered.

- In combining the annual plan with the drumbeat we assume that demand is produced for the upcoming weeks.
- The model assumes a week starts with no batches in the system and ends with no batches in the system. In reality this is a continuous process and not strictly separated in week buckets.
- The capacity planning model is not including the capacity of the emptying and filling pipes. In the scheduling of the BBC this can be a limiting factor as well. Although, the impact of number of filling and empty pipes is implicitly included in the maximum of tank actions available.
- This model does not take simultaneity (timing of batches) into account, because at this planning horizon they are not available. For a more short-term focus this should be included.

4.4.6 Output

After allocating all batches, using the allocation model, the our RCCP approach shows four figures containing the BBC types: small, medium, large and block 10. The figures show the maximum capacity including a best and worst case scenario. When the total of tank actions in a BBC type is between the best and worst case scenarios, the week has a potential to be challenging for the schedulers. Exceeding the best case scenario indicates that some intervention is needed. When the needed tank actions remain below the worst case scenario, no problems are expected. The figures for the small type include can volume, because Block 30 is only connected to can packaging lines and therefore enough can capacity should be available and allocated to the small tanks. In the figures, the y-axis represents the tank actions and the x-axis represents the weeks corresponding with the planned production volumes.

4.5 Validation

This section discusses the validation of the RCCP model. The validation has two components: using 2019 production data as input and testing the model with the people who are knowledgeable of the real world system. An important advantage of testing with the users is that the credibility of the model to the users and the user's confidence in the model increases.

The planning factors are based on the production data of 2019. So, when using the 2019 production data as input for the model, we should see a result that is around the maximum capacity at the peak weeks. Figures 4.4 and 4.5 show that for the bigger tanks most capacity is used with the model allocation, not exceeding the maximum capacity. Figure 4.6 shows that block 10 exceeds the maximum capacity in some weeks but remains below the best case. Figure 4.3 shows that the small tanks never reach the maximum capacity. This suggests that the allocation model creates a more efficient allocation (using less tank actions) of the production quantities to the tanks than reality. This was to be expected because in reality the volume of a beer type is sometimes divided in multiple filtration runs, resulting in more not completely filled BBTs and therefore using more tank actions the complete the same volume. Section 4.4.5 discussed this limitation of the model, because this factor is hard to include. On the other hand, it could be the case that the allocation model creates a more efficient allocation than reality.

Chapter 5 explores if the allocation model can also be beneficial in the operational environment (considering simultaneity and piping) to create a better allocation with less tank actions. Overall, we conclude that the model creates a realistic and slightly positive image of the reality.

We also tested the model and checked the results with the problem owners who are knowledgeable of the real system. The model is tested with an industrial engineer, the manager of operational scheduling and a supply chain specialist. We conducted multiple test runs with feedback loops to improve the model. The outcomes of the tests, for example, was to include a penalty on rest capacity on block 30, because this block is only connected to packaging lines and therefore enough can capacity should be allocated to the small tanks. With the inclusion of feedback we reached the point that all stakeholders are confident in the outcomes of the model to be used for a capacity assessment of the BBC. We conclude that we created a model with outcomes that are considered realistic and with a satisfactory range of accuracy consistent with the application of the model.

