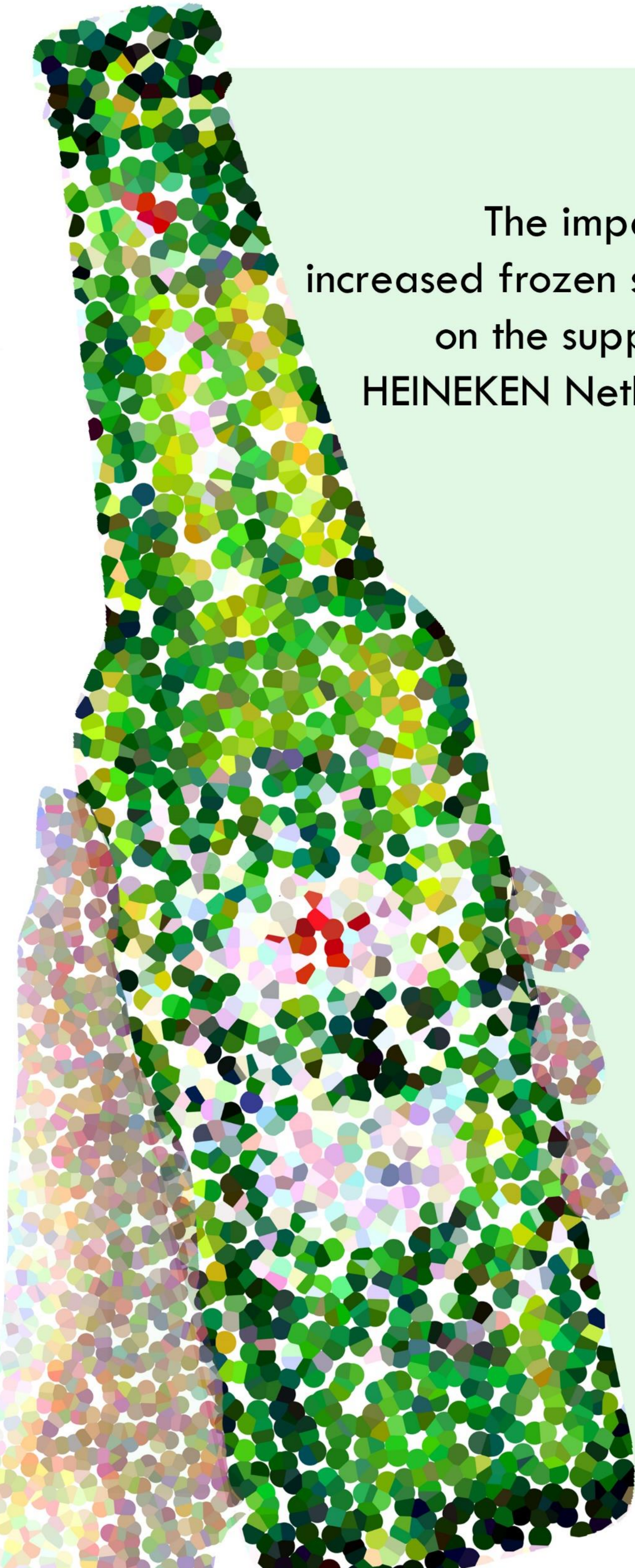

The impact of an increased frozen scheduling interval on the supply chain of HEINEKEN Netherlands Supply

Nicole Veldhuis

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Management Summary

We perform this research at HEINEKEN Netherlands Supply (HNS). HEINEKEN is one of world's most international brewers. In the current situation, HNS maintains a frozen scheduling interval of one week. That means that only the first week of the 13-weeks production plan is frozen. When creating the production plan or schedule, controllable and uncontrollable variables influence the optimality and feasibility of the production plan and schedule. Controllable variables can be controlled by HNS, uncontrollable variables cannot be controlled by HNS. Based on previous researches performed at HNS and the urge to reduce costs, the aim of this research is to determine the impact of an increased frozen scheduling interval of one week on the HNS' supply chain. To achieve this goal, we formulate the following research question:
"What is the impact of an increased frozen scheduling interval on the controllable and uncontrollable variables in production planning and scheduling of HNS and the consequences for the supply chain?"

We identify five players in the HNS' supply chain during the current situation analysis: (1) customers, (2) HNS Planning department, (3) suppliers, (4) carriers and (5) HNS scheduling department. During this research, we argue from two perspectives. When reasoning from a customer's perspective, we refer to week X. Week X is the week in which the products are going to be shipped to the customer. When reasoning from the HNS' perspective, we refer to week Y. Week Y is the week in which the planning process starts. HNS creates in the current situation in week Y a production plan for the weeks Y+1 until week Y+13. The first week, week Y+1, is used as input for the production schedule. We research the situation in which HNS creates a production plan for the weeks Y+2 until week Y+13 and a production schedule for week Y+2. The production schedule of week Y+1 is thus frozen.

Using literature, we conclude that controllable and uncontrollable variables are most effected by an increased frozen scheduling interval. We combine the variables we identify at HNS and variables found in literature to define variables for which we measure the impact of an increased frozen scheduling interval. Table 0.1 shows the chosen variables per player in the HNS' supply chain.

<table>
<tr><th colspan="2">Customers</th><th>HNS planning</th><th>Suppliers</th><th>Carriers</th><th>HNS scheduling</th></tr>
<tr><td>Customer forecast update flexibility</td><td rowspan="2">Safety stock level</td><td rowspan="2">Beer availability</td><td>Material availability</td><td rowspan="2">Transport availability</td><td rowspan="2">Changeover time per line per week</td></tr>
<tr><td>Rush orders or cancellations</td><td>Purchase costs</td></tr>
</table>

Table 0.1 - Overview variables per player in HNS' supply chain

Since the HNS' supply chain is a decentralized supply chain in which each player optimizes its own schedule before sharing the information with the next payer in the supply chain. Therefore, we determine the impact of an increased frozen scheduling interval for every variable separately.

We increase the lead time with one week and use that as input for the safety stock tool that is developed at HNS to calculate the effects on the customer's safety stock levels. We assume that the service level, that is used as input parameter, does not change with an increased frozen scheduling interval. We conclude that for the domestic market on a yearly basis the inventory holding costs increase approximately with € X. For the markets HEINEKEN Germany, HEINEKEN Taiwan and HEINEKEN USA, we conclude that the safety stock levels do not increase as much as for the domestic market. This is due to the fact that the lead time increase is relatively seen less than for the domestic market.

Customer forecast update flexibility is the ability for the customer to change their forecast as late as possible. We distinguish for the measurement of the forecast update flexibility between the MTO customers and replenishment customers. For the MTO customers, we compare the forecast in week

X-4, week X-5 and the actual orders placed at HNS. We conclude that the MTO customer uses in X % of all cases the last week to change their forecast closer to the actuals, but also in X % of all cases the forecast was closer to the actuals in week X-5. For the replenishment customers, we compare the forecast in week X-3, week X-4 and the actual in-market sales, which are the sales of the replenishment customer to their customer. We conclude that an increased frozen scheduling interval would not impact the forecast update flexibility of the replenishment customer. The majority of the forecasts show that the forecast in week X-3 is equal to the forecast in week X-4 and for the other percentage it is equally divided which forecast is closer to the actuals. A decrease in forecast update flexibility might result in more rush orders or more cancellations. We cannot quantify the exact impact on number of rush orders or cancellations, because HNS does not track the number of rush orders or cancellations in the current situation.

HNS almost never observes beer availability as a beer restriction for the production schedule. HNS creates the beer plan based on customer demand forecast in the current situation. Beers with a brewing time of less than a week can be brewed according actual orders when increasing the frozen scheduling interval with one week. That probably results in a higher beer availability. The process of arranging transport on time at the brewery is captured in a day-to-day process. When increasing the frozen scheduling interval, this process does not change and therefore does not influence the carrier transport availability.

HNS measures the material availability based on the number of material restrictions and the total planned materials. Material restrictions arise when a supplier is not able to deliver the required materials on Monday of week Y+1. When increasing the frozen scheduling interval, the number of material restrictions decrease. That results in an improvement of supplier material availability. We discuss the impact of an increased frozen scheduling interval on the purchase costs with the department Contract Management. We conclude that only the carton and draught keg suppliers achieve cost reductions. We expect a one-off saving of € X and a yearly saving of € X.

To determine the impact on the changeover times per line per week, we introduce a MILP. The aim of the model is to determine the sequence, given the production quantities per line per week and material release dates as input. The objective is minimizing the total makespan. We realize an average saving of 14 minutes per can line per week when increasing the frozen scheduling interval, which results in a yearly saving of € X. An increased frozen scheduling interval does not result in changeover time savings for the bottle lines.

Table 0.2 shows the impact of an increased frozen scheduling interval per variable:

Potential savings		**Potential losses**		**No impact**
Decrease in material purchase costs	€ X	Loss in customer forecast update flexibility (MTO)	€ X	Supplier transport availability
Higher material availability	€ X	Increase in inventory holding costs	€ X	
Decrease in changeover time per line per week	€ X	Higher change of rush orders or cancellations	€ X	
Higher beer availability	€ X			

Table 0.2 - Impact of an increased frozen scheduling interval on the controllable and uncontrollable variables

Due to the COVID-19 pandemic, HNS moves their focus from high service level for the customers to realizing more cost savings, even though this might be at the expense of customer service. Therefore, we recommend HNS to continue the research into an increased frozen scheduling interval, because the results of this research seem promising. One of the main recommendations is to determine which processes require change when implementing an increased frozen scheduling interval.

Preface

This research is the result of my internship at HEINEKEN Netherlands Supply to finish the master Industrial Engineering and Management with specialisation Production and Logistics Management. HEINEKEN Netherlands Supply gave me the opportunity to finish my master, even in these crazy times of COVID-19. After working 1.5 weeks at the office, we were obliged to work from home. Our meetings took place online and we returned just two times to the brewery in Zoeterwoude. Even in these crazy times, I managed to successfully finish this research and for that, I would like to use this preface to thank all those people who helped me accomplish this.

First of all, I would like to thank my supervisors Engin Topan and Marco Schutten form the University of Twente for their supervision. Their constructive feedback and support during these months have been very helpful to bring this thesis to a higher level.

Of course, I would also like to thank Marjon van Eijndhoven and Ruud van Oost from HEINEKEN Netherlands Supply. From the start, Marjon and Ruud gave me a very welcoming feeling and especially Marjon always had time to answer my questions or helped me when needed. You always gave me the information that I needed or at least told me where or how I could find the information. You both encouraged me to talk with as much people within HEINEKEN Netherlands Supply as possible, even though it became online meetings. The critical look of you both at the approach and results brought this research to a successful end.

Last but not least, I want to thank my friends and family for supporting me during the writing of this research, but most of all, for making my time as a student one I will never forget!

Enjoy reading this research!

Nicole Veldhuis
Den Haag, November 2020

Contents

List of Tables

List of Figures

List of abbreviations

		Introduced on page
AOC	Advanced Order Commitment	28
AS	Advanced Scheduling	16
BOM	Bill of Materials	4
CS	Customer Service	10
FRP	Flexibility Requirements Profile	75
HGER	HEINEKEN Germany	18
HNC	HEINEKEN Netherlands Commerce	1
HNL	HEINEKEN Netherlands	1
HNS	HEINEKEN Netherlands Supply	1
HTW	HEINEKEN Taiwan	42
HUSA	HEINEKEN USA	42
MPS	Master Production Schedule	4
MPSM	Management Problem Solving Method	5
MTO	Make to Order	11
MTS	Make to Stock	12
OpCo	Operating Company	1
OS	Operational Scheduling	2
SCD	Supply Chain Development	2
TSCP	Tactical Supply Chain Planning	2

Chapter 1 – Introduction

We perform this research at HEINEKEN Netherlands Supply, the production company of HEINEKEN Netherlands. HEINEKEN is one of world's most international brewers. This research provides HEINEKEN Netherlands Supply with advice what the impact is on the HNS' supply chain of increasing the frozen interval. Section 1.1 provides a short introduction about HEINEKEN Netherlands Supply. Section 1.2 introduces the company's planning and scheduling process. Section 1.3 describes the motivation for this research and identifies the main problem that we tackle during this research. Sections 1.4 and 1.5 explain the scope and research questions respectively.

1.1 Heineken Nederland

It all began when Gerard Heineken started a small brewery in the middle of Amsterdam in 1873, in which he brewed the first premium pilsner of the Netherlands. His beer was very popular among the inhabitants of Amsterdam and quickly more people throughout the country were drinking his pilsner. In the past 150 years, the brewery grew and other markets were explored. This is how HEINEKEN became as big as they are today. HEINEKEN has operations in more than 70 countries with more than 85,000 employees. HEINEKEN produces and sells a broad collection of 250 brands in several packaging types for customers all over the world. All breweries that HEINEKEN owns in the world, have one umbrella organisation called HEINEKEN Global, which is located in Amsterdam (NL).

Since the first of January 2020, HEINEKEN Netherlands (HNL) has been split up into three companies: Vrumona, Heineken Netherlands Commerce (HNC) and Heineken Netherlands Supply (HNS). Vrumona is located in Bunnik (NL) and is the branch that produces and sells soft drinks. HNS is the company that owns three breweries in the Netherlands: Zoeterwoude, Den Bosch and Wijlre. With the ownership of these breweries, HNS is responsible for the production of all the beers for domestic and export customers. HNS does not deliver directly to end customers, but to other Operating Companies (OpCos), which in their turn, deliver to their customers. For example, HNC is a customer of HNS, since HNC is the company that is responsible for all the commerce of HEINEKEN in the Netherlands and thus sells beers to supermarkets in the Netherlands. Figure 1.1 visualizes the three HNS locations.

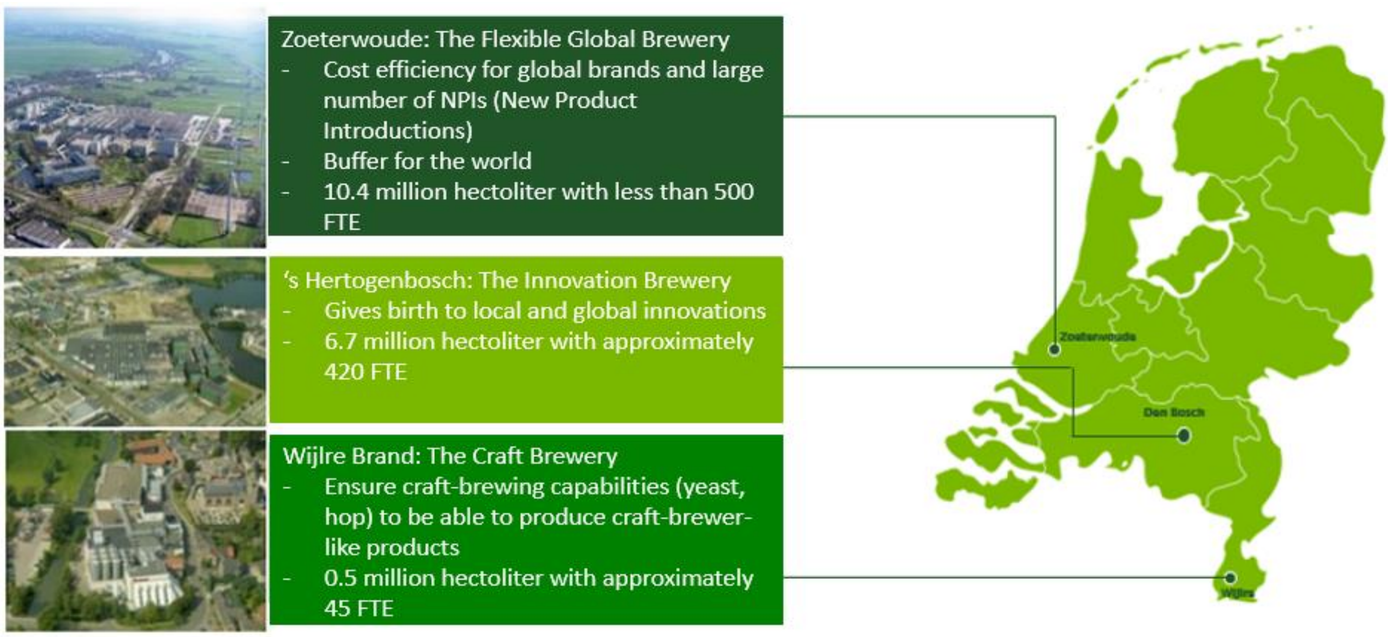

Figure 1.1 - HNS breweries

Figure 1.2 visualizes the organisational chart of HEINEKEN. We perform this research at the department Supply Chain Development in Zoeterwoude.