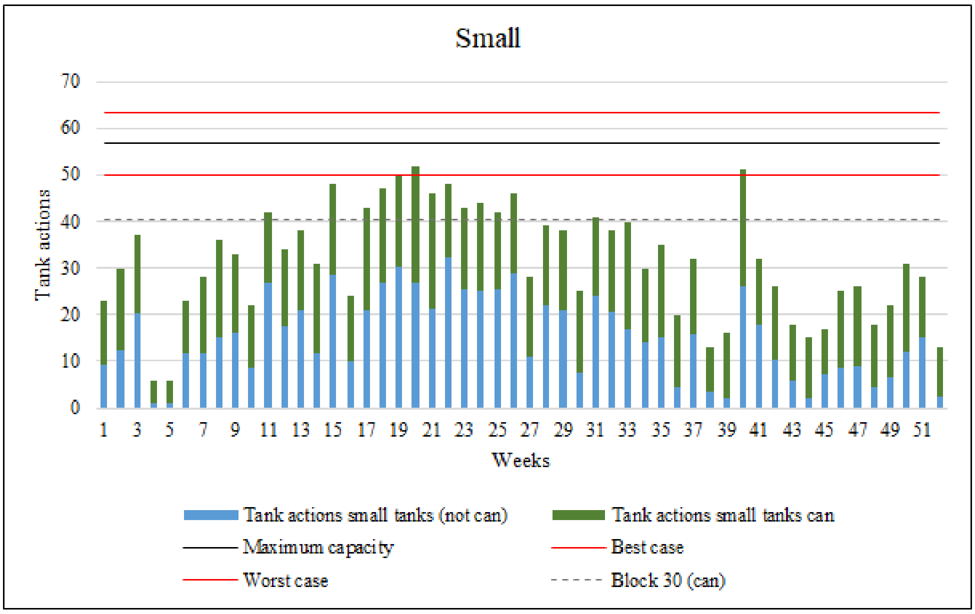

FIGURE 4.3: Allocation and capacity small tanks 2019

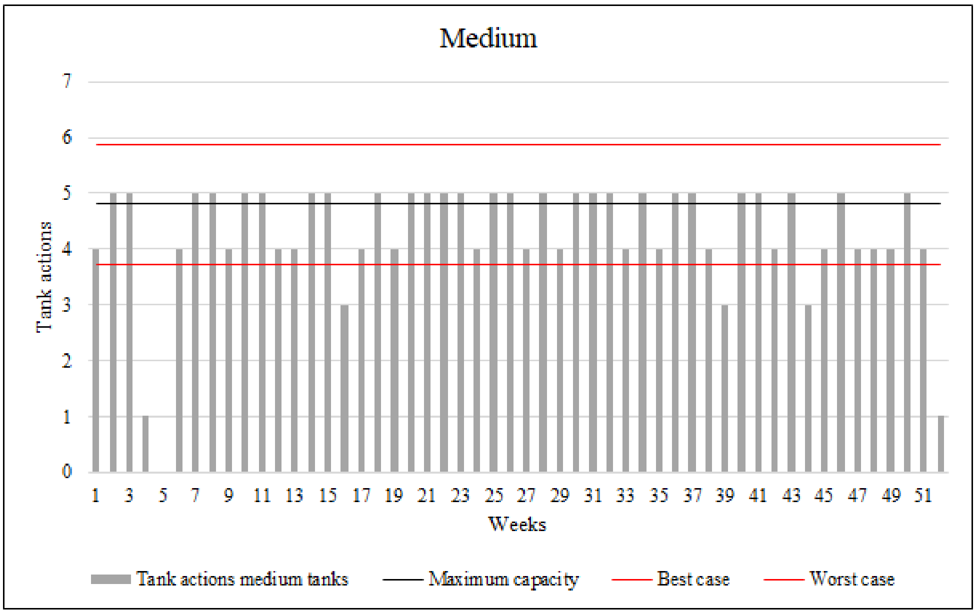

FIGURE 4.4: Allocation and capacity medium tanks 2019

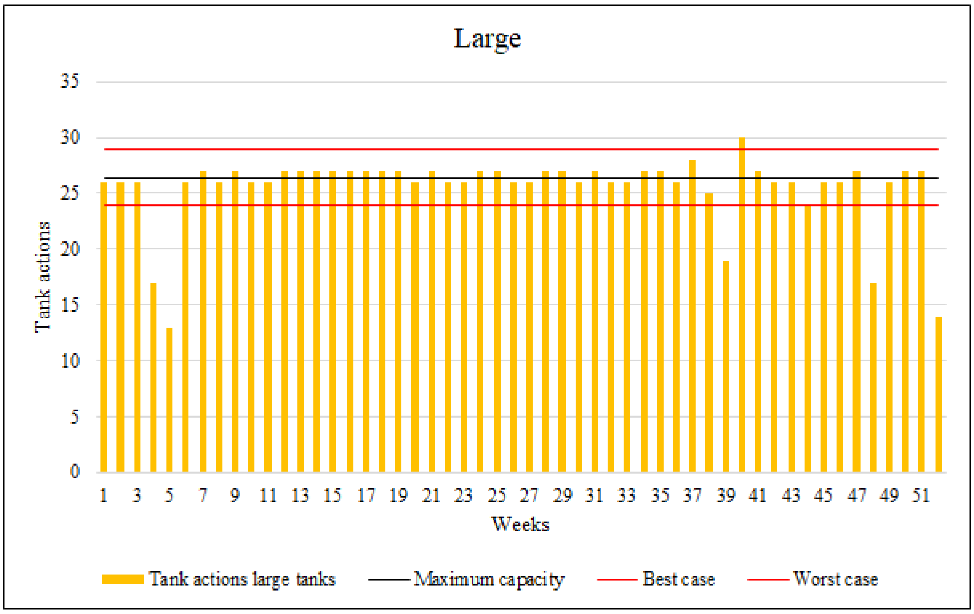

FIGURE 4.5: Allocation and capacity large tanks 2019

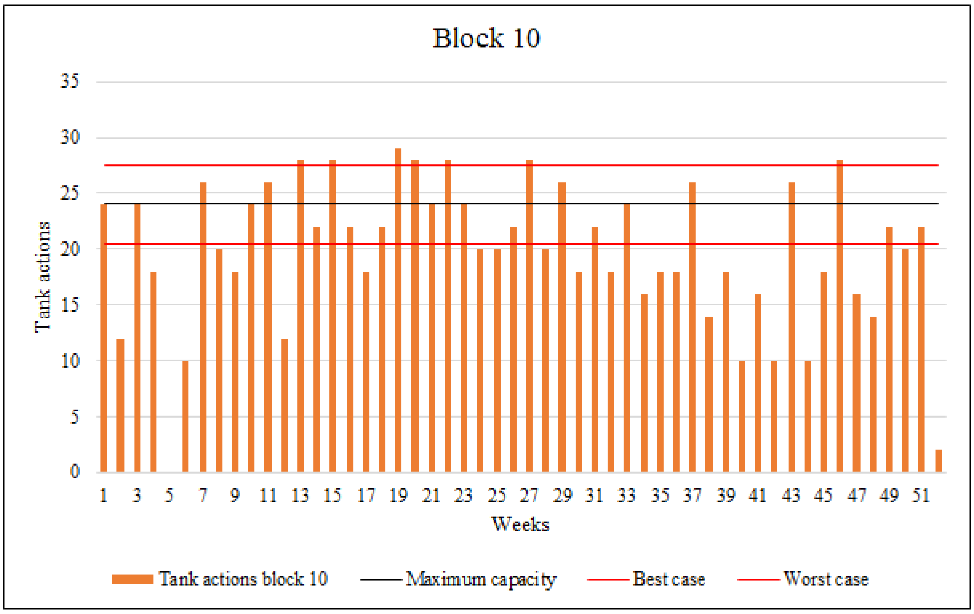

FIGURE 4.6: Allocation and capacity block 10 2019

4.6 Scenario analysis

This section discusses the results of the model in multiple scenarios. First, Section 4.6.1 uses the model to assess the production quantities of the annual plan of 2021 match the available capacity in the BBC. Second, Section 4.6.2 discusses the impact of an investment in the Heineken 0.0 beer production process and third Section 4.6.3 adds dummy volumes to the existing annual plan to analyse the impact of possible new product introductions.

4.6.1 Annual plan

With the annual plan of 2021, we know the production quantities that have to be produced on the packaging lines. As we know, before beer can be packaged it is first stored in the BBC and therefore the production quantities of the packaging lines also have to be able to flow through the BBC. Section 4.4.2 mentions the combination of the annual plan and the production drumbeat, the combination is the input for capacity assessment of the annual plan.

Figure 4.7 shows the allocated tank actions to the small tanks. The figure shows a big rest capacity in most weeks and more than enough can volume to fully use the block 30 capacity. The tank actions never exceed the maximum capacity, but in a worst case scenario weeks 15, 16, 17, 22, 24 and 26 could cause problems with processing the planned volume. However, close to the weeks exceeding the worst case scenario, some weeks still have capacity left. A change in the production drumbeat or production volumes could be a solution the prevent potential problems.

Figure 4.8 shows the allocated tank actions to the medium tanks and Figure 4.9 shows the allocated tank actions to the large tanks. The bigger tanks use the available capacity almost every week. This can be explained by the fact that bigger tanks can handle bigger volumes with less tank actions than the small tanks. From this we also conclude that the big tanks should be used as efficient as possible. For the smaller tanks this is less important due to the small volumes.

Figure 4.10 shows the allocated tank actions to block 10. With the use of block 10 there are not many choices, when 0.0 beer is produced is has to flow to block 10 for the dealcolization. When block 10 is not used for 0.0 it can be used as a normal BBC, as it also has one emptying pipe. This seldom happens because the 0.0 beers mostly uses all capacity of block 10. Figure 4.10 shows that some planned 0.0 volumes do not fit the the current capacity. Three weeks exceed the best case scenario and 13 weeks exceed the worst case scenario. From this we conclude that the planned 0.0 volume is too high for the current BBC capacity. There are too many weeks that can cause problems. The 0.0 volumes is also expected to grow in the upcoming years. Based on the model this growth in volume is currently not possible.

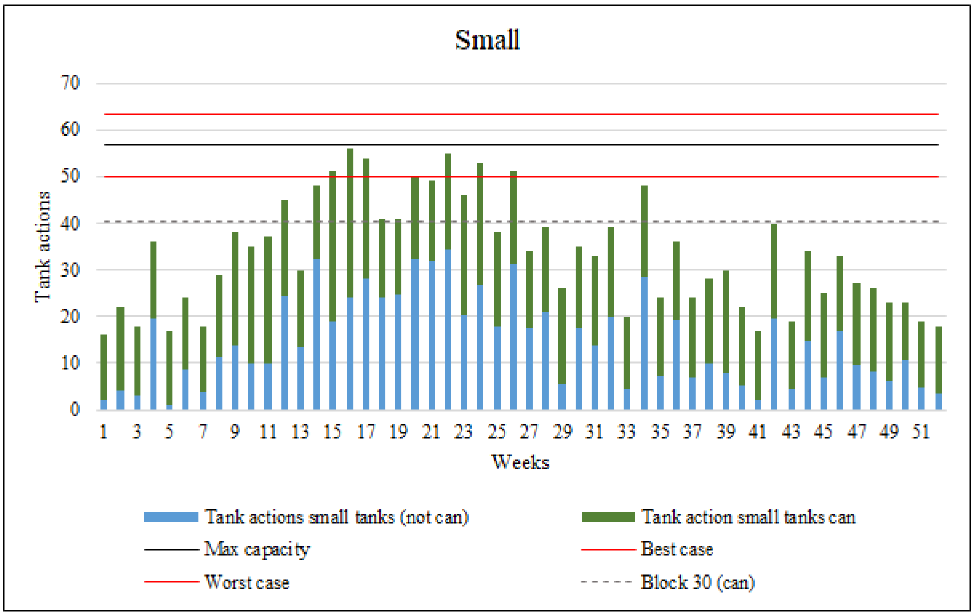

FIGURE 4.7: Allocation and capacity small tanks annual plan

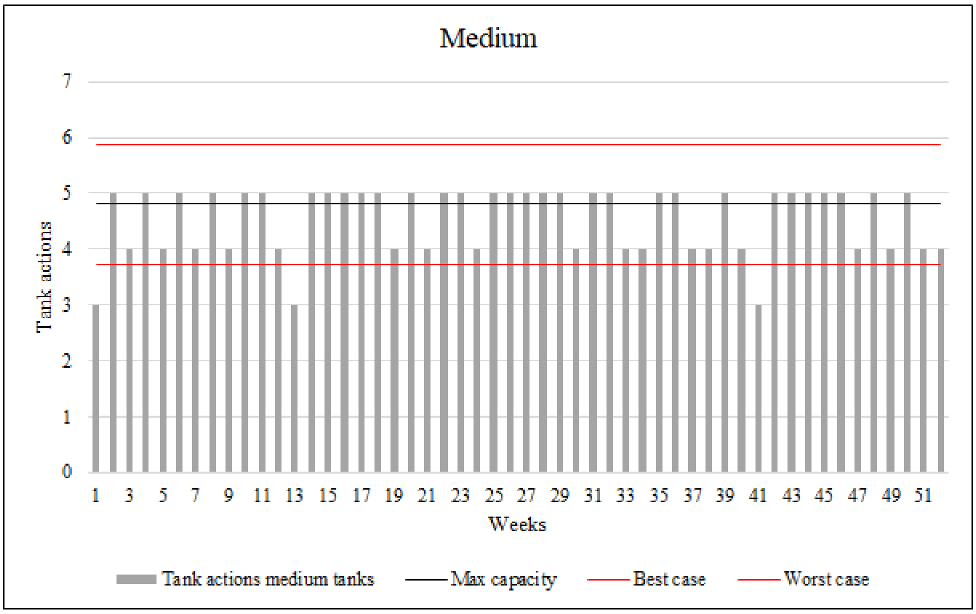

FIGURE 4.8: Allocation and capacity medium tanks annual plan

FIGURE 4.9: Allocation and capacity large tanks annual plan

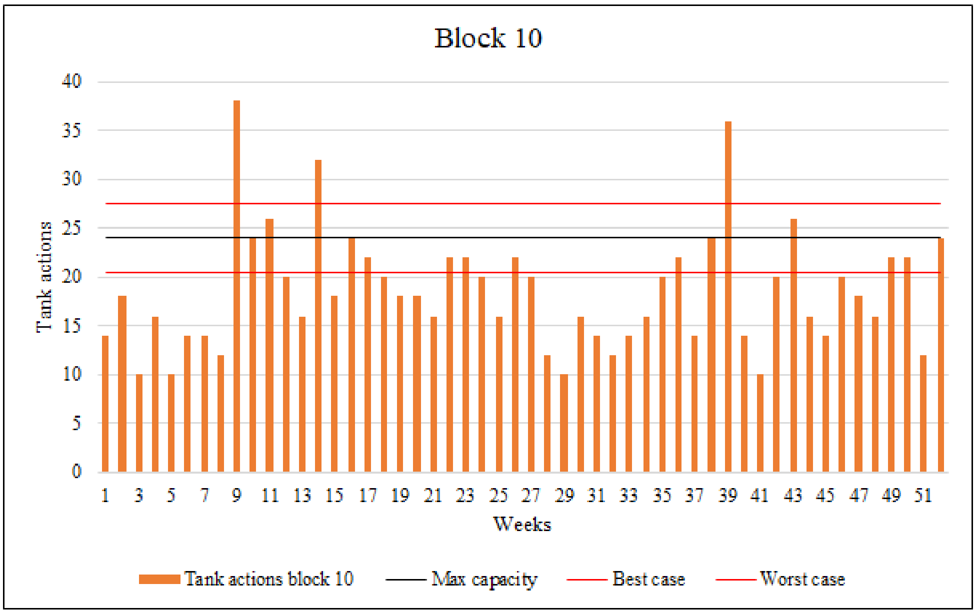

FIGURE 4.10: Allocation and capacity block 10 annual plan

4.6.2 Investment block 10

Section 4.6.1 showed that the capacity of block 10 is insufficient for the current planned 0.0 volume and that block 10 is not ready for a growth of 0.0 beers. The 0.0 beers currently belong to the three step beers, that flow through a BBC three times. Here we asses a possible change in the process of the 0.0 Heineken beer. The change is illustrated in Figure 4.11. The dealcoholization equipment can be connected with the filling matrix, removing one BBC step for the Heineken 0.0 beer. The change in process is not applicable to other 0.0 beers. In this scenario we will remove one BBC step for the normal 0.0 Heineken beer with the current annual plan volumes, to assess what impact this investment has on the 0.0 capacity.