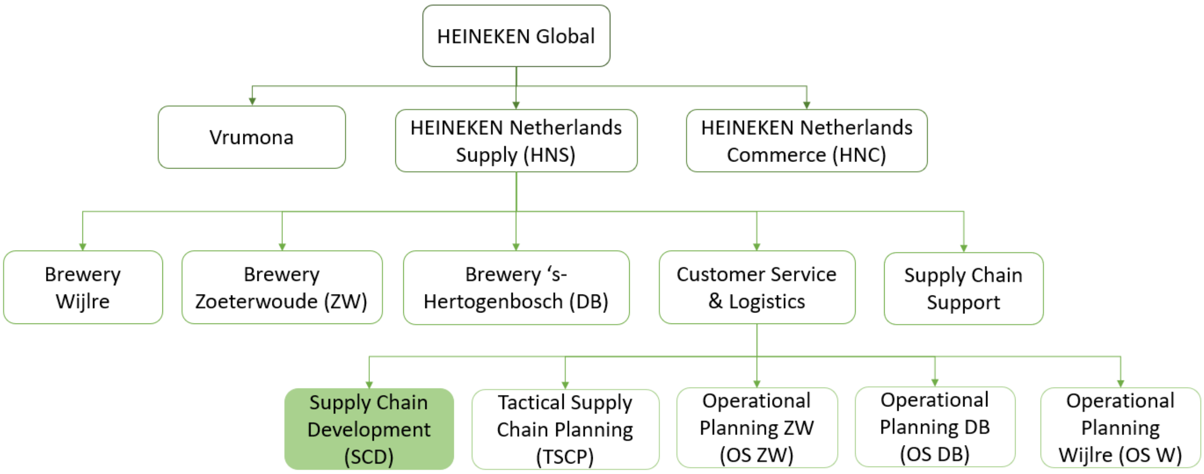

Figure 1.2 - Organisational chart

Zoeterwoude is known as the Flexible Global Brewery. It produces for the domestic customer HNC and all the breweries around the world that are not able to fulfil demand due to under capacity. Zoeterwoude also produces for other OpCos that do not have a brewery, such as HEINEKEN USA or OpCos that are not able to produce a specific beer. The production process in Zoeterwoude is optimized for high volumes and high flexibility. Zoeterwoude produces only 8 different types of beers on 16 different production lines.

Zoeterwoude contains three departments regarding production planning and scheduling. The responsibility of the Supply Chain Development (SCD) department is the long-term decision making, which are plans and projects with a scope of 13 weeks or longer. The three main focus points are: (1) translating the long-term forecast into a long-term production plan, so that opportunities for investments become clear, (2) an 18-month production plan and (3) the determination of safety stock levels at customer's side.

Every month, SCD discusses the production plan for coming quarter with the department Tactical Supply Chain Planning (TSCP). Their responsibilities are production plans and projects with a scope of 1 to 13 weeks. Based on a rolling horizon, TSCP creates every week a 13-weeks production plan of which the first week is used as input for the short-term production plan. TSCP determines on a weekly level what should be produced for the coming weeks on which line. The organisational chart in Figure 1.2 shows that there is just one tactical department for all HNS breweries. That is because TSCP creates the tactical plan for the breweries Zoeterwoude and 's-Hertogenbosch. The production plan and schedule for Wijlre is created at the same department at the brewery in Wijlre.

The last department is Operation Scheduling (OS). This department is responsible for the short-term production plan of HNS, which is the production schedule for the current and next week. OS determines on an hourly level in what sequence all orders from the production plan are going to be produced. Another responsibility is the timing of arrival of the materials and transport goods at the brewery. In the most ideal case, this is fully aligned with the production schedule.

The brewery in 's-Hertogenbosch is known as the Innovation Brewery. This brewery has a wide portfolio of different beers with only 8 production lines. Most of the new beers are introduced here. The variety of beers brings a big challenge when it comes down to planning and scheduling. 's-Hertogenbosch schedules its own filtration and brewing process, which is in Zoeterwoude a responsibility of the TSCP department.

The brewery in Wijlre is also known as the Craft Brewery. This brewery is optimized for a wide variety of beers with a low volume. Only 3 to 4% of HNS' total volume is brewed in Wijlre. This brewery has its own planning department since the volumes and beers that are brewed in Wijlre are different than the beers brewed in Zoeterwoude and 's-Hertogenbosch. Wijlre is left out of scope for the remainder of this research, because the way of working is different from Zoeterwoude and 's-Hertogenbosch.

1.2 Supply Chain Planning Process at HNS

Before introducing the scope of this research, this section provides a short introduction about supply chain planning at HNS. Figure 1.3 shows the planning process from an HNS' perspective with the corresponding time buckets.

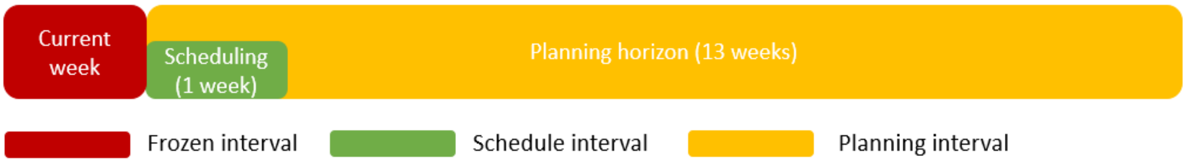

Figure 1.3 - Planning horizon Tactical Supply Chain Department

The supply chain planning process starts with the uncontrollable variable customer demand forecast. Every week, the customers send their demand forecast to HNS for the coming 16 weeks. Figure 1.3 shows that the controllable variable planning horizon of HNS is 13 weeks, which is split up in two intervals: planning and scheduling interval. Controllable variables are variables that HNS can control, such as the planning horizon. Uncontrollable variables are variables that TSCP cannot control, such as the customer demand forecast, since the customer determines what to order for which period. TSCP and OS consider all controllable and uncontrollable variables while creating the production plan or schedule.

Figure 1.3 starts with the red interval is the frozen interval and is not included in the planning horizon. A frozen interval indicates that the production quantities per beer type per line are already determined and cannot change anymore, only with high exception.

The green interval is the schedule interval. Scheduling is the process of creating a production schedule for the coming week. Yet, this schedule can be revised. The input for the production schedule are the controllable variable production quantities per line and the uncontrollable variable material, beer and transport restriction per production order. A production schedule indicates on hourly level what to produce on which line.

The yellow part is the planning interval. This plan does not include a detailed production plan. The production plan only includes medium-term customer demand forecast and available production hours. TSCP considers all controllable and uncontrollable variables when creating the 13-weeks production plan. HNS uses the rolling horizon principle for their production planning process. When planning with a rolling horizon, every time a week passes, another week is added at the end of the interval. Based on this customer demand forecast and the rolling horizon principle, TSCP creates weekly a production plan for the coming 13 weeks. This 13-weeks production plan indicates how much needs to be produced per product per week. The main goal of this 13-weeks production plan is to monitor customer demand forecast over time and to monitor the line capacity given all controllable and uncontrollable variables. This is how TSCP detects early signs of over- or under capacity.

We apply the color-coding from Figure 1.3 throughout the remainder of this research.

TSCP converts the 13-weeks production plan with the help of a Bill-Of-Materials (BOM) into a 13-weeks demand forecast for the suppliers. A BOM is a list that indicates which materials are needed in what quantity to produce a finished good. The combination of a BOM and the 13-weeks production plan results in an HNS demand forecast for suppliers. TSCP updates the production plan and supplier demand forecast weekly and sent it to suppliers. Literature describes the 13-weeks production plan as the Master Production Schedule. Kiran (2019) explains that the first part of the planning horizon is the part in which every week a Master Production Schedule (MPS) is created. An MPS translates a business plan into a comprehensive product manufacturing schedule that covers what is to be assembled or made, when, with what materials acquired when, and the cash required. It forms a key

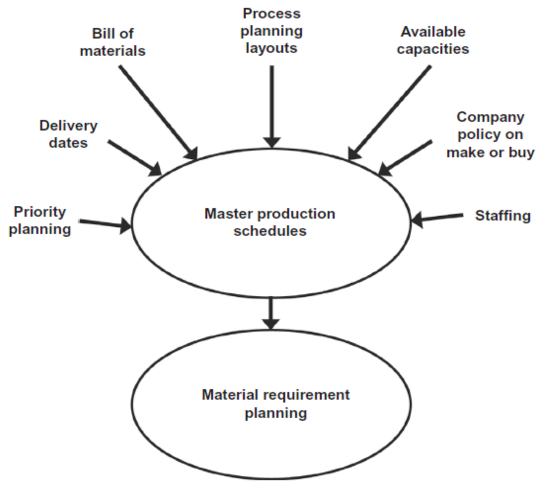

Figure 1.4 - Basic input data for MPS according (Kiran, 2019)

link in the manufacturing planning and control interfacing with marketing, distribution planning, production planning and capacity planning. The MPS is generally followed by an operation schedule, which fixes the total time required to do a piece of work with a given machine (Kiran, 2019). Figure 1.4 visualizes all input that is needed for an MPS according to Kiran (2019).

TSCP receives from another department within HNS the available line capacity per week, since not every line is available every hour of every week due to maintenance or other events. Based on the uncontrollable variables for the HNS planning department available line capacity and the ordered quantities, TSCP determines which amount per beer needs to be produced in the coming 13 weeks. On Monday of week Y, TSCP creates from the first week of the 13-weeks production plan a detailed short-term production plan, which is the green interval as Figure 1.3 shows. Based on that short-term plan, the material planner checks for every supplier if the required quantity of materials are available for production next week. If that is not the case, TSCP double checks if the supplier is not able to deliver the required materials at the start of the week or if the supplier is not able to deliver the required materials at all. If the supplier is not able to deliver the required materials at all, the production order is moved to next week. If the supplier is not able to deliver the required materials at the start of the week but later in that week, a material restriction for that production order arises. Since the production of that production order cannot start before all required materials arrive at the brewery. In parallel is checked if all beer is available for the next week. If a certain beer type is not ready for production, the production of the beer moves to next week, otherwise a beer restriction arises.

The detailed short-term production plan describes per beer how much to produce on what line. This plan is passed on to OS at the end of Tuesday. OS starts at Tuesday with creating an initial production schedule and finishes the final production schedule on Wednesday. The final orders to suppliers are sent on Thursday of week Y for week Y+1. An identification of when the transport goods should arrive in week Y+1 at the brewery is also sent on Thursday of week Y. The process of arranging transport on time at the brewery is a process that is captured in a day-to-day process.

1.3 Problem Identification and Research Goal

Whenever a customer in the world is not able to fulfil demand, HNS jumps in. This is one of the reasons why Zoeterwoude is called the Flexible Global brewery. The main focus of HNS is a high service level for every customer. However, HNS notices that the advantage of accomplishing high customer service levels are high supply chain costs. The management of HNS decided that the supply chain costs should decline and therefore defined the HNS vision of 2021 as follows: "*To become more cost competitive, however remain a strong front runner on innovations and customer service*."

HNS wants to realize this by having a strategic balance between service flexibility and supply chain costs. However, the current performance shows that their supply chain costs are too high and therefore, costs reductions are necessary to remain the strong front runner.

In order to learn how to reduce the supply chain costs at HNS, we apply the Managerial Problem Solving Method (MPSM) of Heerkens & Van Winden (2012). This is a systematic problem-solving approach to find the underlying causes. The MPSM describes seven phases: (1) defining the problem, (2) formulating the approach, (3) analysing the problem, (4) formulating solutions, (5) choosing a solution, (6) implementing the solution and (7) evaluating the solution.

The first step, defining the problem, starts with creating a problem cluster. This problem cluster shows all cause-consequence relations, which in the end results in the underlying problem. We solve the underlying problem in order to solve the main research goal. We base the problem cluster on project meetings with employees from different positions within HNS, such that the problem cluster highlights multiple perspectives.

From the HNS vision for 2021, we observe the following problem: "*Supply chain costs are too high to remain the strong front runner.*" The supply chain costs within HNS consist of inventory holding costs, production costs, procurement costs and transportation costs. Not all costs return in the problem cluster, since it is not possible to reduce all cost items in this research.

According to the MPSM, core problems should fulfil the following requirements: it should be a problem that has relation(s) with other problems in the cluster, no other further causes and must be solvable. From the observed problem, we identity the two core problems:

1. *It is unknown what the consequences of a longer frozen interval are*. A master student from the University of Rotterdam investigated the possibilities of clustering production orders over weeks. However, that research pointed out that HNS already clusters as much as possible, but that it might be beneficial for HNS to increase the frozen scheduling interval. However, it is not known what the impact is of an increased frozen scheduling interval.
2. *HNS' forecast is not stable enough for suppliers and carriers to produce according that forecast*. The medium-term demand forecast that HNS sends to their suppliers and carriers is not very consistent for every week. The consequence of these fluctuations are that it is not cost efficient for suppliers to produce according the demand forecast they receive from HNS. Besides that, HNS sends on Monday of week Y an pre-purchase order to all suppliers for what they want to receive on Monday of week Y+1, but the final purchase order is sent on Thursday of week Y for Monday of week Y+1. This gives suppliers who work on a Make-To-Order basis little time to produce all the required materials on time.

Figure 1.5 visualizes the problem cluster, which starts with the observed problem

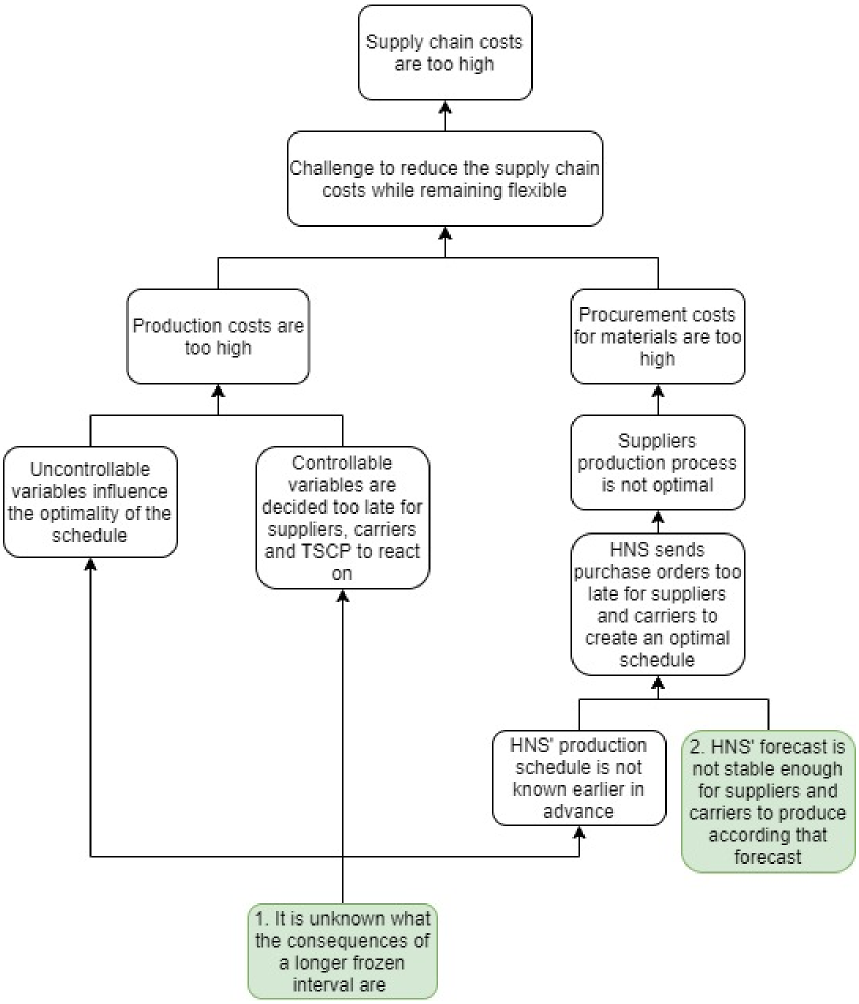

Figure 1.5 - Problem cluster

We choose the first core problem as the core problem that we solve during this research. The current COVID-19 pandemic forces HNS more than ever to focus on reducing costs. Besides that, there is a project from HEINEKEN Global that assumes that HNS has a frozen scheduling interval of two weeks, while for the current situation it holds that HNS has a frozen scheduling interval of one week. The second core problem might have other underlying causes, such as fluctuating customer demand forecast. At HNS, there are already several projects for improving the customer demand forecast and improving HNS demand forecast for the suppliers and carriers.

Sahin et al (2008) describe that the system dynamics theory is a theory which cautions against optimizing on individual supply chain member's performance without considering the impact on the whole supply chain. To prevent the system dynamics to happen, we observe for the whole HNS' supply chain what the consequences are when HNS increases the frozen scheduling interval. We formulate the following problem statement:

"It is unknown what the impact of a longer frozen interval is on the controllable and uncontrollable variables in production planning and scheduling of HNS and on the supply chain of HNS"

The above-mentioned problem statement results in the following research goal:

"The research goal is to identify the impact of an increased frozen interval on controllable and uncontrollable variables in production planning and scheduling of HNS and the consequences for the supply chain."

1.4 Scope

Section 1.1 mentions that HNS owns three breweries: Zoeterwoude, Den Bosch and Wijlre. This research is about the impact of an increased frozen scheduling interval on the planning and scheduling related activities within HNS. Since the brewery in Wijlre has its own planning and scheduling department with corresponding processes that are different than in 's-Hertogenbosch or Zoeterwoude, we leave Wijlre out of scope. The brewery in Wijlre mainly produces for the domestic customer. This results in the fact that Wijlre has other (more complex) beers, lower volumes and other processes regarding the planning. Another reason is that the TSCP department in Zoeterwoude plans productions for Zoeterwoude and Den Bosch, not for Wijlre.

1.5 Research Questions and Research Design

Given the problem statements and research goal, we formulate the main research question in Section 1.5.1. To answer the main research question, we define several sub-research questions in Section 1.5.2 and we explain how the research design looks like.

1.5.1 Research Question

Section 1.3 explains the need for information regarding the HNS' supply chain and formulates a research goal. To achieve the research goal, we define the following main research question:

> *"What is the impact of an increased frozen scheduling interval on the controllable and uncontrollable variables in production planning and scheduling of HNS and the consequences for the supply chain?"*

To answer this main research question, we require more in-depth knowledge. We formulate sub-research questions, which we answer in the coming chapters.

1.5.2 Research Design

Figure 1.6 visualizes the research approach.

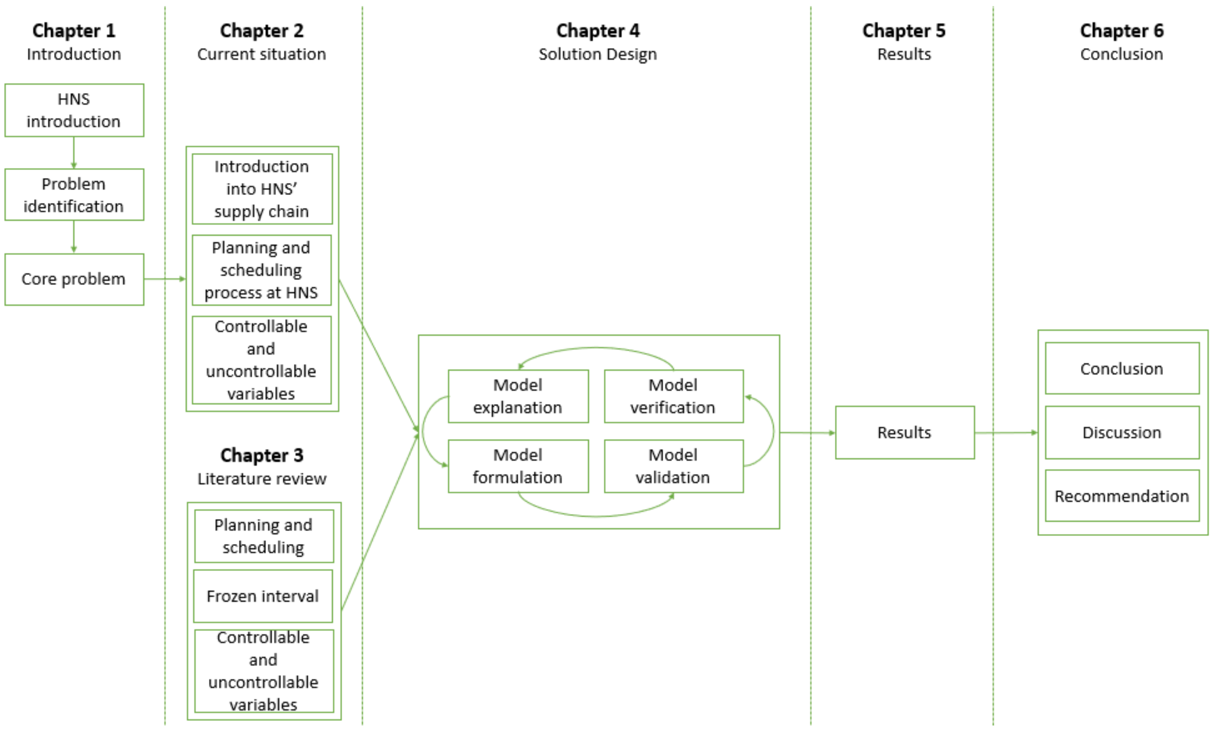

Figure 1.6 - Research approach

Chapter 1 Chapter 2introduces the research and Chapter 2 the current situation analysis. Chapter 3 provides a literature review corresponding supply chain planning and scheduling related to frozen interval. Chapter 4 combines Chapter 2 and Chapter 3 into a solution design. In Chapter 4, we choose controllable and uncontrollable variables so that we come up with a solution design to answer the main research question. Chapter 5 describes the results from the solution design and thereafter, Chapter 6 provides a conclusion, discussion and recommendations for HNS and further research.

Chapter 2 describes the current situation at HNS. By means of employee interviews, we discuss all processes related to supply chain planning and scheduling in more detail. The goal of this chapter is to give an overview of all variables in HNS' supply chain planning and scheduling so that we answer the main research question. Chapter 2 answers the following research question:

1. What variables play a role in supply chain planning at HNS?
    1.1. Which departments and parties are involved in HNS supply chain?
    1.2. How does the processes of planning and scheduling at HNS looks like?
    1.3. Which variables are considered while creating the production plan and schedule?

Chapter 3 provides a literature review. Literature review provides background for the reader. We consult online journals, papers, books and other scientific resources to give a complete overview of the already existing literature regarding planning, scheduling and frozen interval.

2. How is the frozen interval described in literature and its impact on production planning?
    2.1. What is described about supply chain planning and scheduling?
    2.2. What is the definition of a frozen interval?
    2.3. What variables would be affected by increasing the frozen scheduling interval?

Chapter 4 describes the solution design. The solution design combines the current situation and the literature review such that we are able to answer the main research question. We define per player in the HNS' supply chain different controllable or uncontrollable variables, so that we are able to identify per variable what the impact would be of an increased frozen scheduling interval.

3. How should the solution design look like?
    3.1. Which processes change within HNS with an increased frozen scheduling interval?
    3.2. Which controllable and uncontrollable variables do we select to come up with a solution design?
    3.3. How do we measure the impact of an increased frozen scheduling interval on the chosen controllable and uncontrollable variables?
    3.4. Is the model valid according to the chosen validation method?

Chapter 5 explains the results of the solution design described in Chapter 4. Chapter 5 gives an insight in the impact of an increased frozen interval on the supply chain planning process of HNS per player in the HNS' supply chain. Chapter 5 answers the following research question:

4. What is the impact of an increased frozen interval per variable?

The research ends with Chapter 6. This chapter contains the conclusion of this research, in which we answer the main research question. This research ends with a discussion about the assumptions and recommendations for further research.

Chapter 2 - Current Situation

This chapter explains the first research question: "*What variables play a role in supply chain planning at HNS?"*. The goal of this chapter is to analyze the current situation in more detail, which is the third phase of the MPSM. Section 2.1 explains the scope of the HNS' supply chain. Section 2.2 gives more in-depth knowledge about the planning and scheduling process. Section 2.3 highlights all the controllable and uncontrollable variables that TSCP and OS consider while creating a production plan and production schedule. Section 2.4 summarizes all findings.

2.1 HNS' Supply Chain

The goal of this research is to determine the impact of an increased frozen interval on controllable and uncontrollable variables in HNS supply chain. This section answers the first sub-research question: *"Which departments and parties are involved in the HNS' supply chain?"*. All players in the supply chain are stakeholders of this research. Figure 2.1 visualizes all steps from raw material to end product and all storage places throughout the supply chain. Starting from the supplier's side to customer's side at the end of the figure. The bold headings above the text below indicate a player in HNS' supply chain, which we use as main guideline throughout this research.

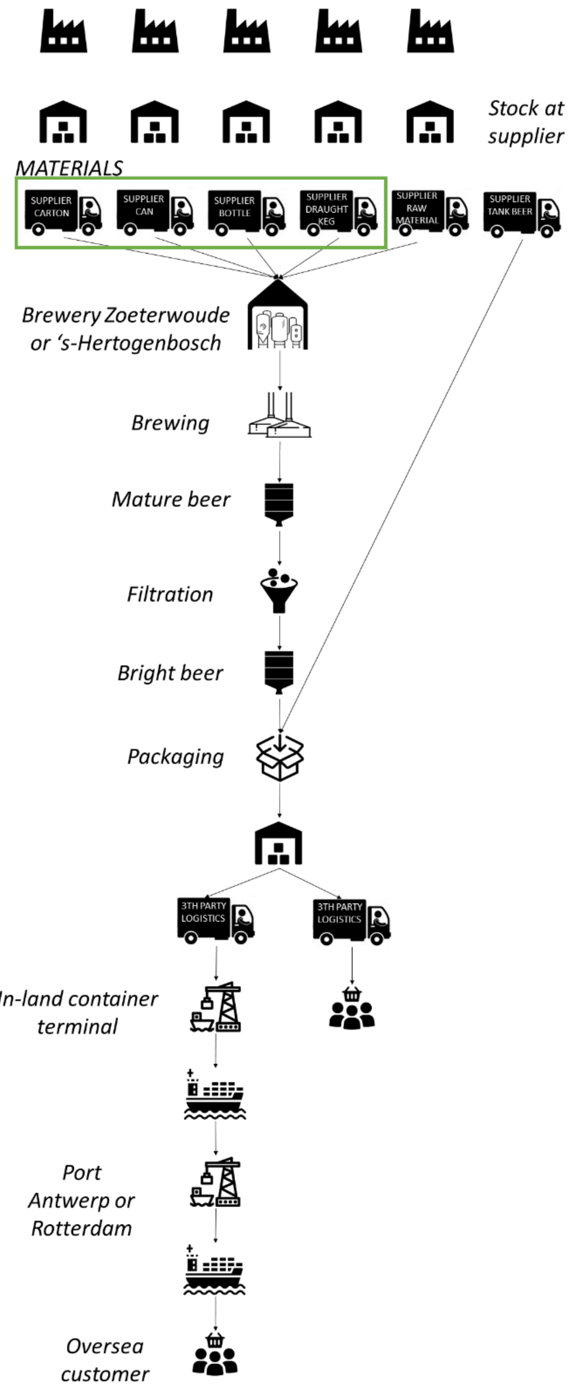

Figure 2.1 – All steps from raw material to beer

Suppliers

As the figure shows, the HNS' supply chain starts at the manufacturing side of the supplier. The HNS' department Contract Management is responsible for all contact and contracts with the suppliers. When there is a new supplier or a supplier is underperforming, it is Contract Management's responsibility to handle it. Contract Management divides the suppliers into five main categories, depending on pack type:

- Carton.
- Can.
- Bottle. The category bottles consist of two types of bottles: returnable and one-way bottles. Returnable bottles have a deposit so that customers return them to the supermarket. These bottles are mainly meant for the domestic market. One-way bottles are, in most cases, meant for export customers. These bottles are not returned to the brewery.

- Draught kegs.
- Raw Materials. Raw materials are materials needed for brewing, such as malt or hop. Raw materials are strategic products. That means that these materials are ordered only a few times a year.

The first four categories are merged for simplicity in Figure 2.1 into the category Materials. Besides the incoming materials into the brewery, there is another category: Tank Beer. Tank beer is not stored in the brewery but goes directly to the packaging process. Tank beer is liquid that is produced somewhere else and packed at HNS. An example of tank beer is Affligem Blond. This beer is brewed in another brewery, transported to Zoeterwoude, where it is packed into a packaging and shipped to customers all over the world.

The next step in the supply chain is the brewing and packaging process at HNS. Most of the materials (except for the raw materials) are ordered on a Just-In-Time (JIT) basis. JIT is the process of ordering the necessary units in the necessary quantities at the necessary time (Yasuhiro Monden, 2011). When the materials are not yet needed at the packaging process, HNS stores the delivered required materials in a warehouse.

Before beer can be packed into packaging, the beers need to be brewed. The brewing process undergoes several steps. It starts at the brewhouse, where raw materials are used to brew beer. Once those steps are finished, beer is stored in temporary tanks. This beer is called mature beer. Mature beer is beer that is finished in the brew house, but not ready for packaging. When the beer is needed for packaging, the beer first needs to be filtrated. After filtration, the beer is ready for packaging. All these steps need good planning and coordination. When all tanks are full of beer and another beer is needed at packaging, this might cause problems.

HNS Planning and Scheduling

The next step is packaging. This process needs good planning, scheduling and supervising. Several departments are responsible for the coordination of this process. First of all, the department SCD is responsible for the long-term planning. Secondly, TSCP is responsible for the medium-term planning and last the department OS is responsible for the production schedule, which is short-term. All these three departments are stakeholders of this research.

Carriers

After packing, the beers are ready for distribution. This is the responsibility of the department Customer Service (CS). This departments takes care of all the contracts and tenders for the transport goods (ships, barges and trucks). It depends on the customer if the beer is kept at stock or directly distributed to the customer. If the destination of the customer is within Europe, pallets are loaded into trucks. If the destination of the customer is overseas, beers are packed into containers, which are first transported from the HNS brewery (Zoeterwoude or ‘s-Hertogenbosch) with a barge to the Port of Rotterdam or the Port of Antwerp. From these two ports, the containers get loaded and shipped to the final destination of the customer. This is where the scope of HNS’ supply chain ends for this research: at customer’s side.

2.2 Supply Chain Planning and Scheduling Processes at HNS

This section answers the sub-research question: “*How does the processes of planning and scheduling at HNS looks like?”.*

First, we would like to make a remark on the writing style for the remainder of this research. The remainder of this research switches between different perspectives. To keep things clear, we refer to week X when reasoning from a customer’s perspective. We define *week X* as the week in which the products are going to be shipped. When reasoning from a HNS’ perspective, we refer to week Y. We define *week Y* as the week in which the planning process starts, so the current week.

Section 2.1 describes the layout of HNS’ supply chain and the perspective from the first four players in HNS’ supply chain. All these processes have to be managed so that every customer, the fifth player, receives the ordered products on time. The scope of this research is short-term planning. Therefore, the departments TSCP and OS are of interest. Section 1.2 briefly explained the processes at those departments. This section provides an insight in the sequence and more in-depth knowledge of the processes.

Figure 2.2 shows the basic steps from an HNS’ perspective in the process from customer demand forecast to shipment. It shows that the planning and scheduling process within HNS starts with the customer demand forecast. The customer demand forecast is sent weekly to HNS with a planning horizon of 16 weeks. The customer demand forecast describes for the MTO customers what they expect to order at HNS. The demand forecast describes for replenishment customers what the customer is expecting to sell to its customers.

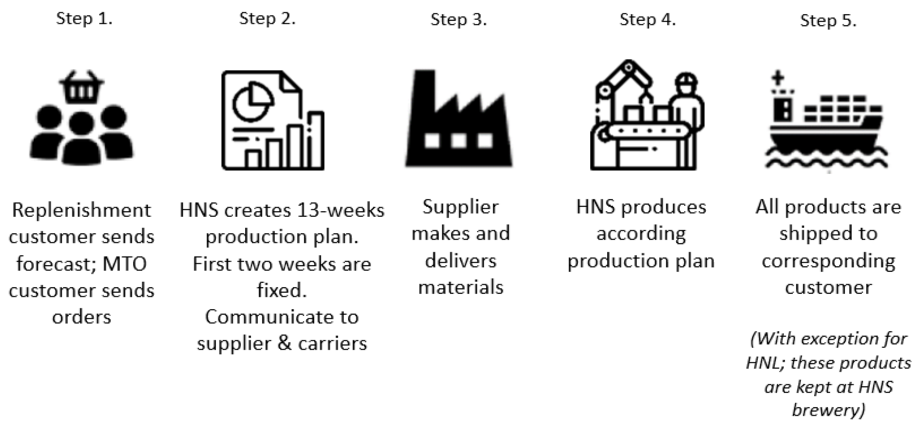

Figure 2.2 - Steps in HNS planning and scheduling process

It is important to mention that the planning and scheduling process deals with different type of ordering policies. HNS divides every customer into one of these three categories:

- **Make-To-Order (MTO)**. MTO is a strategy at which HNS starts producing when the customer sends a purchase order, so the trigger is an incoming order. HNS produces yearly around 18 million hectolitre beer, of which 30% of HNS’ total volume is meant for the MTO customers. The MTO customer sends every week a demand forecast with an horizon of 16 weeks, but HNS only starts producing when a final purchase order arrives. The MTO customer sends the forecast, such that HNS has an impression of what the customer is going to order. The MTO customer sends an order in week Y for products that at the latest will be shipped 4 weeks later, so in week Y+4. Figure 2.3 visualizes the timeframe for an MTO customer. *Demand lead time* is the length of time between the moment that an order is sent to HNS and that the order is shipped to the corresponding customer. This is the time it takes for HNS to schedule and produce the order. Thus, for the MTO customer is the demand lead time 4 weeks.