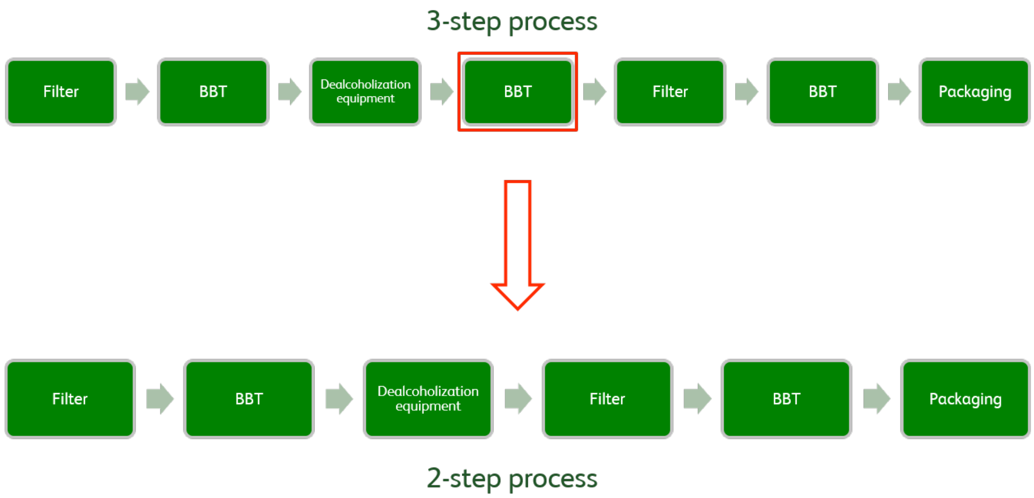

FIGURE 4.11: Change in the 0.0 process

Figure 4.12 shows the change in the occupation of block 10 due to the potential investment of connecting the dealcoholization equipment to the filling matrix. Most of the 0.0 volume is the normal Heineken 0.0 beer where the change in process applies to. Therefore the figure shows a big impact on the occupation. None of the weeks is expected to cause any problems anymore and in most of the weeks a growth of 0.0 volumes is possible. Based on the expectation of the 0.0 growth and the current problems, this investment would be the right decision. The capacity problems in the current year are removed and the process is also ready for the time to come.

4.6.3 New product introductions

The strategic planning department often receives the question if a new product introduction (NPI) fits in the current capacity. With the model we can check what the influence of a NPI is on the BBC performance. This section discusses influences of possible NPIs, through multiple dummy volumes. We run the model with a small, medium and large volume NPI. We also run the model with the addition of several smaller NPIs. Appendix C shows the output figures.

The figures of the annual plan in Section 4.6.1 show a large remaining capacity in the BBC in low demand weeks. In those weeks a new NPI can be added without any problems. Expectedly, the problems occur in the already high volume weeks. When inspecting the problematic weeks, the problems occur at a specific volume of

FIGURE 4.12: Impact of the block 10 investment

planned production volumes and more than 20 beer types. For reasons of confidentiality we don't mention the exact volumes. When only producing one beer type and using all tank actions with completely filled tanks, the BBC can handle a production volume that is 7% bigger. The production of multiple beer types reduces the maximum production volume. When producing more beer types, more half-filled tanks are used, reducing the maximum total production volume. We also see this with adding several smaller NPIs. The model shows that introducing multiple small volumes NPIs, has more impact on the BBC performance than only one larger volume.

Introducing NPIs with current annual plan is not advisable from the point of view of the BBC. In peak season the BBC cannot handle more volume and more beer types. When introducing a NPI it should be replacing another beer type or only be planned in the low demand season.

4.7 Conclusion

This chapter discusses a strategic capacity planning procedure following the CPOPF method with routing constraints. The BBC is not a standard production unit with predetermined production times, therefore this chapter uses the maximum capacity of the BBC determined from historical analysis. To measure capacity, we decide to measure the maximum available tank actions in the BBC based on historical data. With the use of historical data, an allocation model and the theory of RCCP methods, we constructed a long-term assessment of the BBC. For feasible and realistic allocation to the BBC types we use a MILP, that solves the allocation in a matter of seconds.

When using the model to assess the production quantities of the annual plan of 2021, we see that the pressure on the BBC capacity is high, especially in block 10. In peak season there are many weeks that indicate to be challenging for operational scheduling. For block 10 a possible investment exists that removes a tank step for the production of the Heineken 0.0 beer. When including this in the model we see that this investment creates free capacity to make the 0.0 process ready for the future. We also add dummy volumes to the annual plan to check where problems will occur. From this we conclude that the full capacity of the BBC is reached at a specific production volume and more than 20 types of beers. However, with production of less beer types the total produced volume could be higher. The procedure can be used as a tool for the strategic planning department to be able to take the BBC capacity into account and spot bottlenecks in an early stage. This capacity assessment can also be used for a quantitative argumentation in what impact investments in the BBC will have. A limitation of the model is that it is hard to say what the impact is of more piping in the process, as the impact of the filling and emptying pipes is implicitly included in the available tank actions from production data.

We also conclude that the allocation model looks promising for the planning and scheduling on the shorter term horizons. With the model the best allocation using the least amount of tank actions can be determined. The model assumes independent week buckets and can easily be created for a situation where more level of detail is required. This chapter uses the annual plan, which is based on forecasts and includes 52 weeks, but we can also use a different parameters based on actual orders in the operational environment. With an addition of extra constraints to consider emptying pipes, filling pipes and simultaneity in combination with actual production input, feasible allocations could be discovered fast. Chapter 5 discusses how the allocation model can be used in the operational environment and help the schedulers to create the BBC schedule in less time.

Chapter 5

Short-term Allocation Model

This chapter expands the allocation model as described in Chapter 4. In Chapter 4 we recognized that the allocation model could also be useful for shorter planning horizons. On the long-term planning horizon, a lower level of detail is needed because the input is based on forecasts. Also, the purpose of long-term planning is not to create a detailed production plan but to make decisions effecting the long-term capacity. On the short-term horizon more is known about actual orders and a detailed schedule should be constructed. This chapter goes into the detailed weekly schedule for the BBC, using the allocation model constructed in Chapter 4 as a building block. Currently the scheduling of the BBC takes the operational schedulers a lot of time. A complete plan can take days to construct. With the allocation model we aim to help the schedulers to create the BBC schedule in less time. With construction the allocation model we answer the research question: *"How can we improve the Bright Beer Cellar planning/scheduling process?"*

First, Section 5.1 introduces important decisions in scheduling the BBC. Then, Section 5.2 describes the tailored model for the short-term allocation of the BBC. Section 5.3 describes the input for the tailored model and Section 5.4 explains the output of the model that is usable for the schedulers, when scheduling the BBC. Next, Section 5.5 discusses the validation of the model. Finally, this chapter concludes with Section 5.6.

5.1 Scheduling decisions

For the scheduling of the BBC we can decompose the decisions in three components. Chapter 3 discusses the decomposition of smaller scheduling problems to create manageable problems. This section uses this approach to explain the BBC scheduling process and investigate where we can improve the scheduling process. When decomposing the scheduling process, we see three problems: batching, allocation and sequencing. Figure 5.1 shows the weekly scheduling process when the problems are decomposed. Every decision has its own influence on the performance of the BBC and Sections 5.1.1, 5.1.2 and 5.1.3 discuss them respectively.

5.1.1 Batching

The process of batching is done based on the available packaging schedule, where the schedulers create the demanded inflow of beer for all the packaging runs. Figure 5.2 shows a part of the packaging schedule of Heineken. Every colored bar is a packaging run and the color indicates what type of beer is packaged. Multiple runs

FIGURE 5.1: The weekly scheduling process

of the same beer can use the same BBT for inflow of beer. The scheduler has to choose which runs will be batched together in a BBT.

In the batching, schedulers want to limit the number of filtration runs to reduce set-up times for filters and create efficient batch sizes to efficiently use the available tank volumes. Some packaging runs that are batched together can have a different timings, e.g. the first run on monday and the second run on wednesday. This can cause the batch to occupy a BBT multiple days. When not batched together, two smaller batches occupy two BBTs but for a smaller amount of time. The scheduler has to make the trade-off between as big as possible batch sizes and the total occupation time. Bigger batches use the complete volumes of BBTs and reduce set-ups but have long occupation times, in comparison with smaller batches that have short occupation times but need more filtration runs.

Batching packaging runs also prevents the draining of beer. The inflow of beer in the BBC is not always equal to the exact demand of the packaging runs and vice versa. When batching the packaging runs a tank is only emptied once and this reduces the risk of draining beer at the end of a packaging run.

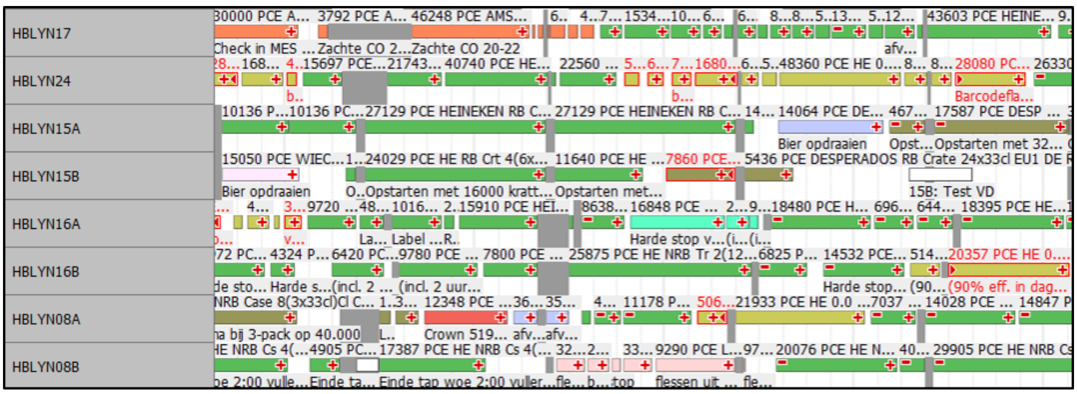

FIGURE 5.2: Example of a Packaging schedule Heineken

5.1.2 Allocation

When the batching is complete, the batches can be allocated to the tank blocks. Here the schedulers can choose to allocate a batch to small, medium or large tanks. The volume of a batch is an important factor in this decision, because more efficient use of the tank volumes can result in less used tank actions. In the allocation process the schedulers also have to take the available filling and emptying pipes into account. Not every batch can be filtered or emptied simultaneously. A good allocation of batches to the BBC blocks prevents the simultaneity issues with the filling and emptying pipes. Preventing the simultaneity issues can save the schedulers much time.

5.1.3 Sequencing

The last decision schedulers have to make is when to start filling a BBT. From the packaging schedule we already know when beer has to be available for packaging. The decision of starting filtration and thus filling the tank is left. The schedulers standard use a time buffer of 8 hours before the scheduled time that the beer is needed for packaging. In reality disturbances at the packaging lines can occur, where the time buffer in the BBC creates some robustness for the BBC schedule. Therefore, a BBT is filled at least eight hours before the first packaging run of a batch starts. In some cases a BBT is filled earlier due to a availability filters, filling and emptying pipes. Filling a BBT earlier then needed creates longer occupation times.

5.1.4 Conclusion scheduling decisions

The batching, allocation and sequencing all have their own influence on the BBC performance and are influenced by multiple factors. Most of the factors influencing the BBC performance are out of scope of this research. Therefore, in the context of this research, we cannot influence these factors. For example, in the batching and sequencing process many scheduling choices could be made, but when considering the fixed packaging plan and the filter availability the decision is often quite straightforward and leaves not much room for alternative choices. The limited degree of freedom is due to Heineken's decomposed planning and scheduling process, focused on efficiently using the packaging capacity.

Some degree of freedom is still left in the allocation of batches to BBC blocks. Chapter 4 already introduced an allocation model for this type of problem. Section 5.2 extends the model and creates a tailored model to be used in the operational scheduling.

When having the packaging schedule as focus, problems can emerge at the BBC scheduling. In the sequencing and batching little freedom of choice is left, that can cause a BBT to be occupied for a large amount of time. Therefore, we expect that a holistic approach to the filtration, BBC and packaging scheduling could be beneficial. Chapter 3 shows that a holistic approach does not search for the most efficient packaging plan, but creates a plan that works for all production steps, eventually increasing the total output. Using the holistic approach comes with more complexity due to a larger scope and more research should point out what benefits a holistic approach can offer.

5.2 Allocation model

Section 5.1 concludes that in the operational environment the allocation problem is a problem where still improvement is possible. According to the operational schedulers, the difficulty in the BBC process is, finding a good division of batches over the BBC and taking simultaneity into account. This section expands the model from Chapter 4 to include the simultaneity and piping.

To include simultaneity and piping, we introduce time windows to the model. With the use of time windows we can take the timing of batches inside the week into account. In the model in Chapter 4, the timings of the production in the week buckets are unknown and therefore cannot be included in the model. On the operational horizon the timings of production inside the week are known. What beer is packaged on what day is available because of the packaging schedule. To include the timing in the week we include the parameter d_{ik}. The parameter d_{ik} adds the timing of packaging to every job and the parameter n_j includes the maximum of simultaneous jobs in a time window (based on the emptying pipes dedicated to a BBC block). With the introduction of the time windows and new parameters, we add an extra constraint to the model, making sure that the allocation to blocks does not have too many simultaneous jobs. From the objective function we remove the penalty for the rest capacity of block 30, because the input of the operational model adds more level of detail, the penalty for the rest capacity is not necessary anymore.

Indices

Jobs	$i = 1,..., \mathrm{I}$
BBC types	$j = 1,..., \mathrm{J}$
Time windows	$k = 1,..., \mathrm{K}$

Parameters

b_{ij} = Required number of tank actions for beer type i in BBC type j

m_j = Maximum batches per week in BBC type j

$$c_{ij} = \begin{cases} 1 & \text{if beer i can be allocated to type j} \\ 0 & \text{otherwise} \end{cases}$$

$$d_{ik} = \begin{cases} 1 & \text{if job i is in time window k} \\ 0 & \text{otherwise} \end{cases}$$

I = Number of jobs

J = Number of BBC types

K = Number of time windows

z_j = Penalty for exceeding capacity in type j

s_j = Penalty for rest capacity in type j

n_j = Maximum of batches in a time window in BBC type j

Decision variables

$$x_{ij} = \begin{cases} 1 & \text{if beer type i is allocated in BBC type j} \\ 0 & \text{otherwise} \end{cases}$$

R_j = Rest capacity in BBC type j

E_j = Exceeding capacity in BBC type j

Objective function

$$
\begin{aligned}
&\text{Min} \sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij}b_{ij} + \sum_{j=1}^{J} E_j * z_j && && \\
&\text{S.t.} \quad \sum_{j=1}^{J} x_{ij} && = 1 && \forall i \\
&\qquad \sum_{i=1}^{I} x_{ij}b_{ij} + R_j - E_j && = m_j && \forall j \\
&\qquad x_{ij} && \leq c_{ij} && \forall i,j \\
&\qquad \sum_{i=1}^{I} x_{ij}d_{ik} && \leq n_j && \forall j,k
\end{aligned}
\tag{5.1}
$$

5.3 Input model

When focusing on the short-term scheduling of the BBC more level of detail can and should be added to the model. This section explains what the input parameters are for the short-term model.

5.3.1 BBC types and emptying pipes

In the long-term planning in Chapter 4 we only used the small, medium, large and block 10 as BBC types. For the short-term scheduling we change the BBC types to the types in Table 5.1. Every block has its own dedicated filling and emptying pipes and this is an important constraint in allocating a batch to a BBC block. Therefore, the types for this model are the blocks as described in Chapter 2. Block 40 is still divided in the medium and small tanks, where we assume one emptying pipe of block 40 is used for the medium tanks and two emptying pipes for the small tanks. Block 10 is omitted in the short-term model, because the allocation of the 0.0 beers to this block is fixed.

Table 5.1 shows the maximum batches available for every BBC type. We determined the maximum batches in the same manner as in Chapter 4 using 2019 production data. For this model we rounded the maximum of batches up to create integers. In reality no half tank actions are available, so using whole numbers creates better results.

5.3.2 Tank actions and time windows

When scheduling the BBC the complete packaging schedule is available. From the packaging schedule we can extract the needed volume of beer and the timing of the inflow of beer. The complete duration of a tank action is often longer than one day. Therefore we decide to use seven time windows, one for each day. Due to the length of a tank actions, smaller time windows are not required, this would only increase the complexity of the model and not increase the accuracy of the results.

Table 5.2 illustrates what information is extracted from the packaging schedule and what information the model uses as input. Every job has an amount of HLs, that

TABLE 5.1: Parameters for the operational model

Type	Tanks	Max batches (m_j)	Pipes (n_j)
Block 30	5	14	1
Block 40 - Small	4	11	2
Block 40 - Medium	2	5	1
Block 50	6	17	3
Block 60	6	17	3
Block 70	8	18	5
Block 80	4	9	2

are used to calculate the tank actions. The can column is part of the connectivity parameter c_{ij} showing what volumes can be allocated to block 30. The k columns give the number of emptying pipes that are needed for the volume in the accompanying time window. The volumes in Table 5.2 are fictitious and merely used for illustrative purposes. The relative position of the jobs do correspond with reality.