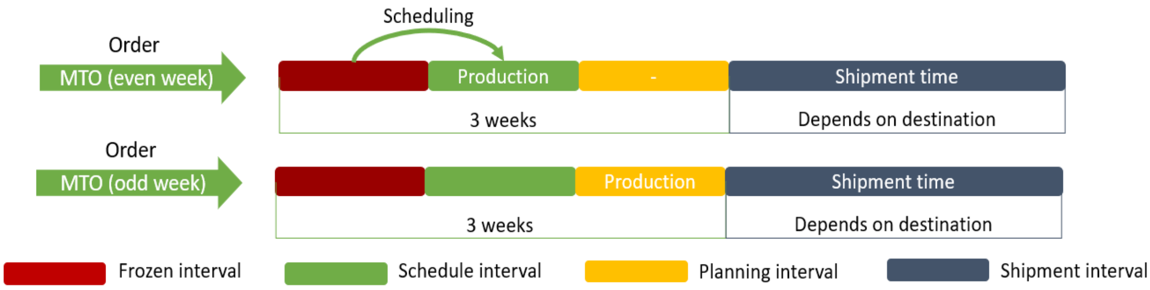

Figure 2.3 - Order process for MTO customers

Figure 2.3 shows that not all products are produced in the same week. Some beer types are only produced every two or four weeks, depending on the production cycle of that beer type. When TSCP creates a schedule in week Y for week Y+1 and they observe an order containing a beer type that should be produced in week Y+2 due to cyclicity of the product, TSCP plans that beer in week Y+2 instead of week Y+1. Since the customer does not know that certain products contain cyclicity, HNS communicates to the customer that HNS needs 3 weeks to plan, schedule and produce the beer. This gives HNS some flexibility in when to produce the beer and combine several customer orders. An example is SOL. This beer is only produced in the odd week numbers, because customer demand is too low and costs are too high to produce SOL every week.

- **Replenishment**. Replenishment is an order policy at which HNS produces according to a customer demand forecast and the target stock level. In total, 40% of HNS' total volume comes from the replenishment customers. The customer communicates an upper and lower bound for their stock level and a target stock level. HNS monitors the exact stock level and determines when the customer needs extra products based on customer demand. Based on those two variables, HNS creates a shipment plan per replenishment customer. A *shipment plan* describes how much to produce per beer per replenishment customer. Replenishment is applied to non-domestic customers. It holds for replenishment customers that the customer is owner of the finished goods from the moment of transport. Figure 2.4 shows the timeframe for the replenishment customers.

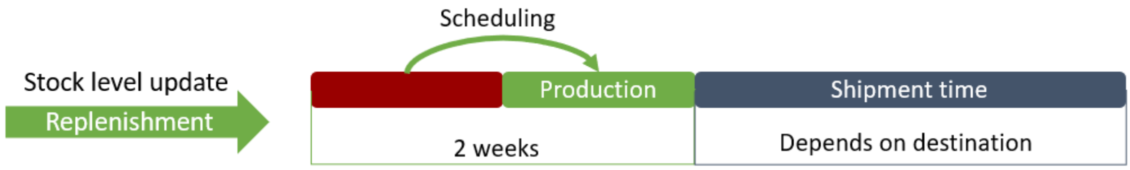

Figure 2.4 - Order process for replenishment customers

- **Make-To-Stock (MTS)**. MTS is a strategy at which HNS produces according a forecast. The remaining 30% of HNS' total volume is meant for the MTS customer. The MTS customer communicates the lower and upper bound for the stock level and HNS determines the exact height of stock, as long as it remains between the upper and lower bound. MTS is applied to the domestic customer, so only for HNC. The safety stock is HNS' property until it is received at customer's side. Therefore, the MTS stocks are kept at the breweries in Zoeterwoude or 's-Hertogenbosch until the beers are shipped to the customer of HNC. Figure 2.5 shows the timeframe for the MTS customer.

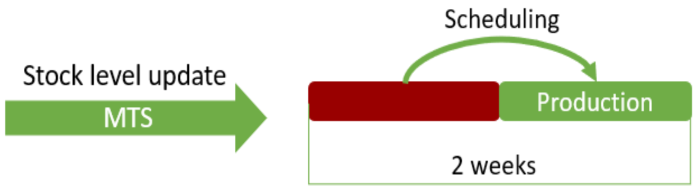

Figure 2.5 - Order process for MTS customers

All customers keep safety stock to prevent the customer against uncertainty during lead time. This is a method to prevent the customer from stockouts. HNS uses the ABC analysis to determine the safety stock levels per product for the replenishment and MTS customers. The safety stock levels of the MTO customers are the responsibility for the corresponding MTO customer and thus not of interest for HNS. The ABC analysis is an inventory categorization technique that assigns products to one of the three categories (A, B or C). The category defines the service level a customer receives. The higher the service level, the higher the safety stock, the lower the chance of a stock-out.

Based on ordered quantities from the MTO customers and shipment plans for the MTS and replenishment customers, TSCP creates a 13-weeks production plan. We explain this process from the HNS' perspective. This process starts at Monday of week Y. This 13-weeks production plan indicates per week the expected amount to produce and how this will affect line capacity. For example, if TSCP observes an increase in demand forecast in 5 weeks, they might decide to produce some of the beers in advance and increase the stock level for some replenishment customers to the upper bound, such that the line capacity is flatten. This method prevents HNS from having line availability issues.

Based on this 13-weeks production plan and the BOM, the material planner at TSCP creates a demand forecast for the suppliers. This demand forecast is updated and sent weekly to all suppliers, so that suppliers know what HNS might be ordering in the coming quartile. This gives the suppliers the opportunity to produce in advance and keep materials on stock if needed.

The first week of the 13-weeks production plan is frozen. The next week is used as input for the detailed production plan. This detailed production plan describes per beer per line the quantity that has to be produced somewhere in the week. The objective of the detailed production plan from the TSCP perspective is to maximize utilization of production lines so that every customer order is produced.

The process of creating a detailed production plan is one of the processes that is of interest for this research. Figure 2.6 summarizes the steps explained in the planning process that occurs on Monday of week Y.

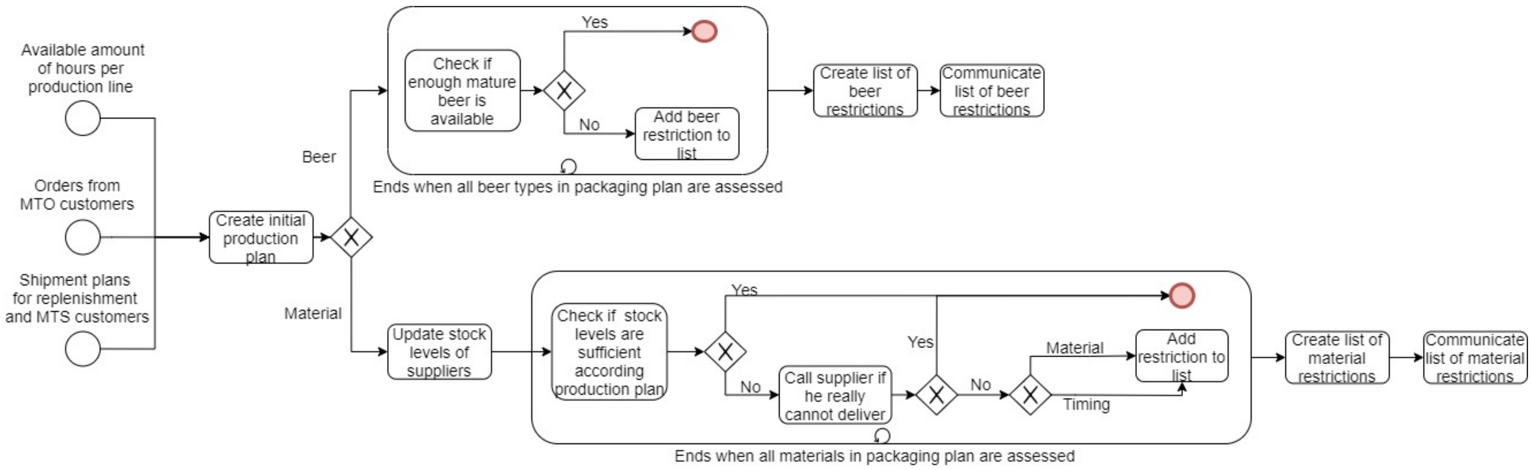

Figure 2.6 - Detailed planning process at TSCP - Monday

As Figure 2.6 shows, the planning process starts on Monday with two variables that cannot be controlled by the department TSCP. These two uncontrollable variables are used as input for the initial detailed production plan:

- *Available hours per production line.* Not every production line is completely available every week due to preventive maintenance or other events. Therefore, the planner receives weekly the updated version of the line availability to prevent infeasible production quantities. TSCP receives the available hours per production line from another department within HNS and therefore is this variable uncontrollable for the department TSCP. This is the reason why the available hours per production belongs to the category uncontrollable variables.
- *Orders from MTO customers.* These are the quantities per beer type that should be produced in the next week for the MTO customers. The TSCP department cannot control what the MTO customers order. Therefore, we consider the orders from the MTO customers as an uncontrollable variable.

The third variable is one that HNS can control and is therefore a controllable variable:

- *Shipment plans for MTS and replenishment customers.* Based on the forecast of the MTS and replenishment customers and the target stock level, HNS determines for every customer how much to produce from which beer type, which is the shipment plan. HNS determines if the stock level is above target, but below the maximum level or below target but above minimum level. This is because HNS determines how much they produce exactly for every beer type for every customer.

Based on the initial detailed production plan, the beer and material planners check if all required beers and materials are available for production. This detailed production plan and the BOM combined indicate how much per material is needed for production. The material planner checks on Monday of week Y if all the required materials are on stock at the suppliers or if the supplier is able to deliver the required materials on Monday of week Y+1. If that is not the case, the material planner calls the supplier to double check if the information is correct and tries to push the supplier to deliver the required materials on Monday of week Y+1.

If the supplier is not able to deliver the materials on time, it depends on the expected delivery date if the production order remains in the production plan. If the expected delivery date is later than Monday of week Y+1, this delivery date is called a material restriction. There are two types of material restrictions: material timing restriction and a material volume restriction. A *material timing restriction* is a when a supplier is not able to deliver the materials on Monday of week Y+1, but on another day later that week. A *material volume restriction* is when the supplier is not able to deliver the whole order in the required week. For example; 50% of the order arrives in week Y+1 and 50% of the order arrives in week Y+2. In most cases, when a material volume restriction arises, the product is moved to another week in which the complete order is available. TSCP documents all products with a volume or timing material restriction in an Excel file. This Excel file is used as input for the revision of the initial detailed production plan and for the production schedule.

The beer planner creates in week Y-1 a beer planning for which beers should be brewed in week Y. He determines which beers should be brewed in week Y, so that these can be used for production in week Y+1 or in later weeks if the beer requires a longer brewing time. Figure 2.7 visualizes this beer planning process.

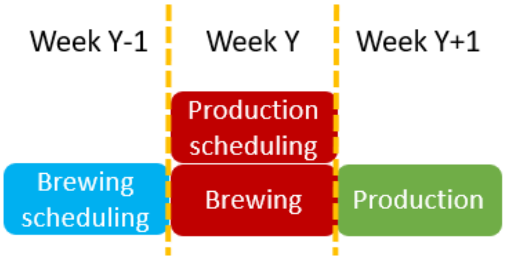

Figure 2.7 - Beer planning process

However, in the current situation are the actual MTO orders and shipment plans for the replenishment customers for week Y+1 not known yet in week Y-1. That means that the beer planner creates a beer planning based on forecasts of customers, which still can revise. Therefore, the beer planner checks for every beer in the production plan if the beer is available for production when needed. It might occur that the forecast change a lot and therefore it might occur that the needed beer is not available or not in the right quantity. If there is not enough beer available at the start of the week, that production order gets a beer restriction. These beer restrictions are also stored in an Excel file, so that it can be used for revision of the production plan.

On Tuesday, the planner determines per material or beer restriction if the product remains in the production plan with a restriction or whether the production run should move to the production plan of the next week. Figure 2.8 shows the planning process that occurs on Tuesday.

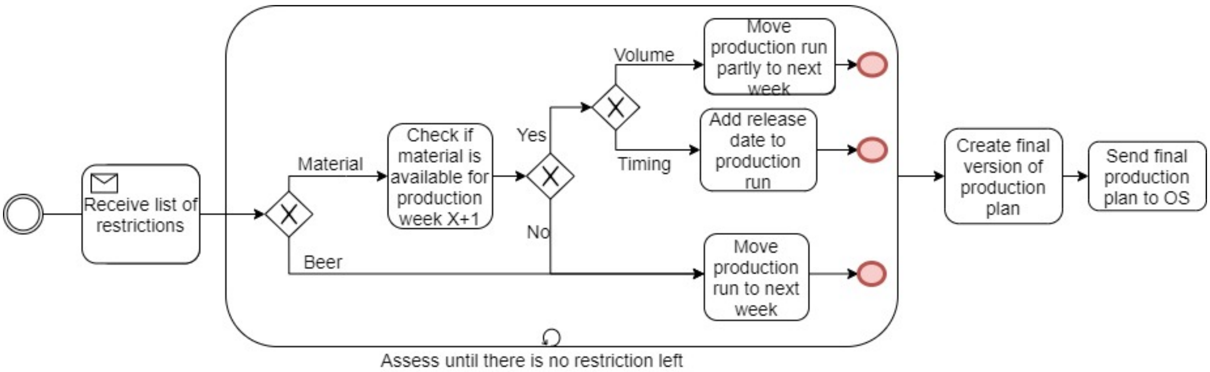

Figure 2.8 - Detailed planning process at TSCP – Tuesday

When there is no restrictions left to assess, the production plan for week Y+1 is finished and sent to OS at the end of the day. Figure 2.9 shows the scheduling process on Wednesday and Thursday at OS.

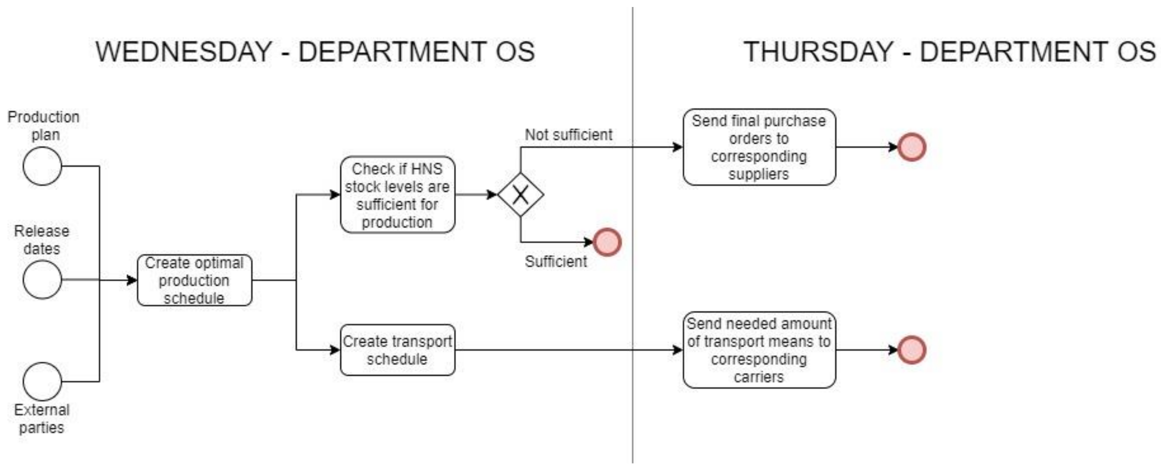

Figure 2.9 - Scheduling process

At Wednesday, the OS scheduler starts with creating a production schedule based on three uncontrollable input variables:

- *Production plan*. The production plan is the output of the planning process described above. This plan indicates per beer per line per week what quantity needs to be produced. This production plan cannot be changed by the department OS.
- *Material and beer release dates*. This separate Excel file indicates per product whether there is a material volume restriction, material timing restriction or beer restriction that should be taken into consideration while creating the production schedule.
- *External parties.* Some production runs require the expertise of an external party. The timing of the external party is known before the scheduler starts scheduling. Which has as consequence that the scheduler has to take into consideration that a certain production run must start when the external party arrives.