TABLE 5.2: Input extracted from the packaging schedule, where the k columns indicate the number of needed emptying pipes in the time window

Job	Volume	Can?	k_1	k_2	k_3	k_4	k_5	k_6	k_7
1	5300	1	1	2	2	2	2	2	2
2	4000	1		2	2	2	2	2	2
3	1400	0	1	2	2	2	1		
4	994	0		1	2	2	1		
5	716	0				1	1	1	
6	661	0		1	1	1			
7	479	1		1					
8	363	0				1	1	1	
9	301	0						1	
10	193	0						1	
11	169	0			1				
12	166	1			1				
13	157	0		1					
14	153	0			1	1			
15	117	0						1	
16	59	0					1		
17	21	0		1					

Table 5.2 shows that the first jobs are big volumes and are produced almost every day. For the large volume jobs we relax the binary decision variable x_{ij} and allow the model to allocate the large jobs to multiple blocks. In reality the big volumes are also often allocated to multiple blocks.

5.4 Output

This section discusses the output of the model that can be used by the operational schedulers to construct their weekly plan. The output of the model shows what job should be allocated to what block. The figures that a scheduler can use is portrayed in Figure 5.3 and Figure 5.4. In the figures the scheduler can see in what block a job should be stored. The figures portrayed here are based on the input of Table 5.2. For generating the output, the model only needs short calculation times. In the figures the exact volumes on the y-axis are removed for confidentiality reasons.

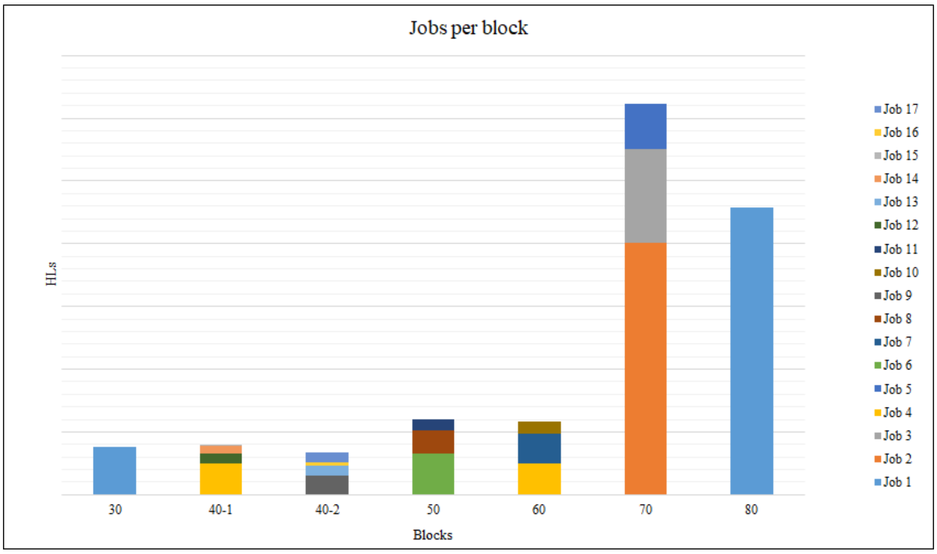

FIGURE 5.3: Output operational model: Example allocation of 17 jobs to blocks

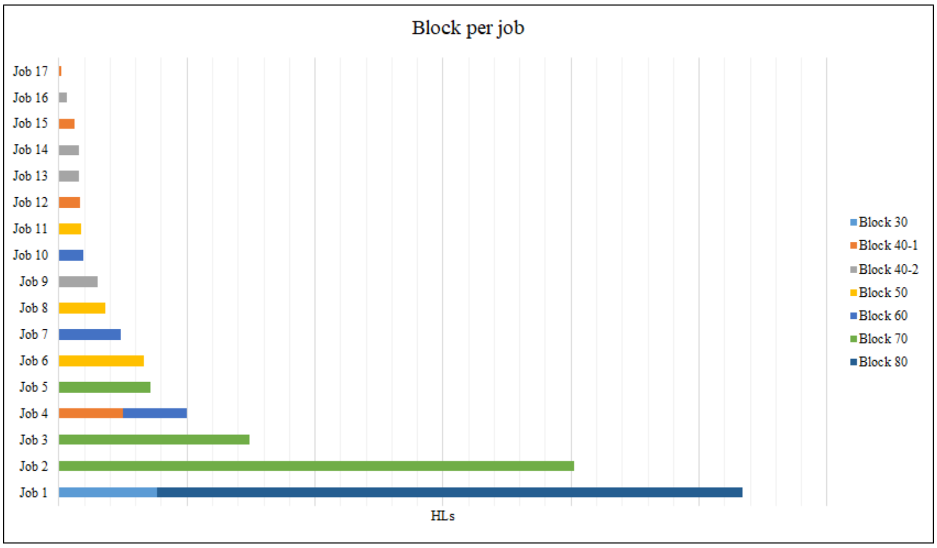

FIGURE 5.4: Output operational model: Example allocation of 17 jobs to blocks

The figures show that the big volume jobs are mainly allocated to the big tanks and some volume to block 30. The smaller volumes beer are mainly allocated to the smaller tanks.

When testing the model with multiple weeks we see that the maximum of simultaneous batches does not lead to infeasibilities or problems in using the available capacity. This suggests that the current number of emptying pipes is enough to effectively use the current number of tanks.

5.5 Validation

This section discusses the validation of the model in two components: comparing the outcomes of the model with the allocation in reality and using the model together with an operational scheduler to create a BBC schedule.

Figure 5.5 shows the comparison between actual allocations and the allocations of the model. In the volumes of the model and reality some small differences exist, due to the fact that a filtration is not able to filter the exact amount of needed beer for packaging. The red blocks highlights the most important differences, but overall the model creates a similar allocation. We see that in the real allocations, beer types can be stored in five different blocks, where the model chooses allocate the same beer type to fewer different blocks.

When we compare the model and reality in several weeks, we see that the model and reality use around an equal amount of tank actions and similar allocation. From this we conclude that the gain of the model is not necessarily in the reduction of tank action but in the time savings of the schedulers. The model is able to create similar allocation with short calculation times.

For the second component of the validation we used the model in cooperation with an operational scheduler to create a new BBC schedule. When creating the BBC schedule with the allocations of it resulted in a feasible schedule, that is constructed faster than in the normal situation. The scheduler believes the model can help in constructing the weekly schedule of the BBC.

5.6 Conclusion

This chapter answered the research question: *"How can we improve the Bright Beer Cellar planning/scheduling process?"*

The process of scheduling the BBC is to some extent already fixed by the other production steps and the factor in the BBC scheduling that still has some freedom of change is the allocation of batches to BBC blocks. With an extension of the allocation model constructed in Chapter 4 we construct an allocation model for the operational scheduling. With the addition of time windows and the available emptying pipes, it results in a model that can be used by the operational schedulers helping them to create the BBC schedule. The model creates feasible allocations in seconds, where the weekly BBC schedule can take the scheduler hours to days. With the use of the allocation model the process of scheduling the BBC can be improved and done in less time.

Heineken decomposes the scheduling of the complete production in multiple smaller scheduling problems, where the packaging schedule is leading. For future research we recommend to look into a holistic scheduling approach. In this chapter we conclude that there is only a little degree of freedom in the BBC scheduling, when it has

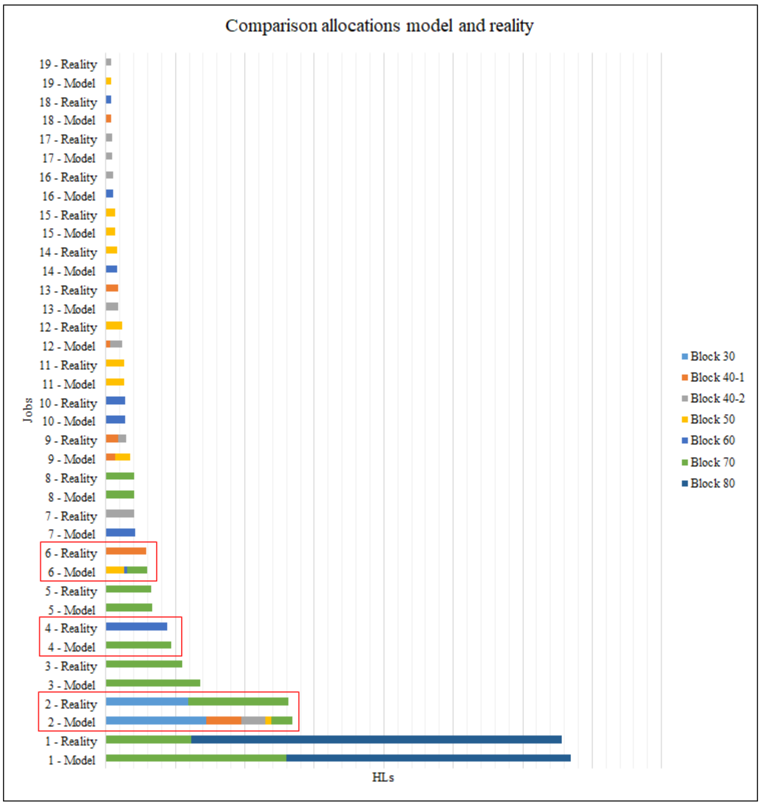

FIGURE 5.5: Comparison real allocation and model allocation of 19 jobs, where the red blocks indicate the biggest differences

to follow the packaging schedule. When the packaging lines are the only bottleneck in the production, it is a good approach to make this production step leading, but with the current scheduling process the BBC raises some limitations as well. A holistic approach could increase the total output of the system, where the trade-off can be made on the impact of a packaging schedule on the occupation of the BBC.

Chapter 6

Conclusions, Discussion and Recommendations

This final chapter includes the conclusion, discussion and recommendations of this research for Heineken. Section 6.1 provides the conclusion for this research, followed by a discussion in Section 6.2 and finally Section 6.3 provides the recommendations of our findings.

6.1 Conclusions

Heineken experienced difficulties with the scheduling of the Bright Beer Cellar (BBC). The BBC is an intermediate buffer in production, before packaging and after filtration, and is supposed to be an enabling part in production. Due to the fact that the BBC should be enabling, it has not been a part that is taken into account in capacity calculations at strategic and tactical level. Nevertheless, operational scheduling create a schedule from day to day and experience the BBC to be a bottleneck, not enabling but rather limiting other crucial productions steps. The need arose to create quantitative capacity assessment of the BBC and the question if the current gross capacity can be used more efficiently. Therefore we defined the objective of this research with two questions:

1. *'How can the net capacity of the bright beer cellar be determined?'*

2. *'How can the net capacity of the bright beer cellar be increased?'*

In Chapter 1 we structured our research by introducing several research questions, here we present the most relevant remarks acquired from answering the research questions throughout the research.

In Chapter 2 we analyzed the current situation and concluded that the BBC has grown to be a complex step in production over the years with many constraints. The BBC is originally a buffer and should have sufficient capacity to be able to fulfill the desired packaging schedule. A buffer has a different nature as regular production steps and with the buffer nature it is difficult to say something about the capacity. Due to the fact that a buffer doesn't have standard production times that can be used in capacity calculations. In combination with the great complexity of the BBC this makes it a difficult part in the production process of Heineken to determine the net capacity for. From occupation data we conclude that the BBC is indeed used to its maximum capacity at many points in time and that unusable gaps in the schedule are also in important factor to include in the BBC capacity calculations.

In Chapter 3 we performed a literature study focused on long-term capacity assessment and the scheduling of production systems with buffers. With literature we found the Rough-Cut Capacity Planning (RCCP) methods that can be used for capacity planning on the long-term and is able to bridge the gap between the short-term and long-term planning. In combination with the loading/allocation problem the Rough-Cut Capacity Planning procedures are promising for the capacity assessment of the BBC. For the allocation model a MILP can be constructed to solve the n problem in reasonable time. The allocation model could be useful for the both the RCCP approach and the operational scheduling. In literature most articles assess the complete system in the planning and scheduling problem. In this research we are limited to the part of the BBC in the production process. Thus, the complete system has already been decomposed into a smaller problem. The biggest difference with the problem in this research and the problems in literature is that the literature has a focus on actual processing stages and in this research the focus is on the intermediate buffers. To the best of our knowledge, literature does not discuss the scheduling and capacity planning of the intermediate buffers. Especially a problem were the buffer space is shared between different production routes and great complexity exists. Buffer spaces are seldom mentioned as a bottleneck because in most production environments this is not an limiting resource and most of the time even unlimited. Therefore, we recognize this as a gap in literature.

With the recognized gap in literature in Chapter 4 we use the RCCP approach and transform it to be applied to a buffer system using actual production data. When using this model to analyze the annual production plan of Heineken we conclude that in peak season the maximum capacity is reached in some weeks and that the 0.0 volume planned in 2021 is too big for the current capacity. An investment in the 0.0 process could remove the capacity problem in block 10 and prepare the BBC for the future where a growth of 0.0 volume is expected. When adding dummy volumes to the annual plan of 2021 we conclude that the problems in the BBC arise at a planned 155.000 HL and more than 20 beer types. Adding more beer types in the peak season is not recommended because the planned volumes in the annual plan are already using most of the available capacity in the BBC.

The capacity assessment using actual production data as maximum capacity and an allocation model can be used by the strategic planning department to be able to take the BBC capacity into account and spot bottlenecks in an early stage. We also conclude that the allocation model could be useful on the operational level to improve the scheduling of the BBC.

In Chapter 5 we extend the allocation model used in the RCCP approach to be applied to the operational scheduling. In constructing the model, we recognize that the process of scheduling the BBC is to some extent already determined by the other production steps and the factor in the BBC scheduling that still has some freedom of change is the allocation of batches to BBC blocks. This makes it hard to actually improve the performance of the BBC, because the time a BBT is occupied is dependent on other factors outside the scope of this research. Nevertheless, with the operational allocation model the operational schedulers can determine a feasible allocation in less time. To improve the performance of the BBC a more holistic scheduling approach could be useful.

Overall, in this research we created a new approach in assessing buffer capacities in a brewing environment on the long-term planning horizon. With the long-term capacity assessment we also constructed an allocation model that helps the schedulers in finding feasible schedules for the BBC faster.

6.2 Discussion

Within this research there are several limitations that have to be mentioned. This section discusses the most important limitations.

The first point of discussion are the planning factors. The maximum number of tank actions is based on actual production data, where we implicitly include the influence of other factors impacting the BBC performance. This is an important assumption to include the many factors impacting the BBC performance, but it also prevents us from determining the influence of, for example, more emptying and filling pipes. More piping should increase the maximum number of tank actions. Nevertheless, with the current model an analysis of what the impact is of adding more piping in the BBC is difficult. With that being said, based on the operational model we expect that the current piping is enough to effectively use the current BBC capacity.

The second point of discussion is the allocation model used in the RCCP method. On the long-term there are no exact (day to day) timings available of when beer is going to be produced. Therefore, in the long-term allocation, we treat the weekly beer volumes as one job, when in reality a beer type can be split in multiple batches over the week. On the long-term it is difficult to include day to day timings, simultaneity of beer production and the available piping, although they can be important limitations in the operational environment. Therefore, we see that the model creates a slightly more positive image of reality. As a consequence, when production quantities fit in the current capacity with RCCP method it doesn't necessarily mean that in the operational scheduling no problems will arise. Hence, when the needed tank actions in a week are between the worst and best case scenario, we consider the week as a critical week. On the other hand, when the production quantities don't fit in the model we can state that some intervention is needed, because in this case problems in operational scheduling are to be expected.

6.3 Recommendations

This final section describes the recommendations concerning this research.

- **Yearly check the annual plan with the RCCP method:** When the RCCP is used on a yearly basis problems, problems in the BBC can be spotted in an early stage and potential interventions can be set in motion on time.
- **Use rules of thumb in the tactical planning to reduce BBC pressure:** In this research we see that problems in the BBC start above a specific production volume and more than 20 beer types. When big volumes have to be produced, above the specific production volume the tactical planning should not plan more than 20 beer types to prevent problems in the BBC. Whenever the production volume is smaller more beer types can be produced. Therefore, the limitation of beer types should only be considered when producing large volumes.
- **Use the allocation model in scheduling the BBC:** In the current situation of scheduling Heineken uses a manual constructive heuristic. We recommend to use the allocation model, when creating the weekly BBC schedule, the model

creates an allocation taking all planned batches into account and prevents rework later in the scheduling process. This can save valuable time of the schedulers.

- **Invest in the 0.0 capacity:** The current capacity in block 10 is not sufficient for the current annual plan and also not sufficient for the future where the 0.0 volume is expected to grow.
- **Critically approach new investments in flexibility to increase BBC capacity:** The BBC process is already highly flexible and the operational allocation model suggests that more piping is not needed to use the available capacity of tanks. More flexibility only makes the job of the schedulers easier, because more options are available in making the schedule, but we expect that it will not have a great impact of the net capacity of the BBC. Therefore, an investment in flexibility for the purpose of increasing BBC capacity is not advisable.
- **Future research in a holistic approach:** Heineken decomposes the scheduling of the complete production in multiple smaller scheduling problems, where the packaging schedule is leading. For future research we recommend to look into a holistic planning/scheduling approaches. When the packaging lines are the only bottleneck in the production, it is a good approach to make this production step leading, but with the current scheduling process the BBC raises some limitations as well. A holistic approach could increase the total output of the system, where the trade-off can be made on the impact of a packaging schedule on the occupation of the BBC. Especially, when the BBC remains a bottleneck in the production process, this could be a valuable research.