Based on these input variables, the OS scheduler creates an initial production schedule for week Y+1 in Advanced Scheduling (AS). AS is the tool that is used at HNS for scheduling. This tool creates a schedule, based on the predefined dispatching rules of HNS. The first dispatching rule is that the tool combines all beer types. After all beers are combined as much as possible, the tool combines all orders with the same pack type. The objective of the production schedule is to create a production schedule with as less changeover time as possible per line. Changeover time is the time it takes to change the line from one production run to the next production run.

In combination with the current HNS material stock levels, the material scheduler determines if there are enough products at stock at HNS for production, otherwise the purchase order is sent on Thursday to the suppliers. Based on the production schedule, the transport scheduler determines which truck or container is needed at which day in the week. The transport schedule is created and sent to all carriers. The transport schedule is just an estimation of when the transport goods are needed. The real timeslot at which HNS needs the transport good is confirmed only a few days before the transport good is really needed. This is the end of the planning and scheduling process.

2.3 Controllable and Uncontrollable Variables

This section answers the sub-research question: *"Which variables are considered while creating the production plan and schedule?"*

During planning and scheduling, the planner has to consider all variables that influence the feasibility or optimality of the production plan or schedule. Section 2.2 mentions several controllable and uncontrollable variables that are considered while creating the production plan or schedule. This section explains how these variables are applied or measured in the current situation. Section 2.3.1 introduces all controllable variables and Section 2.3.2 explains all uncontrollable variables which are considered during the planning and scheduling process.

2.3.1 Controllable Variables

A controllable variable is a variable that HNS can control. This subsection explains the seven controllable variables that we identify during the current situation analysis and how HNS applies or measures these variables.

HNS Planning horizon
The process of planning and scheduling starts with choosing a planning horizon. The planning horizon is the amount of time periods for which the production planner is planning ahead. The HNS planning horizon for the current situation is 13 weeks.

HNS Frozen interval
The second controllable variable is the frozen interval. The frozen interval is the part of the planning that cannot change anymore. In the current situation, the frozen interval is one week, since only the production schedule of the current week is frozen. The goal of this research is to determine the impact of an increased frozen scheduling interval.

HNS Shipment plans for the MTS and replenishment customers
The third controllable variable that we identify is the amount to produce for the MTS and replenishment customers, also known as the shipment plans. Based on the forecast that the customer sends and their current stock level, TSCP determines weekly how much to produce for each MTS and replenishment customer. With an increase frozen scheduling interval, we might expect that the process of determining the shipment plans does not change.

Safety stock levels for MTS and replenishment customers
The fourth variable which is used as input for production planning are the stock levels of the MTS and replenishment customers. The stock levels of the customers exists out of cycle stock and safety stock. Cycle stock is the amount of inventory that is planned to be used given a pre-defined period. Safety stock is the stock that prevents the customer from uncertainty during lead time. The MTO customers keep safety stock, but this is not HNS property. Therefore, HNS determines the optimal safety stock for their MTS and replenishment customers. HNS calculates the customer's safety stock levels with the help of a safety stock tool. This tool is developed at the HNS department SCD. This tool calculates the theoretical optimal safety stock level in high and low season per product for the MTS and replenishment customers. Equation 2.1 shows the formula that is used in the tool.

$$\text{Safety Stock} = z * \sqrt{(\text{Lead time} * \ \sigma_D^2 + \ \text{Demand}^2 * \sigma_{LT}^2} \tag{2.1}$$

The equation shows that five variables determine the safety stock level per product per season:

- *Z value*. Section 2.2 explains that HNS uses the ABC analysis to determine the safety stock level per product per customer. The desired service level is used as input for the normal distribution, such that the z value can be defined. The higher the service level, the higher the z value, the higher the safety stock, the lower the chance of a stock-out. If a product is assigned to category A, the product should at least have a service level of 99.6%, for a category B product a service level of 98% should be guaranteed and for a category C product is 95%. We assume that the z value does not change with an increased frozen scheduling interval. The current z value per product remains the same.
- *Lead time*. Lead time is the time between the customer sends the order and when the customer receives the ordered quantity. The lead time might increase with an increased frozen scheduling interval, because the current planning and scheduling process is as short as possible, so therefore, HNS might need one week extra to produce the required materials when increasing the frozen interval. This results in a longer lead time.
- *Demand variation* (σ_D^2). The demand deviation is the difference between the forecasted demand and the actual sales or orders. The demand variation might increase, since customers have to send their forecast over a longer period. Forecasting for a longer period ahead gives more uncertainty and thus might result in a higher demand variation.

- *Mean demand during the lead time period*. The demand is the quantity a customer needs to fulfill orders. An increased frozen scheduling interval does not influence the mean demand during the lead time period. The lead time period increases, but that does not result in a higher or lower mean demand.
- *Supply variation* (σ^2_{LT}). The supply deviation is the difference between the planned supply and the actual supply. The supply variation might increase due to an increased frozen interval, because customers have to order over a longer period, which results in a higher variation in the planning process at HNS. When customers have to order over a longer period, the uncertainty increases, which results in customers that forecast something different than they eventually order. That results in a higher difference between the planned supply and the actual supply.

Based on these input numbers, the tool determines for the MTS customer and for the replenishment customer HEINEKEN Germany (HGER) the optimal safety stock level given a pre-defined service level. The tool is developed for other replenishment customers as well, but these customers state that they determine the optimal safety stock level by themselves. HNS does not know the exact safety stock levels for those customers, but HNS knows the target stock level, which includes the safety stock. HNS strives to keep the stock level around the target level and ensures that the stock level is higher than the lower bound, but lower than the upper bound. The safety stock level of the MTS and replenishment customers is a controllable variable, since HNS influences the variables used as input for the formula in Equation 2.1.

Customer forecast update flexibility
The fifth controllable variable is the customer forecast update flexibility. This controllable variable is correlated to the uncontrollable variable forecast accuracy. *Customer forecast update flexibility* is the ability for the customer to change the order or forecast as late as possible. The customer wants high update flexibility, since this gives the customer the freedom to change the forecast or order without any consequences. However, for the other four players in the HNS' supply chain, this updating flexibility might be disadvantageous, because the earlier they know when to deliver, the higher the chances they are able to deliver the required materials. For the current situation it holds that the MTO customers have to send their final purchase order 4 weeks before shipment and for the replenishment customers it holds that they can adapt their forecasts up to 3 weeks plus shipment time. Lower forecast update flexibility might result in rush orders or cancellations. This might result in rush orders, because customers gain new insights during the frozen interval. When these insights might result in out-of-stocks, the customer places a rush order at HNS. For the current situation, it holds that rush orders rarely occur. Therefore, HNS does not track the number of rush orders, thus it is not known how often a rush order occurs.

Another possibility is that new insights result in a sudden decrease in demand forecast, the customer wishes to cancel the order, otherwise the customer would receive too much. Higher inventories result in high inventory holding costs. For the current situation, it holds that cancellations only happen with high exception. For the replenishment or MTS customers, it holds that when the customer ordered too much, the order still continues, but the shipment plans for the weeks thereafter will be adjusted downwards. HNS does not accept cancellations from the MTO customers. When the MTO customer ordered too much, the customer adapts their forecast for the weeks thereafter.

HNS Beer availability
The sixth controllable variable is the HNS beer availability. Beer availability is defined within HNS as how often a mature beer is on time for production. This includes the filtration process that the mature

beer has to undergo before the beer can be used for production. HNS beer availability is a controllable variable, since HNS schedules the whole brewing process: from start to filtration.

The beer availability is also divided into two categories: the availability of mature beer and the availability of bright beer. When the tactical beer planner creates a production plan for brewing beers, the orders and shipment plans are not fixed yet. Therefore, the brewing plan is based on forecast of customers. Due to demand fluctuations, availability of beer also fluctuates. When there is a sudden increase in a certain type of beer, it can occur that the beer is not brewed yet or that the right amount of beer is not available. This is the availability of mature beer. When this happens, the production run should be delayed to next week and the customer demand might not be met on time. The second availability type for beer is the availability of bright beer. When mature beer is brewed, it is stored in tanks. Before this beer can be packed, it needs to be filtrated. When a certain type of beer is needed in the week, it needs to be filtrated first. It can be that the mature beer is available, but there is a restriction on when filtration can take place. This results in an extra beer release date in the schedule.

HNS Production cycles

The last controllable variable that we identify during the current situation analysis are the production cycles. Section 2.2 explains that production cycles indicate with which cyclicity a beer is produced. Not every beer is produced weekly, since there is not enough demand. It is more cost-efficient to cluster beers with lower demand to one big production run every 2 or 4 weeks, than produce small batches every week. Every product has its own production cycle which is determined at the TSCP department. The production cycles do not change with an increased frozen scheduling interval, because the cyclicity is based on yearly product demand. The yearly product demand might not increase or decrease drastically that the production cycles should be changed due to an increase in frozen scheduling interval.

2.3.2 Uncontrollable Variables

An uncontrollable variable is a variable which HNS cannot change directly. This subsection explains the four uncontrollable variables which we identified during the current situation analysis.

Customer demand forecast

The first uncontrollable variable that we identify is the customer demand forecast. Every customer sends weekly their 16-weeks demand forecast to HNS. This demand forecast describes for the MTO customer what the MTO customer expects to order for the coming weeks at HNS. For the MTS and replenishment customers, it describes what the MTS or replenishment customer expects to sell to his customers. A reliable demand forecast is important for stability in the supply chain. Therefore, HNS stimulates all customers to send an accurate forecast and also measures how accurate their demand forecast was. HNS measures this with the uncontrollable variable forecast accuracy. *Forecast accuracy* is how accurate the customer predicts the actual sales or order. HNS measures the customer forecast accuracy at three different points in time.

The grey arrows in Figure 2.10 indicate from a customer’s perspective the points in time at which HNS measures the customer forecast accuracy.

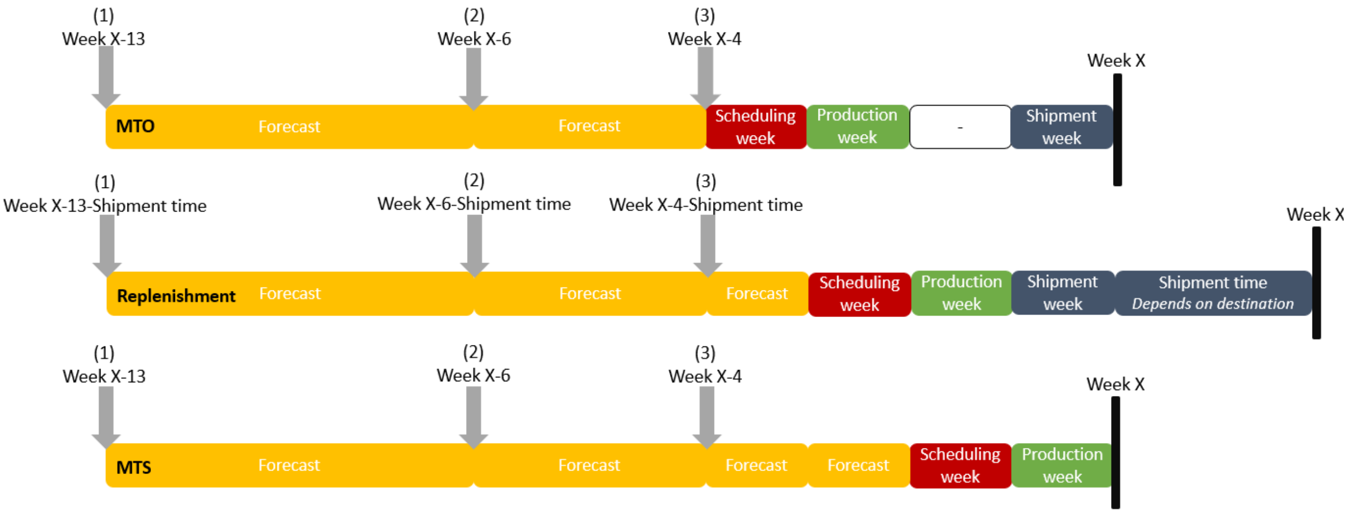

Figure 2.10 – Customer forecast accuracy measurement points

Figure 2.10 shows that for all the different order policies the measure points are the same, since the grey arrows are at the same place in the figure. However, the end of the horizon differs for the replenishment customer. HNS incorporates for the replenishment customer the shipment time in the forecast accuracy calculation, because HNS compares the forecasted quantity for week X with the actual sales of the replenishment customer in week X. HNS does not incorporate the shipment time for the MTO and MTS customers, because the MTS customer does not have shipment time and for the MTO customer compares HNS the difference between the forecasted quantity in week X and what the customer actually orders for shipment in week X.

The end of the horizon, the week in which the order should be shipped to the customer, is indicated with a black bar. This is week X. The first measurement from a customer's perspective is in week X-13. This is the furthest point in time in which HNS uses the customers demand forecast as input for their production planning.

The second point in time at which HNS measures the customer forecast accuracy is in week X-6. This point is close to the actual order point for MTO customers, which is X-4. To have a good impression of the actual order for an MTO customer, this is an important measure point. For replenishment customers, this point is three week away from the point that HNS is creating a shipment plan and for the MTS customer it is even four weeks away from the shipment plans.

The last measure point is arrow 3, in week X-4. For MTO customers, it is important to know what they forecast and what the actual order is. Replenishment customers still have one week to update their forecast. For MTO customers it occurs that the actual order is not the same as the forecasted quantity. This might be due to the fact that there is a human touch in the ordering process. A person might decide to just order a bit more or less due to unforeseen events in the near future.

Supplier Material availability

The second uncontrollable variable is the material availability. We define material availability as how often a material arrives on time for the production process. For every supplier, HNS has a supplier service level. Equation 2.2 shows the formula which HNS uses to determine the supplier service level.

$$SL(\%) = 1 - \left(\frac{\#\ material\ restrictions\ (timing+volume)}{Total\ \#\ planned\ materials}\right) \quad (2.2)$$

This formula shows that there are two main variables that influence the supplier service level: the number of material restrictions and the total number of planned materials. A material restriction is divided in two categories of restrictions: either volumes or timing. A material volume restriction is when the supplier is not able to deliver the required amount in one week. The timing material restriction is when the supplier is not able to deliver the required materials at the start of the week. For the timing restriction holds that the production of that beer type can only start after the supplier is able to deliver the required materials.

Carrier Transport availability
The third variable is the carrier transport availability. Transport availability is defined as the number of times the transport is at the right time available at the brewery. After production, the finished goods have to be transported to their next destination. The distribution of finished goods happens by means of transport modes. The main transport modes are trucks, container ships and barges. The goal of the transport schedule is to arrive all transport modes JIT. That means that the transport scheduler aligns the arrival of the transport mode with the end of production process, since it is too expensive and not efficient to keep finished goods at stock at the brewery. Therefore, the load schedule is optimized so that the finished goods can immediately be packed into a container or truck.

HNS changeover time per week per line
The fourth uncontrollable variable that we identify is the changeover time per line per week. Changeover time is the time it takes for HNS to change the line from a production order to the next production order. The objective of the production schedule is to minimize the total changeover time per line, because less changeover time results in more production time so higher output rates. Since HNS wants to minimize the changeover times during the week, HNS measures at three points the changeover time.

The first measure point is at the department TSCP. Based on the production plan, TSCP determines the planned changeover time. When OS receives the production plan, they create a production schedule in which OS considers all material, beer and transport restrictions. When the production schedule is finalized, OS calculates the scheduled changeover time. When the production schedule is executed, OS also measures the realised changeover time. The goal of measuring these different changeover times is to monitor what the impact is of different variables on the changeover time.

2.4 Conclusion on Current Situation

This chapter answers the research question: "*What variables play a role in supply chain planning and scheduling at HNS?"*

Section 2.1 starts with describing the scope of the HNS' supply chain for this research. We identify five players in the supply chain:

- **Suppliers**. The suppliers are categorized by the type of material they deliver to HNS.
- **HNS Planning**. The HNS planning department has the responsibility to create a 13-weeks production plan of which the first week is used to create a production plan for next week. They also manage the stock levels of customers, monitor stock levels of materials at supplier side and have the responsibility for the brewing and filtration planning.
- **HNS Scheduling**. The responsibility of the HNS scheduling department is to create a production schedule on an hourly level. This also includes the arrival of materials to the breweries, arrival and departure of finished goods and transport goods.
- **Carriers**. The carriers ship the finished goods to the customers in Europe or overseas.

- **Customers**. This is the start and end point of the HNS' supply chain. It starts with the customer forecasting and ordering products and it ends with the customer receiving the ordered quantity.

Section 2.2 elaborates more on the planning and scheduling process from the HNS' perspective. All customers are divided in one of the three order policies: MTO, MTS or replenishment. Based on all demand forecasts and orders that TSCP receives on Monday, a 13-weeks production plan is created. This production plan is translated into a material forecast and sent to all suppliers and carriers. The first week of this production plan is used as input for the production schedule. Based on the production plan, the OS scheduler creates an optimal schedule. On Thursday, the production schedule for next week is finished and cannot change anymore. All suppliers receive the final orders of HNS per material and all carriers know when the transport goods are needed.

The last section of this chapter, Section 2.3, describes all variables that play a role in creating the production plan and schedule. Table 2.1 summarizes all identified controllable and uncontrollable variables.

Controllable variables	Uncontrollable variables
HNS planning horizon	Customer demand forecast
HNS frozen interval	Supplier material availability
Customer safety stock levels	Carrier transport availability
Customer forecast update flexibility	HNS changeover time per line per week
Shipment plans for MTS and replenishment customers	
HNS production cycles	
HNS beer availability	

Table 2.1 - Controllable and uncontrollable variables at HNS

The planning horizon is the time horizon for which HNS creates a production plan. The frozen interval is the number of intervals in which the plan cannot change anymore. For the current situation it holds that the planning horizon is 13 weeks of which the first one is frozen, so a frozen interval of 1 week. The customer safety stock levels is the amount of finished goods that a customer keeps at stock to prevent against stock-outs during lead time. Customer forecast update flexibility is the ability for customer to change their forecast as late as possible. Shipment plans describe the amount that HNS needs to produce for the MTS and replenishment customers. The HNS production cycles indicate how often a certain type of beer is produced. Some beers are produced every week, others once every two weeks or even once every four weeks. The HNS beer availability is the percentage of how often a beer is available for production.

The customer demand forecast is the forecast the MTO, MTS and replenishment customers send weekly to HNS in which they forecast what they are going to order. Supplier material availability indicates the availability of materials for production. Carrier transport availability indicates how often the transport goods were on time at the brewery. HNS changeover time per line per week identifies the total minutes in the week the line stands still to change the line from a production order to the next one.

Chapter 3 – Literature Review

This chapter answers the research question: "*How is the frozen interval described in literature and its impact on production planning?"* Section 3.1 introduces production planning and scheduling. Section 3.2 provides a definition of frozen scheduling interval and several ways to freeze a portion of the production plan. Section 3.3 explains methods to measure how a frozen interval impacts the supply chain. This section ends with a summary in Section 3.4.

3.1 Introduction into Production Planning and Scheduling

This section answers the sub-research question: *"What is described about supply chain planning and scheduling?"*. We first answer this research question before diving into the literature of variables that will be affected by an increased frozen scheduling interval.

Coordinated planning and control of operations, i.e. production, storage and distribution processes, is a central element of Supply Chain Management (SCM) (Stadtler, 2005). Dudek & Stadtler (2007) describe that there are two ways to coordinate operations. One way is by centralized planning. Centralized coordination throughout the supply chain happens at medium-term level. Centralized planning requires access to all relevant information. It can fail because individual partners are involved in several supply chains. Therefore, a decentralized decision-making process is more often applied. This implies that every partner in the supply chain makes its own decisions based on the available information.

Nahmias & Olsen (2015) describe that the production function of a company can be seen as a hierarchical process. Figure 3.1 visualizes this hierarchical process.

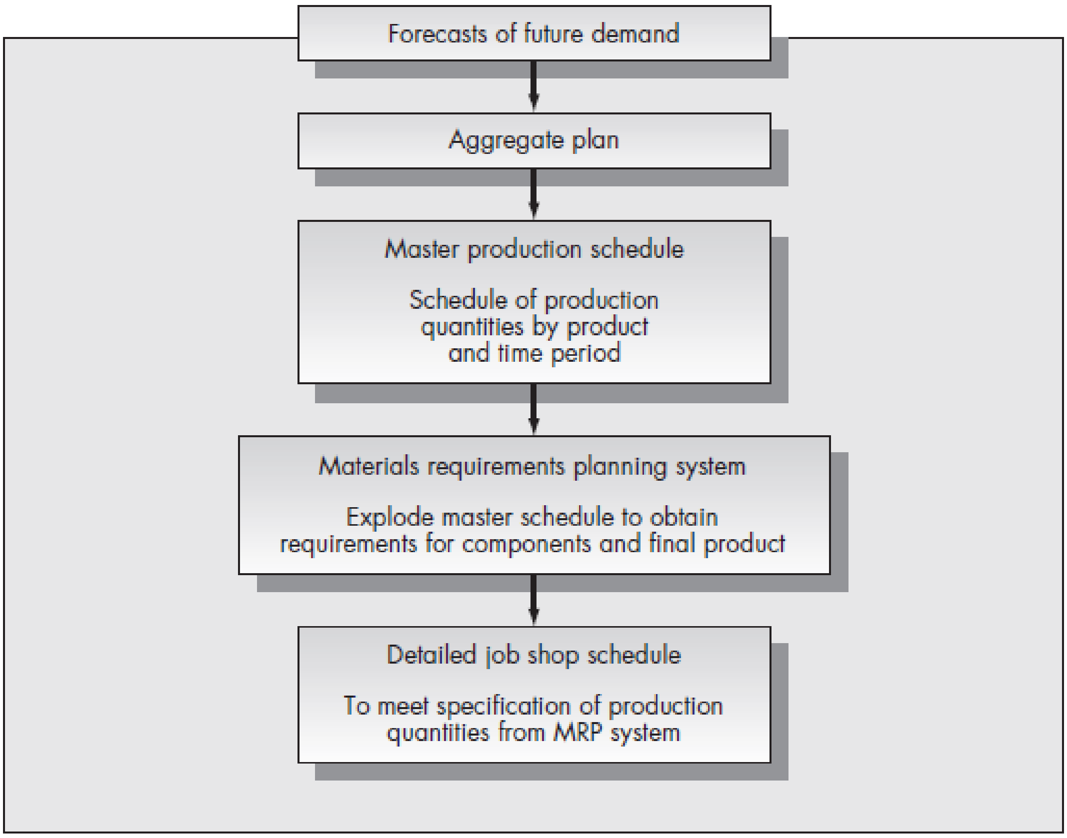

Figure 3.1 - Hierarchy of production decisions (Nahmias & Olsen, 2015)

Figure 3.1 shows that the production function starts with the forecasting of future demand for sales over some predetermined planning horizon. Anticipated customer demand is transmitted to the downstream manufacturers in a supply chain using different types of demand forecasts (Lian et al., 2006). These forecasts provide input for determining the sales and operation planning. Thomas & McClain (1993) describe that *production planning* is the process of determining a tentative plan for how much production will occur in the next several time periods, during an interval of time called the planning horizon. Kreipl & Pinedo (2009) state that the main objectives in medium-term planning involve inventory carrying costs, transportation costs, tardiness costs and the major setup costs. The tactical production plan must be translated into the MPS. The MPS results in specific production goals by product and time period. Tang & Grubbström (2002) describe that the MPS is essential in maintaining customer service levels and stabilizing production planning within an MRP environment. Usually, an MPS will face the pressure to re-plan because of the changes of operational circumstances. There are basically two conditions that result in re-planning: (1) a rolling effect due to extension of the planning period or (2) when demand is uncertain. There is always a forecast error and therefore the old plan has to be modified to adapt to new information to keep production cost low and maintain service level. A rolling horizon is to re-plan the MPS each period whenever information is updated. This tracks the development of demand closely but generates instability.

MRP is one method for meeting specific production goals of finished-goods inventory generated by the MPS. Baker (1993) describes three principal inputs for MRP: the MPS, BOM and the Inventory Status (INV). The result of the MRP analysis is specific planned order releases for final products, subassemblies and components.

Finally, the planned order releases must be translated into a set of tasks and the due dates associated with those tasks. This level of detailed planning results in the production schedule. *Production scheduling* is more detailed than a production plan, coupling individual products with individual productive resources, using smaller time units or even continuous time (Thomas & McClain, 1993). A production schedule fixes the total time required to do a piece of work with a given machine or which shows the time required to do each detailed operation of a given job with a given machine (Kiran, 2019). A short-term detailed schedule incorporates the jobs that have to be scheduled in such a way that one or more objectives are minimized (Kreipl & Pinedo, 2009). In real-time implementation of a production plan or schedule is often called *dispatching*.

We conclude that planning models differ from scheduling models in a number of ways. Planning models often cover multiple stages and optimize over a medium-term horizon, whereas scheduling models are usually designed for a single stage and optimize over a short-term horizon. Restrictions and variables from the medium-term are considered while creating the short-term schedule. Some of the variables can be controlled by the planning departments, other cannot. This research is about determining the impact of an increased frozen scheduling interval on the HNS' supply chain. Therefore, we first introduce in Section 3.2 the definition of a frozen interval. Thereafter, Section 3.3 introduces variables to determine the impact of an increased frozen scheduling interval.

3.2 Frozen Interval

This section answers the sub-research question: *"What is the definition of a frozen interval?"*

A rolling horizon forces the MPS to re-plan each period whenever new information is updated. This tracks the development of demand but generates instability. Herrera & Thomas (2009) define instability as the difference between production quantities scheduled by an MPS in a cycle. The yellow bar in Table 3.1 indicates instability. It shows that in a certain period, for example period 2, the customer sends the forecast for the periods 2, 3, 4 and 5. Instability is when the demand fluctuates among weeks, which we observe in Table 3.1, because the demand for week 2 is low, for week 3 is high and that pattern repeats.

Period	1	2	3	4	5	6	7	8
1	X	X	X	X				
2		15	98	34	86			
3			X	X	X	X		
4				X	X	X	X	
5					X	X	X	X

Table 3.1 - Example of MPS instability in a rolling horizon

Another consequence of re-planning is nervousness in the schedule. Herrera & Thomas (2009) define nervousness as the difference between quantities scheduled by the MPS in different cycles, for a period in the planning horizon. The green bar in Table 3.2 shows an example of nervousness. The table shows that the customer sends in period 2, 3, 4 and 5 a forecast for period 5. The Table 3.2 shows that the forecast send in the periods 2,3,4 and 5 for period 5 fluctuates a lot. These fluctuations are called nervousness.

Period	1	2	3	4	5	6	7	8
1	X	X	X	X				
2		X	X	X	86			
3			X	X	24	X		
4				X	101	X	X	
5					37	X	X	X

Table 3.2 - Example of MPS nervousness in a rolling horizon

The results of instability and nervousness are that the shop cannot carry out the MPS, with consequences as capacity utilization and customer service levels decrease, throughput times and costs of inventories increase (Gerald Heisig, 2002). Tang & Grubbström (2002) describe that one solution to avoid instability is to freeze a portion of the planning horizon to stabilize the schedule. Herrera & Thomas (2009) describe that frozen intervals consist in fixing periods in the planning horizon, in which, changes hoped for later reschedules are not allowed. The advantage of freezing a portion of the production plan is thus to decrease schedule instability. E. P. Robinson et al. (2008) describe that the disadvantage of longer frozen intervals is an increase in schedule costs.

J.H.Y Yeung et al (2010) describe two freezing methods. The freezing method indicates the approach for setting the duration of the frozen order schedule. A distinction is made between an order-based freezing method and a period-based freezing method. An order-based freezing method freezes the timing and quantity of the first pre-defined number of orders, while the remaining orders are termed liquid and subject to revision in the subsequent planning cycle. In the period-based freezing method, a n-period frozen time interval is established, where the orders within this time interval are frozen and all others are liquid.

Sahin et al. (2008) describe different re-planning frequency methods: period-based or order-based. In a period-based procedure, the re-planning time interval, r, is set to a specified number of time periods. Each successive re-planning iteration occurs after rolling r periods ahead and the lot sizes are updated for the next T-n+r time periods. For an order-based system re-planning occurs after the manufacturer executes a preset number of orders. While easier to implement and often applied in industry, period-based re-planning approaches consistently perform poorer than order-based approaches. This is because period-based methods ignore order cycle durations.

3.3 Controllable and Uncontrollable Variables

The goal of this section is to obtain a broader view on what is available in literature about controllable and uncontrollable variables in planning and scheduling that will be affected by an increase in frozen scheduling interval. This section answers the sub-research question: *"What variables would be affected by increasing the frozen scheduling interval?"* Section 2.3 outlines the controllable and uncontrollable variables from an HNS' planning department perspective. The goal of this section is to provide a possible approach for modelling our research problem. To find out how to model the variables, we approach the literature review also from an HNS' planning perspective to classify a variable in the category controllable or uncontrollable. We read papers that also consider the frozen interval as a controllable variable and see which variables they define to determine the impact of that controllable variable.

We split this section into two subsections. Section 3.3.1 describes how literature approaches the consequences of an increased frozen scheduling interval on the controllable variables. Section 3.3.2 highlights the uncontrollable variables and a possible approach for modelling.

3.3.1 Controllable Variables

Section 3.2 explains that an MPS needs to be revised, based on changes in customer demand or demand forecast. To avoid excess changes, management often chooses to implement a frozen interval. Before implementing a frozen interval, it is important to consider the right freezing parameters. Freezing parameters are first introduced by S. V. Sridharan et al. (1987) and were later on more often mentioned in literature as well (Nedaei & Mahlooji, 2014; E. P. Robinson et al., 2008; Sahin et al., 2008; Zhao & Lee, 1996). The major freezing parameters mentioned in literature are:

- *The planning horizon* (N) is the number of periods beyond the total production lead time for which the production schedules are developed in each planning cycle. In an MTO environment, the planning horizon is heavily influenced by how early in advance customers are willing to place their orders. S. V. Sridharan et al. (1987) found that the length of the planning horizon should be an integer multiple of the natural order cycle length. Baker (1977); Blackburn & Millen (1980); Carlson et al. (1982) also conclude that MRP systems perform better when the planning horizon is a multiple (K) of the natural order cycle.
- *The re-planning periodicity* (R) is the number of periods between re-planning. The greater the value of R, the less frequently the re-planning will occur, the less responsive the system will be to the demand changes, and the higher the risk of stock-outs.
- *Frozen interval* (FP) is the number of scheduled periods within the planning horizon for which the schedules are implemented according to the original plan. (S. V. Sridharan et al., 1988) addresses schedule instability, concluding that lengthening the frozen interval reduced schedule instability.

One of the earliest researches found was the research from Zhao & Lee (1993). They study the impact of the MPS freezing parameter upon the schedule instability and costs. Zhao & Lee describe nine independent variables, of which three are the MPS freezing parameters as mentioned in Section 3.3.1. The other six are described as the environmental factors. Environmental factors are factors that influence the MRP system performance and influence the selection of the MPS freezing parameters. These environmental factors are variables that are also applied at HNS. HNS determines the setting of these environmental factors. That is why we consider these environmental factors as controllable variables:

- Methods of freezing MPS. They apply the period-based and the order-based freezing method.
- MRP structure. This includes the fabrication process and the assembly process.
- Cost parameter. The echelon holding cost for the end item are fixed, but the production setup costs are varied. This is done to vary the natural order cycle length.
- Lot-sizing rule. Zhao & Lee use the Silver-Meal and the cost-modified Silver-Meal lot-sizing rules.
- Demand pattern. They generate demand using a normal distribution.
- Forecasting models to generate forecast demand for end-items.

Beutel & Minner (2012) describe that forecasting demand in undoubtedly one of the main challenges in supply chain management. Inaccuracy of forecasts results in overstocks and respective markdowns or the other way around, it can result in shortages and unsatisfied customers. To secure supply chain performance against forecast inaccuracy, an important countermeasure is safety stocks. The size of safety stocks required to obtain a certain customer service level depend on the degree of demand uncertainty and the corresponding forecast errors. V. Sridharan & Laforge (1994) show that an increased frozen scheduling interval does not result in a major loss in customer service but results in higher inventory.

Most literature researches into MRP system performances assume safety stock to be an uncontrollable variable. They assume that safety stock level change due to changes in freezing parameters. However, Bai et al. (2002) investigate how the level of end item safety stock impacts the system performance by setting it at two different levels: low and high. They consider safety stock level thus as a controllable variable. Their study shows that safety stock helps to reduce total costs by reducing total set-up cost and total change costs.

3.3.2 Uncontrollable Variables

We expect that both controllable variables and uncontrollable variables will be affected by an increased frozen scheduling interval. Literature introduces several uncontrollable variables to determine the performance of the system under various conditions. We look at papers that also use take the frozen interval as a controllable variable and see which uncontrollable variables they define to determine the impact of an increased frozen scheduling interval. The introduction of Section 3.3 mentions that we look at variables that are uncontrollable for the HNS' planning department.