Appendix A

Product groups based on technical constraints

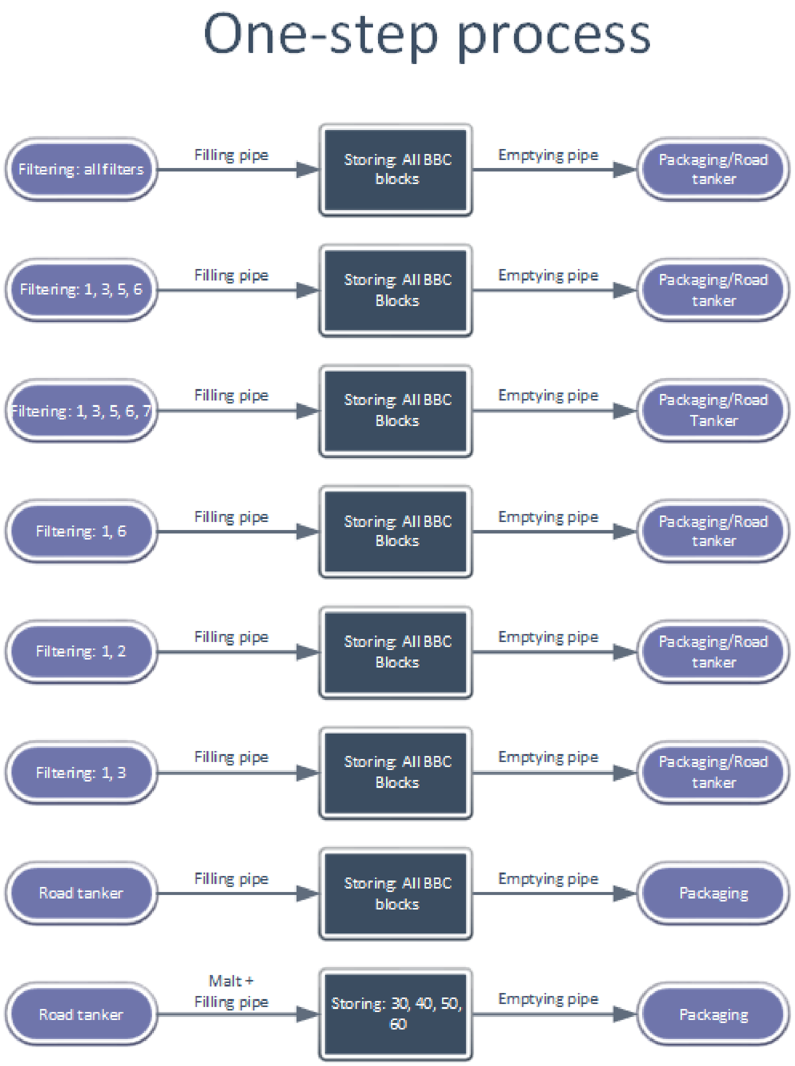

FIGURE A.1: One-step product groups

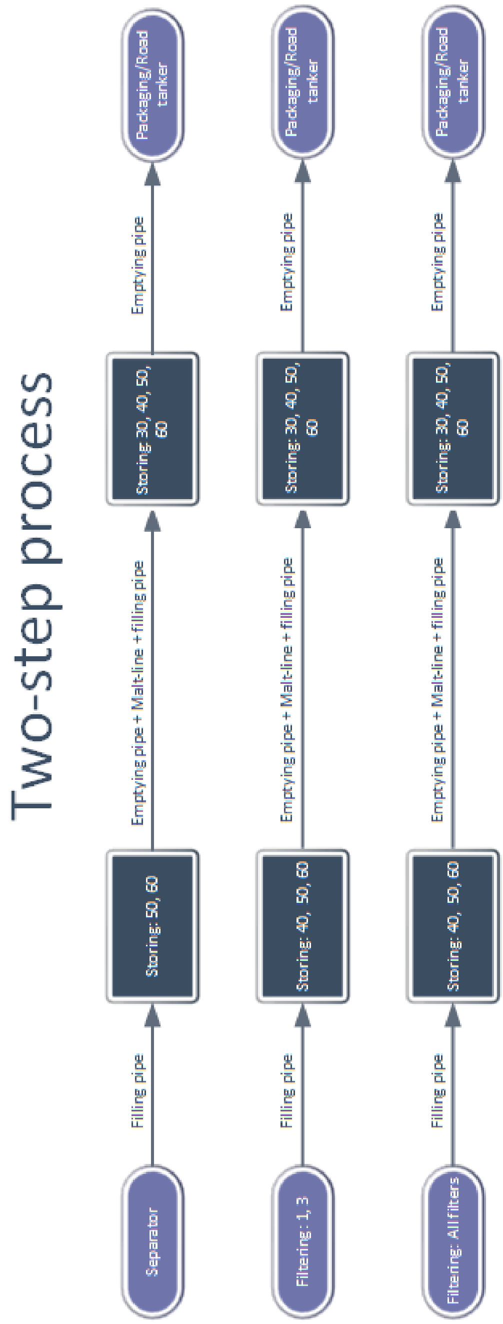

FIGURE A.2: Two-step product groups

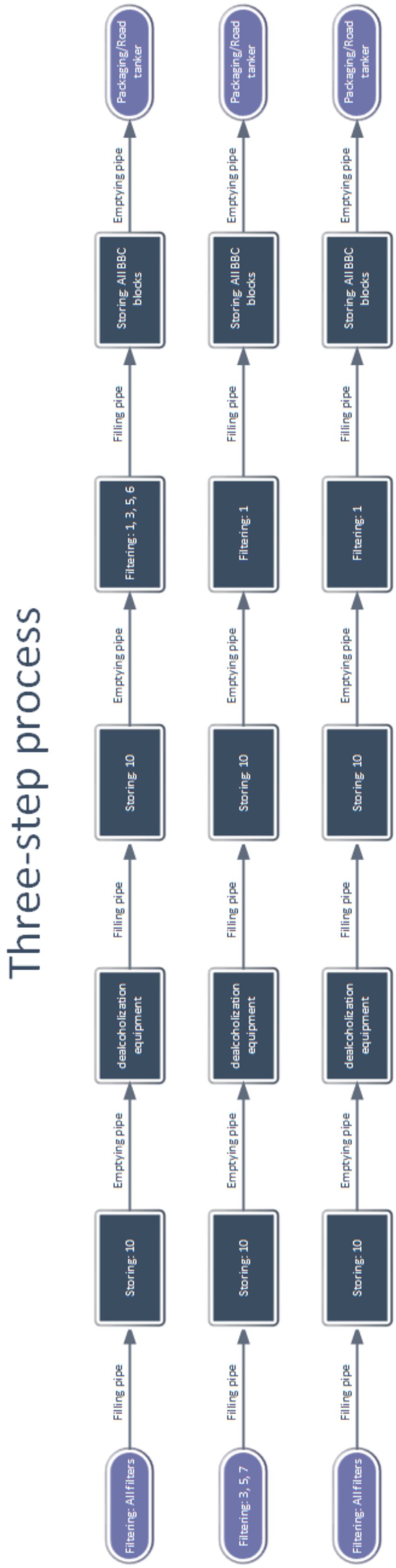

FIGURE A.3: Three-step product groups

Appendix B

BBC Occupancy Graphs

Figure B.1 shows the total occupation of all BBTs and Figures B.3, B.2 and B.4 show the occupation of the different type of tanks. The figures are based on production data of 2019.

The graphs show the total amount of BBTs that are occupied on a given time. A tank can be occupied with different actions. The graphs make a distinction in actions between filling, buffering, emptying and the waiting time of the system. Filling occurs when a BBT is being filled with beer through a filtration run. Buffering occurs when the tank is filled and is waiting to be emptied. Emptying occurs when a tank is being emptied through a packaging run. Waiting time of the system occurs when there a planning gaps between different batches in the BBC. When a gap between two scheduled batches only has a span of hours this cannot be considered as free capacity, as the tank cannot be used for other batches in this gap. The threshold in considering a gap as free capacity or waiting time of the system, is the average of the total time a batch usually occupies the system. When the gap is bigger than the average time, the tank is not occupied and when the gap is smaller than the average time the tank is occupied as waiting time of the system. We consider the waiting time of the system as planning inefficiency for the BBC. To determine the amount of tanks occupied with each action on every hour over the timeline of 2019 the occupation is measured. To create a readable graphs, the graphs include the daily averages. The red line corresponds with the maximum number of available tanks in the system. For the 4100 HL tanks the occupation exceeds the maximum, because in some occasions the tanks are already emptied before the tank is completely filled, which results some tanks to be in more occupying states and raises the total above to number of available tanks.

FIGURE B.1: Average daily occupation of all Bright Beer Tanks

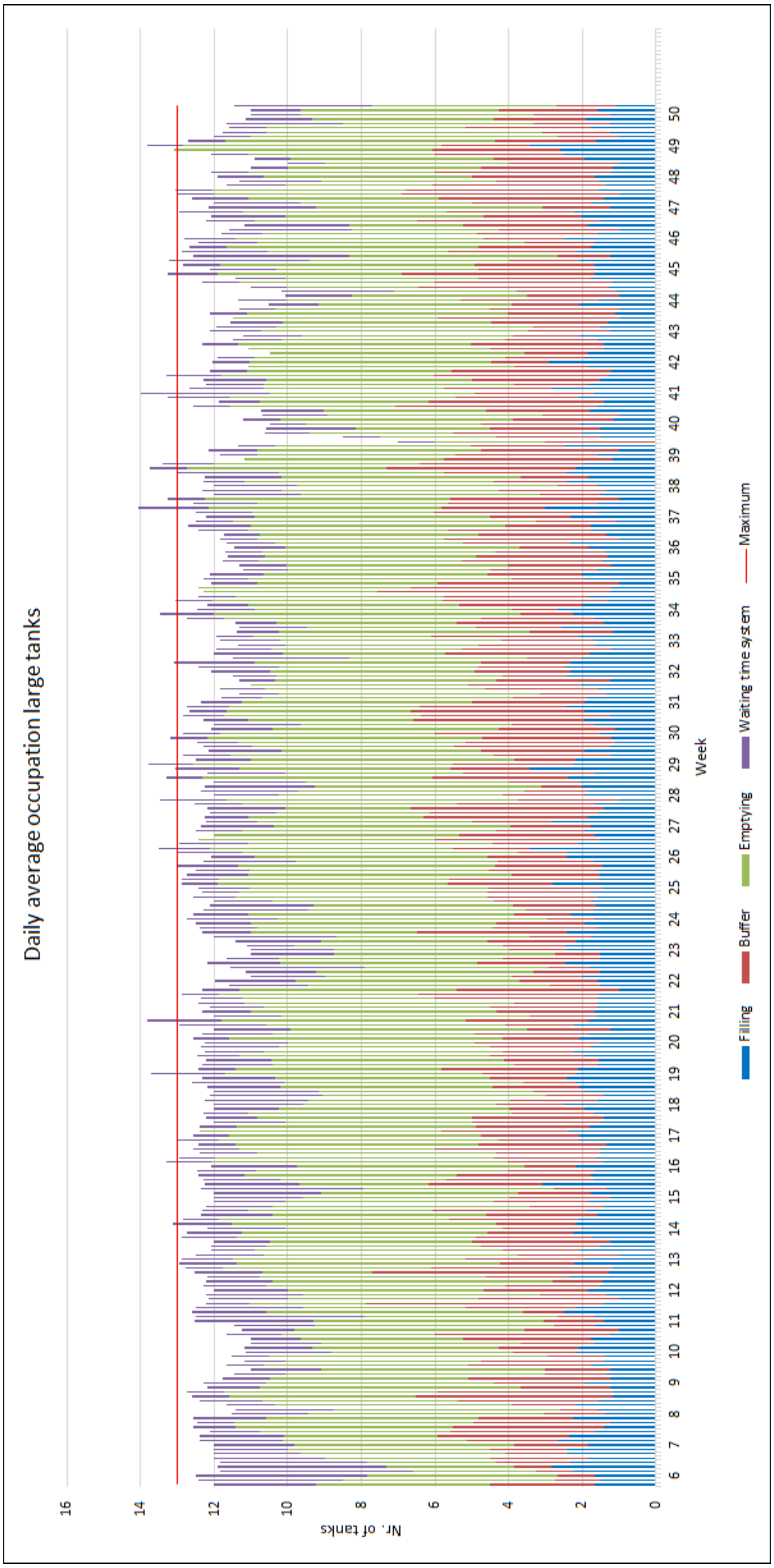

FIGURE B.2: Average daily occupation of 4100 HL Bright Beer Tanks

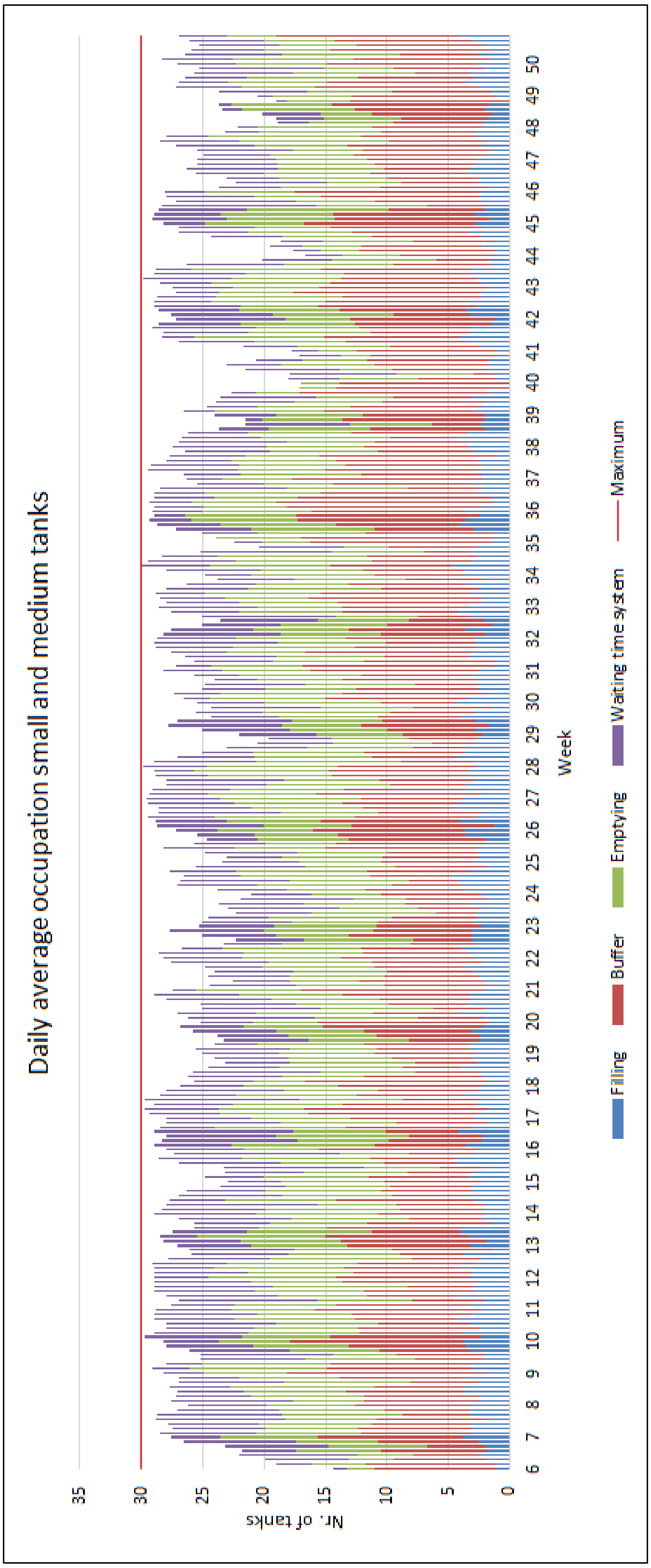

FIGURE B.3: Average daily occupation of 850HL and 1700 HL Bright Beer Tanks

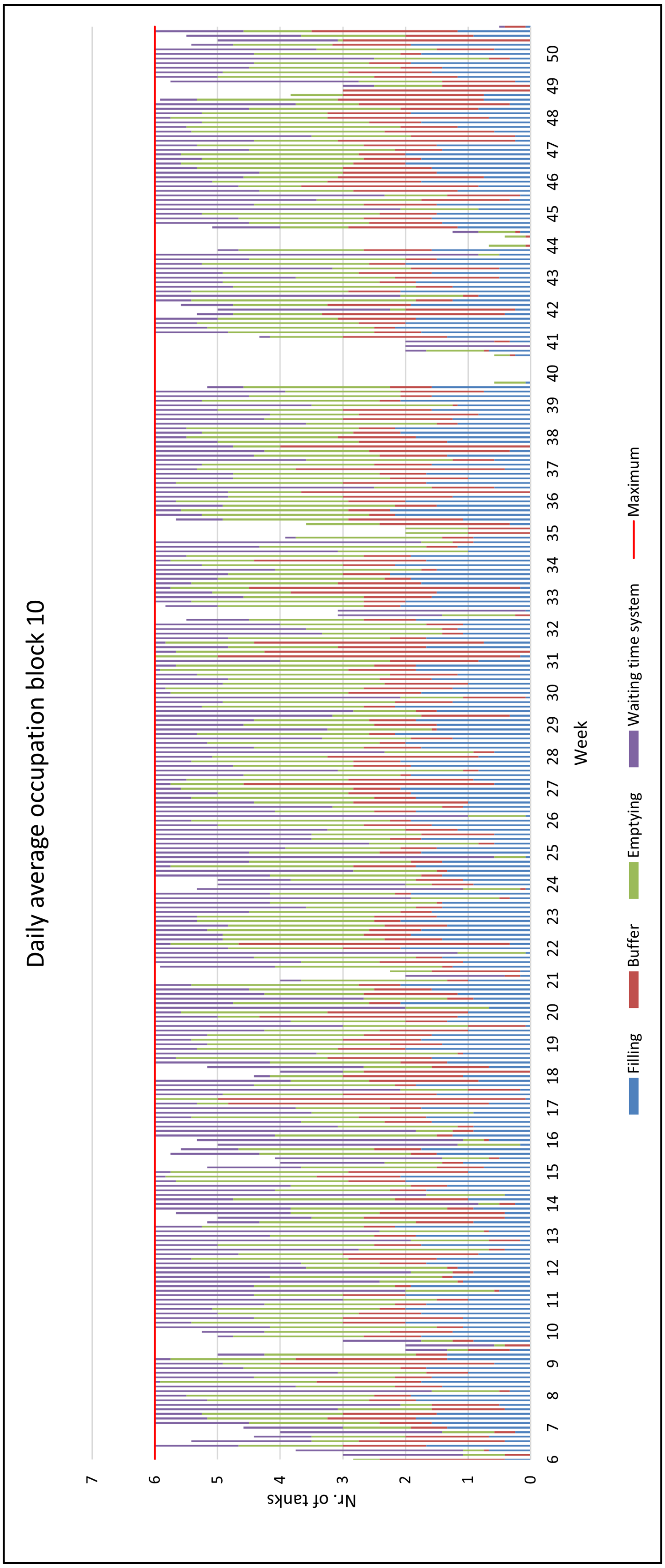

FIGURE B.4: Average daily occupation of block 10

Appendix C

Figures NPIs

The figures are removed for the public version.

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