Continuing on the research performed by Zhao & Lee (1993), they introduce three dependent variables to evaluate the performance of environmental factors on MRP systems: total costs, schedule instability or nervousness and service level. Service level is defined by Zhoa & Lee as the percentage of end item demand that are satisfied. Zhoa & Lee use the frozen interval as a controllable variable to evaluate the impact of the freezing parameters on the dependent variables. To study the impact, they design two simulations. The first generates demand forecast and simulates the forecasting process. The second simulation develops an MPS and MRP under a rolling horizon procedure and calculates performance measures. They test three hypothesis of which the last one is of interest for this research.

The hypothesis is: "*Forecasting errors significantly influence the selection of the planning horizon, freezing portion freezing method and re-planning periodicity.*" Zhao & Lee conclude that for a period-based freezing method, a higher freezing portion results in higher total costs. However, a higher freezing portion at the same time results in lower schedule instability. It holds for the service level that it declines with a higher freezing portion. Zhao & Lee (1996) encounter in their follow-up research that if demand is uncertain, a longer frozen interval often results in a higher cost and a lower service level, but the instability is reduced.

Sahin et al. (2008) also use the three major controllable freezing parameters planning horizon, re-planning periodicity and frozen interval to identify the main driver of MPS/AOC policy costs. AOC is an abbreviation for Advanced Order Commitment, whereby the manufacturer places purchase orders in advance of the vendor's minimum replenishment lead time to improve supply chain integration. To assess the impact of those freezing parameters on the MPS/AOC policy, they define the following three uncontrollable variables: schedule instability, cost error and integration opportunity costs. Schedule cost error is introduced by Sridharan et al (1987) as the percentage increase in the actual rolling schedule cost over a benchmark policy costs. The integration opportunity cost is specially added for the AOC research. Sahin et al (2008) utilize computer simulation for analysis instead of analytical models due to mathematical difficulties imposed by the rolling horizon. We do not consider AOC in this research and therefore left out of scope for the remainder of this research.

Sahin et al. (2008) involve multiple supply chain members in their study. They create a distinction between type 1 and type 2 instability to measure the instability for several supply chain members. Type 1 measures the number of rescheduled units as a percentage of the total demand over the experimental horizon. Type 2 measures changes in the timing of orders as a percentage of the total number of executed orders in a simulation run. Equations (3.1) and (3.2) show the different formulas for type 1 and 2 respectively.

$$Manufacturer's\ Type\ 1 = (MT1) = \left(\sum_{s=1}^{S} \sum_{i=Ms}^{Ms-1+KN-1} \frac{|Q_i^s - Q_i^{s-1}|}{D} \right) * 100 \qquad (3.1)$$

$$Manufacturer's\ Type\ 2 = (MT2) = \left(\sum_{s=1}^{S} \sum_{i=Ms}^{Ms-1+KN-1} \frac{|Y_i^s - Y_i^{s-1}|}{U} \right) * 100 \qquad (3.2)$$

For which i is the time period, M_s is the beginning of planning cycle s, S is the number of planning cycles in the simulation run, Q_i^s is the manufacturers order quantity in time i during planning cycle s, Y_i^s = 1 if the manufacturer schedules an order in period i during planning cycle s and 0 otherwise. D is the total demand over the simulation run and U is the number of orders the manufacturer executes over the simulation run.

Tang & Grubbström (2002) describe a similar approach. They define system nervousness as frequent changes in the MPS that results in schedule adjustments in the system. To calculate the schedule instability or nervousness, they apply Equation 3.3:

$$I = \frac{\sum_{i=1}^{n} \sum_{k>1} \sum_{t=M_k}^{M_k+N-1} |Q_{ti}^k - Q_{ti}^{k-1}|}{S} \qquad (3.3)$$

Where, i is the item index, n is the total number of items in the MRP structure, t is the time period, K is the planning cycle, Q_{ti}^k is the scheduled order quantity for item i in period t during planning cycle k, so Q_{ti}^{k-1} is the scheduled order quantity for item i in period t during planning cycle k-1. M_k is the beginning period of planning cycle k, N is the planning horizon length and S is the total number of orders in all planning cycles.

Bai et al. (2002) employ a simulation model in which they consider the frozen interval as a controllable variable. Their goal is to investigate how four environmental factors affect the MRP. The four controllable variables that Bai et al choose are the frozen interval, re-planning periodicity, safety stock level and lot-sizing rules. The safety stock level and lot-sizing rules are two new controllable variables that we did not consider so far. They choose three uncontrollable variables to see what the impact is of an increased frozen scheduling interval: schedule instability, total costs and service level. The total cost consists of three components: total set-up costs, total holding costs and total cost of changing the MPS. Bai et al include 64 experimental combinations in their simulation study. From their simulation study, they conclude that for system instability, results indicate that frozen interval, forecast accuracy and lead-time are the most significant system parameters. Their study proves that the interaction between the frozen interval and the forecast accuracy is weak. The frozen interval is more important in impacting the total cost than forecast accuracy. They also prove that an increased frozen scheduling interval results in lower total costs mainly due to a decrease in total change costs, which are costs that occur when the MPS has to change due to new demand information. The total inventory holding costs increase with an increased frozen scheduling interval.

Section 3.3.1 mentions that Nedaei & Mahlooji (2014) propose a framework to evaluate the interaction effect of the environmental factors and major freezing parameters. However, their research distinguishes from other researches based on the chosen uncontrollable variables. Nedaei & Mahlooji (2014) also consider the frozen scheduling interval as a controllable variable and use the following four uncontrollable variables for a full-factorial experimental analysis on the frozen scheduling interval:

- Manufacturer's natural order cycle length. The manufacturer's natural order cycle is the average number of periods covered by the economic order quantity (Zhao & Lee, 1993). The manufacturer's natural order cycle length can be calculated as follows $N = \sqrt{\frac{2*S}{H*D}}$, where S is the ordering cost, H is the unit holding cost per period, and D is the average demand per period (Sahin et al., 2008).
- Vendor order-size flexibility. This concept is introduced by Sahin et al. (2008). This variable indicates the vendor's relative efficiency in responding to the manufacturer's order on a lot-for-lot basis.
- Manufacturer's capacity tightness. The capacity tightness is the ratio between the total available capacity and the total demand.
- Smoothness utility coefficient. This variable is introduced in literature by Nedaei and Mahlooji. They define smoothness utility coefficient as the preference for the manufacturer in the multi-objective MPS to have more smoothed production volumes.

Nedaei & Mahlooji (2014) conclude that when the manufacturer deals with an inflexible vendor, considerable advantages are gained from extending the manufacturer's planning horizon and gathering a larger set of demand data in the MTO supply chain. Moreover, they conclude that while the vendor's instability decreases by lowering the frozen scheduling interval length, the manufacturer's schedule instability decreases with longer frozen time intervals.

Literature about supply chain planning differs from one echelon perspective to multiple echelons. The one echelon supply chain perspective is when the research considers just one echelon or unit. For example, what the impact of an increased frozen scheduling interval is only on the manufacturer. When research considers multiple echelons, they incorporate suppliers or customers in the research. Aisyati et al. (2017) summarize literature available about freezing parameters. They divide literature that describes one echelon level into literature that uses simulations or models to determine the freezing decision variables. In multiple echelon level, the model determines the optimal solution of freezing decision variables using mathematical models.

Ponsignon & Mönch (2014) introduce a simulation-based framework that allows for modeling the behavior of the customer demand and the production system. Figure 3.2 visualizes the framework introduced in their paper.

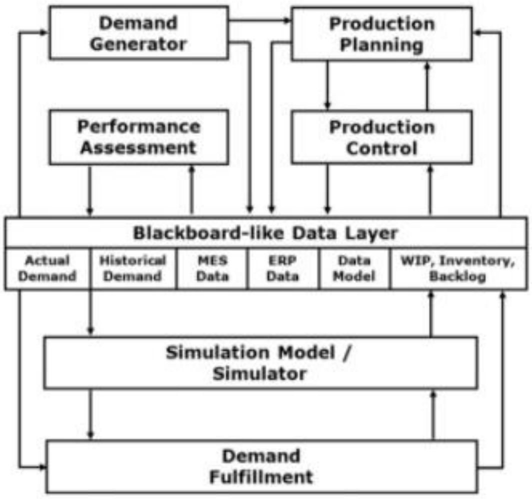

Figure 3.2 - Simulation-based framework introduced in (Ponsignon & Mönch, 2014)

The framework shows that the simulation is divided in several stages: demand generator, data layer and production. The idea of the simulation is that every stage is executed separately, just as in a decentralized supply chain. First, the model generates demand, that they use as input for the production planning module. This production planning module has an MP algorithm implemented. The outcome of this production planning module are requests for finished products that have to be due at the end of the period of the planning horizon. These are input for the next module: the production control module. This module transforms the production plan that is provided by the planning module into a lot release schedule. It also exclusively considers the due quantities for the period in the execution interval. To control the production in the base system, Ponsignon and Mönch use the Earliest Due Date (EDD) dispatching rule.

Holthaus & Rajendran (1997) describe that dispatching rules can be classified in a number of ways:

- Process-time based rules. These rules ignore the due-date information of jobs. The process-time based rules have been found to minimize the mean flowtime.
- Due-date based rules. These rules schedule the jobs based on their due-date information.
- Combination rules. Combination rules make use of both process-time and due-date information.

The scheduling module introduced in the model of Ponsignon and Mönch can also be simulated as a Job Shop Scheduling Problem. Schutten (1998) describes the classical job shop scheduling problem as a problem whereby a shop is given consisting of *m* machines $M_1, M_2, \dots, M_m$. On these machines, a set of *n* jobs $J_1, J_2, \dots, J_n$ needs to be scheduled. The objective is usually to find a schedule that minimizes the makespan, which is the total time to process all jobs. The minimum makespan problem of a job shop scheduling problem is a classical combinatorial optimization problem that has received considerable attention in the literature.

3.4 Conclusion on Literature Review

This chapter answers the research question: "*What can be found in literature about frozen scheduling interval and its impact on production planning?*"

Section 3.1 introduces planning and scheduling. Literature distinguishes between centralized and decentralized decision making. Since the HNS' supply chain is a decentralized one, we focus solely on the decentralized decision making supply chains in literature. Furthermore, Section 3.1 explains that production planning is the process of determining a tentative plan for how much to produce in the next several time periods. Production scheduling is more detailed than planning. It fixes the total time required to do a piece of work with a given machine.

Section 3.2 explains the idea of a frozen interval. An MPS feels the pressure to re-plan, because of changes in operation circumstances, which might result in instability. One way of preventing from instability is to freeze a portion of the MPS. Literature distinguishes between an order-based freezing method or period-based freezing method. Order-based freezing method is that the first J orders are fixed. When applying the period-based method, the first J periods are fixed.

Section 3.3 describes that literature about frozen scheduling interval always considers the freezing parameters planning horizon, re-planning periodicity and frozen scheduling interval as controllable. Literature defines several uncontrollable variables such that they determine the impact of those controllable variables on the uncontrollable variables. We classify a variable as controllable or uncontrollable when HNS is able to control the variable or not. Table 3.3 provides an overview of the variables found in literature.

Controllable variables	Uncontrollable variables
Planning horizon	Schedule instability
Re-planning periodicity	Different types of supply chain related costs
Frozen interval	Customer service level
Manufacturer's smoothness utility	Safety stocks
	Manufacturer's natural order cycle length
	Vendor order-size flexibility
	Manufacturer's capacity tightness

Table 3.3 - Controllable and uncontrollable variables found in literature

The planning horizon is the time horizon for which HNS creates a production plan. The re-planning periodicity is the interval between each planning cycle. The frozen interval is the interval in the planning that is frozen, it cannot change anymore. The manufacturer's smoothness utility is a controllable variable that defines the preference for the manufacturer in the multi-objective MPS to have more smoothed production volumes.

Schedule instability is the frequent changes in the MPS that result in schedule adjustments in the system. Several types of supply chain related costs are introduced in literature: inventory holding costs, MPS change costs or production set-up costs. Customer service level is the percentage of end item demand that are satisfied. Manufacturer's natural order cycle length is the average number of periods covered by the Economic Order Quantity (EOQ). Vendor order-size flexibility indicates the vendor's relative efficiency in responding to the manufacturer's order on a lot-for-lot basis. Manufacturer's capacity tightness is the ratio between the total available capacity and the total demand.

Chapter 4 – Solution Design

The goal of this research is to determine the impact of an increased frozen scheduling interval on the supply chain of HNS. We describe in Section 2.1 that the supply chain of HNS consists of five players. Chapter 3 describes controllable and uncontrollable variables that will be affected by an increased frozen scheduling interval. We combine in this chapter variables from literature and from the current situation analysis to come up with a solution design. This chapter answers the research question: "

Section 4.1 describes which processes change when implementing an increased frozen scheduling interval. Section 4.2 introduces for every player in the HNS' supply chain controllable or uncontrollable variables. Subsequently, Section 4.3 explains which variables we choose for the customer's perspective. Section 4.4 introduces the variables from an HNS Planning perspective. Section 4.5 describes the supplier side and Section 4.6 from carrier's side. In Section 4.7 introduces a Mixed Linear Integer Programming (MILP) model to assess the variables for HNS scheduling's perspective. We discuss in Section 4.8 the validity of the Mixed Integer Linear Programming (MILP) model. Section 4.9 summarizes this chapter.

4.1 Introduction

Section 2.1 explains that the scope of HNS' supply chain consists of five players: (1) customers, (2) HNS Planning department, (3) Suppliers, (4) Carriers and (5) HNS Scheduling department. Chapter 3 reviews the problem from a literature's perspective. This chapter combines both views on the problem and introduces a solution design to measure the impact of an increased frozen scheduling interval on controllable and uncontrollable variables. To do so, this section answers the sub-research question: *"Which processes change within HNS with an increased frozen scheduling interval?"*

First of all, literature distinguishes between a centralized and decentralized decision-making model throughout the supply chain. It holds for HNS, that every player in the supply chain optimizes its own schedule before passing it to the next player in the supply chain. Therefore, we choose the model to be a decentralized model. To structure the remainder of this research, the sequence of the five players are always mentioned from the HNS' planning perspective. First the customers, who send an order or forecast, then the HNS planning department, who sends the pre-purchase orders to the suppliers and carriers and thereafter the HNS scheduling department who creates a production schedule on an hourly level.

The first players in the supply chain are the MTO, MTS and replenishment customers. Based on their own market forecasts, MTO customers decide what to order at HNS and the MTS and replenishment customers decide what to forecast to HNS. These customer demand forecasts are weekly updated and shared with HNS.

The second player in the supply chain is the HNS' planning department. Every Monday, HNS receives all the forecasted and ordered quantities from every customer. From these quantities, TSCP creates a 13-weeks production plan. From the first week of this 13-weeks production plan, TSCP creates a detailed production plan, given all controllable and uncontrollable variables. Both the 13-weeks production plan and the detailed production plan are translated into a 13-weeks and short-term material forecast for suppliers and a transport plan for carriers.

The third player in the scope of HNS' supply chain are the suppliers. All suppliers receive weekly a 13-weeks material forecast. On Monday of week Y, all suppliers receive an identification of what HNS is going to order for week Y+1. HNS expects from their suppliers that they are able to deliver the required materials on Monday in week Y+1. Based on this detailed information, the supplier checks he is able to deliver the required materials on Monday in week Y+1. If the supplier is able to deliver on Monday, the supplier sends a confirmation. If the supplier is not able to deliver the required materials on Monday of week Y+1, but on another day, the supplier sends the expected delivery date.

The fourth player in the HNS' supply chain are the carriers. When the detailed production schedule is finished, the OS scheduler communicates the expected amount of transport goods per day to the corresponding carrier. HNS aligns with the carrier just a few days before the actual transport goods are needed the exact time of arrival at the brewery for the transport goods.

The last player in the supply chain is the scheduling department at HNS. Every Tuesday, OS receives the production quantities for the week thereafter. From the production plan, OS creates an hourly production schedule on Wednesday in which they determine when to produce which order per line. They also arrange that the materials for production and transport goods are at the brewery when needed.

Chapter 2 elaborately explains the current way of working. The current way of working is established in a day-to-day scheme. On Monday all orders are gathered and an initial production plan is created. On Tuesday the material planner revises the production plan and communicates the production plan to the schedulers. On Wednesday an initial production schedule is created and last checks regarding materials, beer and transport availability are done. On Thursday the production schedule for the next week is frozen and suppliers receive the final purchase order. When increasing the frozen scheduling interval, we speake of increasing the frozen scheduling interval in week buckets. In the current situation, when creating a production plan, the MTO orders are known. When we increase the frozen scheduling interval with one day, the initial production plan should be created on Friday. Which means that all customers should send their forecast or orders on Thursday evening. This means that the customers send their forecasts half a week earlier, while the frozen scheduling interval increases with just one day. More advantages are expected with increasing the frozen scheduling interval with one week. Therefore, we refer to week buckets when referring to an increased frozen scheduling interval, instead of days.

From literature, we learn in Section 3.2 that there are two ways to freeze a portion of the planning: order-based or period-based. When we decide to apply the order-based freezing method, we freeze the timing and quantity of the first J orders, for which HNS can determine how many orders. In the period-based freezing method, we freeze a pre-defined number of periods. Many studies proved that the order-based method outperforms the period-based method. HNS applies in the current situation the period-based freezing method, since HNS freezes one week. Therefore, to stay as close to the current situation, we choose to apply the period-based freezing and increase the frozen scheduling interval with one week. This research is to determine the impact of an increased frozen scheduling interval, instead of completely changing HNS' way of working. Figure 4.1 visualizes a summary of the current situation and shows the difference with the researched situation from a HNS' perspective.

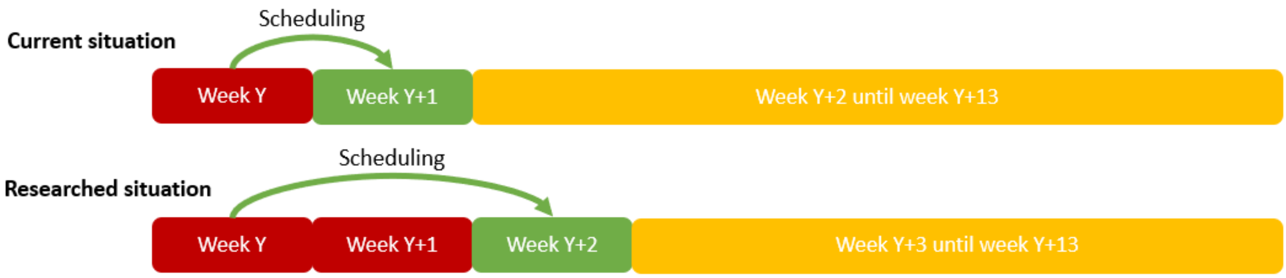

Figure 4.1 - Current and researched situation

Figure 4.1 shows that the main difference between the current and the researched situation is that an extra red block is added. That extra red block indicates the increased frozen scheduling interval. In the current situation, TSCP creates in week Y a production plan for week Y+1 until week Y+13. From this production plan, the current week Y, is frozen and they create a detailed production plan for week Y+1. TSCP communicates this detailed production plan to OS, who create an hourly production schedule for week Y+1 given all controllable and uncontrollable variables.

For the researched situation, we assume that the scheduling interval increases with one week. That indicates that TSCP creates a production plan for the weeks Y+2 until Y+13, since the production quantities for week Y+1 are already scheduled in week Y-1. From this 13-weeks production plan, TSCP creates a detailed production plan for the first not frozen week, which is week Y+2. TSCP determines for this week how much to produce for which customer and passes this plan onto OS. OS creates a production schedule for week Y+2, since week Y+1 is already determined. From now on, we refer to current situation as the situation with one week frozen scheduling interval and we refer to researched situation for the situation with two weeks frozen scheduling interval.

4.2 Solution Design

This section combines all controllable and uncontrollable variables found during the current situation analysis and the literature review. Subsection 4.2.1 highlights all the variables from the current situation and from literature. We choose the variables to determine the impact of an increased frozen scheduling interval. Subsection 4.2.2 presents per player in the supply chain which controllable or uncontrollable variable we apply to determine the impact of an increased frozen scheduling interval.

4.2.1 Choice of Variables from Literature and Current Situation

This subsection answers the sub-research question: *"Which controllable and uncontrollable variables do we select to come up with a solution design?"*. The list combines all controllable variables that we observe during the creation of the production plan and schedule or that we observe in literature:

- Planning horizon. The number of periods the department TSCP plans ahead.
- Frozen interval. The number of periods in the planning horizon in which nothing can change.
- Customer safety stock levels. Safety stocks cover customers from uncertainty during lead time.
- Forecast update flexibility. The ability for customers to update their forecast as late as possible.
- Shipment plans for MTS and replenishment customer. The amount HNS determine to produce for the MTS and replenishment customers.
- Production cycles. Indicates the frequency of production per beer type: if a beer is produced weekly or every two or four weeks.
- Re-planning periodicity. The number of periods between re-planning.

We do not consider the variables production cycles and re-planning periodicity in the remainder of this research. The production cycles are not correlated with the frozen interval. Therefore, we conclude that implementing an increased frozen scheduling interval of one week does not change the production cycles. We do not consider the re-planning periodicity in this research. Since we increase the frozen scheduling interval with one week, the number of re-planning periods will also increase with one week. The re-planning periodicity does not affect other variables that are of interest for this research. Therefore, we leave the re-planning periodicity out of scope. We consider the other for the remainder of this research.

During the current situation analysis at HNS and literature review, we observe the following uncontrollable variables:

- Customer demand forecast. The forecast that a customer sends to HNS.
- Supplier material availability. The material availability indicates how often a material is on time at the brewery.
- HNS Beer availability. The number of times bright beer is available when the production starts.
- Carrier transport availability. Transport availability is the amount of times transport goods are on time at the brewery.
- Changeover time per line per week. The changeover time indicates the total minutes per line it takes to change the line from a production run to the next production run.
- Schedule instability. Schedule instability is that the production schedule changes every time due to the fact that new insights arise and those new insight result in rescheduling.
- Supply chain related costs. These supply chain related costs might variate between inventory costs, purchase costs or production costs.
- Customer service level. This is the percentage of end item demand that is satisfied.
- Manufacturer's natural order cycle length. The manufacturer's natural order cycle is the average number of periods covered by the economic order quantity
- Vendor order-size flexibility. It represents how efficient a vendor reacts on customer demand from the manufacturer.
- Manufacturer's capacity tightness. The capacity tightness is the ratio between the total available capacity and the total demand.
- Manufacturer's smoothness utility. This is the preference for the manufacturer in the multi-objective MPS to have more smoothed production volumes.

The uncontrollable variables that we do not consider for the remainder of this research are the manufacturer's smoothness utility and the capacity tightness. The manufacturer's smoothness utility is a variables that is used in a joint-multi objective functions and is not of interest for this research. Not all data is available to measure the capacity tightness.

We combine in Subsection 4.2.2. the chosen controllable and uncontrollable variables into one solution design.

4.2.2 Application of the Chosen Variables

This subsection answers the sub-research question: "*How do we measure the impact of an increased frozen scheduling interval on the chosen variables?'*. Ponsignon and Mönch (2014) introduce a framework that allows for modelling the behavior of the customer demand and the production system. In their framework, all players in the supply chain are connected. We choose their idea of several stages, influencing each other as the basis of this research's solution design. Ponsignon and Mönch determine the performance of an increased frozen scheduling interval on master plans based on six performance measures. Other papers design a simulation to determine the optimal setting for the frozen interval length. HNS wants to know what the impact is on the HNS' supply chain when HNS increase the frozen scheduling interval instead of researching the ideal frozen interval. Therefore, we do not use the simulations used in those papers but the variables that they came up with to measure the impact of an increased frozen scheduling interval. An increased frozen scheduling interval at HNS mainly influences the short-term planning, the scheduling process. We do not use all performance measures from the paper, but a combination between literature and the measures which are currently important at HNS.

As Section 4.1 explains, the HNS supply chain is a decentralized one: every player in the supply chain optimizes its own schedule. Therefore, we split the several players and determine per player in the supply chain the impact of an increased frozen scheduling horizon. We also split the solution design due to complexity and the interest of HNS. HNS is interested in where they would benefit or experience disadvantages from increasing the frozen scheduling interval. Three layers are needed, because the model should represent the customers, HNS planning & HNS Scheduling departments (also considered as the manufacturer) and as third player the suppliers and carriers. We did not find a three-layer supply chain model in literature. When modelling all parts, the whole problem would become complex. Therefore, we decide to determine the impact of an increased frozen scheduling interval separately on every player or variable.

We determine the impact on the controllable and uncontrollable variables, based on historical data of the year 2019. We choose historical data instead of simulated values, because all historical data that we need is available at HNS. Another reason for choosing historical data, is because it might be insightful to know for HNS how certain things, such as the production schedule, would have looked like with an increased frozen scheduling interval.

We choose the historical data from year 2019 as input, instead of year 2020 for two reasons. The first reason is because 2020 is not over yet. This has as consequence that we cannot model a whole year. Modelling a whole year has as advantage that we consider seasonality, so that we observe the reactions of suppliers in high and low season. The second reason for choosing historical data from the year 2019 is the COVID-19 pandemic in the year 2020. The COVID-19 pandemic started in December 2019 in China. In February 2020 COVID-19 started to spread through the Netherlands and in March 2020, the Netherlands got in an intellectual lockdown. From the beginning of February 2020, HNS observed trouble from the COVID-19 in China throughout the HNS' supply chain and after March 2020 more problems arose. Not all containers and ships were returned to Europe, due to the chance of contaminating other people in the world. This caused many restrictions in the production schedule, which are not representative to the past few years. Customers constantly changed their forecasts, due to the fact that restaurants and bars had to close. It is a time in which nothing is certain and everything changes every week. Therefore, the year 2020 is hopefully not a representative year.

We choose two performance measures for the customers: service level and forecast accuracy. Figure 4.2 shows the solution design for the customers.

Figure 4.2 - Solution Design (Customers)

Based on the current situation and variables found in literature, we assess the impact of an increased frozen scheduling interval on the customer service level and forecast accuracy as Figure 4.2 shows. We explain the choice and the exact method of measuring below:

- **Customer forecast accuracy**. Forecast accuracy is the degree of closeness of the statement of quantity to that quantity's actual value (Vermorel, 2013). We measure the impact on the forecast accuracy based on the following two variables:
    - *Forecast update flexibility.* Section 2.3 explains that forecast update flexibility is the ability for customers to adapt their forecast as late as possible. However, when we increase the frozen scheduling interval with one week and we keep all processes the same, customers have to send their orders one week earlier so that the production plan is based on actual orders. However, we want to know how this will influence the customer's forecast update flexibility. Therefore, we measure the quantity with which the customer lowers or upgrades their demand forecast in the last week before the actual order deadline.
    - *Number of rush orders or cancellations*. Section 2.3 explains that a rush order occurs when a customer orders products after the original deadline passed. The customer is in real need for the products, HNS is able to produce the required materials on time, thus HNS accepts the rush order. The costs for a rush order are equal to a not-rush order, since this process rarely occurs. When we increase the frozen scheduling interval and the customer has to order one week earlier, it might occur more often that a customer is in real need of products on a short notice but the original order deadline already passed. Section 2.3 also explained that for the current situation, it holds that HNS only accepts cancellations with high exception. When the customer observes lower sales than expected, in most cases, the customer lowers the forecasts for the weeks in which the customer still can adapt the forecast.
- **Customer service level**. From literature we learn that customer service level is defined as the percentage of end item demand that are satisfied. To measure the impact on service level, we use the following controllable variable:
    - *Customer safety stock levels*. A customer keeps safety stock to prevent against stock outs. Stock also prevents customer against uncertainty during lead time. When we increase the frozen scheduling interval, the lead time also increases. Therefore, we want to know what the impact is of one week extra lead time on the stock levels of the MTS and replenishment customers.

Figure 4.3 visualizes the solution design for the other three players. We determine the performance measures for the HNS Planning, supplier and carrier part separately from other modules. However, to determine the impact on the HNS scheduling part, we need the input from other modules. This is the reason for combining the parts in Figure 4.3.

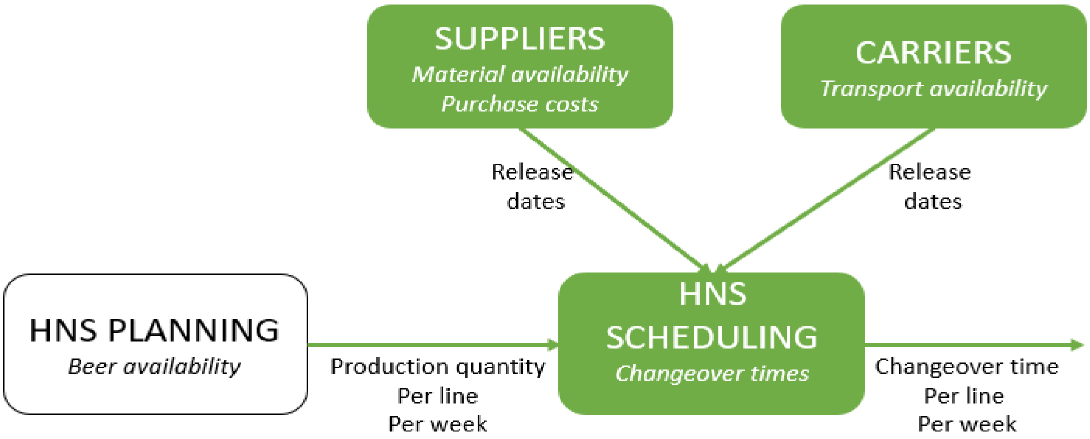

Figure 4.3 - Solution Design (HNS Planning, HNS Scheduling and Carriers & Suppliers)

Figure 4.3 shows the performance measures per player. Below we explain the chosen variables:

- **HNS beer availability**. Beer availability is not a controllable variable that TSCP measures. However, for this research we define *beer availability* as the number of times bright beer is available when the production starts. Since it is not a measurable variable at TSCP, we will not quantify the impact. However, we expect an impact on the beer availability and therefore we determine the impact qualitatively.
- **Carrier transport availability**. Transport availability is the amount of times transport goods are on time at the brewery. When the carrier receives the moment of delivery earlier, it might be the case that carriers plan their processes more efficiently, which result in higher transport availability.
- **Supplier material availability**. We define material availability as how often a material is on time at the brewery for the production process. We measure the supplier material availability with the help of the uncontrollable variable number of material restrictions.
  - *Number of material restrictions*. Section 2.3 explains that we express the material as a service level per supplier. HNS measures this as the number of material restrictions divided by the total planned materials. Material restrictions are the number of times the supplier is not able to deliver the requested materials on time. Therefore, we measure the material availability in number of restrictions. When increasing the frozen scheduling interval, we expect to have a smaller number of material restrictions, since suppliers have more time to produce the required materials.
- **HNS changeover time per week per line**. The changeover time per week per line is an important measure that is currently used at HNS.
  - *Minutes changeover time per line per week.* We expect that with an increase in frozen scheduling interval, the OS scheduler is able to create a production schedule with less changeover time. Less changeover time is favorable for HNS, since less changeover time results in more available production time. For some of the lines HNS experiences under capacity, which has as consequence that HNS has to outsource some of the production, which is more expensive than producing at the HNS brewery.

- **Supplier purchase costs**. The purchase cost is the total price that HNS pays to all suppliers for the incoming materials. In literature we observe that costs are a main variable to determine the impact of an increased frozen scheduling interval.
  - *Lower or higher purchase costs for materials.* We expect that with an increased frozen scheduling interval, the supplier retrieves the final purchase order one week earlier and that enables the supplier to produce more efficiently. When the supplier is able to produce more efficiently, the supplier saves costs. The supplier might process these savings in the purchase costs that HNS pays to the supplier.

Section 4.3 explains the exact method for measuring the impact on of an increased frozen scheduling interval on the performance measures from a customer's perspective. Section 4.4 explains the HNS planning variables, whereas Section 4.5 explains the supplier side and Section 4.6 the carrier side. We finish the explanations of the different variables in Section 4.6 with the HNS scheduling department.

4.3 Customers

The customers are the first players in the supply chain for whom we determine the impact of an increased frozen scheduling interval. The customer demand is the quantity that a customer orders or forecasts for a predefined time interval. From the customer's perspective is forecasting a process full of uncertainty. Is the right amount ordered at HNS? Are the customers of the customer still ordering what they expected to? Is the safety stock sufficient or should it increase?

From literature, (Beutel & Minner, 2012), we learn that inaccurate forecasts result in overstocks or shortages. To secure supply chain performance against forecast inaccuracy, safety stocks are needed. The level of safety stocks required to obtain a customer service level depends on the degree of demand uncertainty and the corresponding forecast errors. An improvement of forecast therefore directly results in inventory savings and service level improvements.

We state that the main performance measure for the customers is service level. Zhao & Lee (1993) define the service level as the percentage of end item demand that is satisfied. Based on this article and the current way of measuring at HNS, the impact of an increased frozen scheduling interval on the customers is measured in forecast accuracy and safety stock levels. Both are influencing each other. With a decrease forecast accuracy, an increase in safety stock level is needed. Therefore, we choose to return both aspects in the solution design.

The proposed model of Ponsignon and Mönch (2014) describes that for the planning stability, a simulation model is not required. Planning stability comes from the customer demand. When customer demand is stable, chances are higher that the planning is also stable. Therefore, we measure the performance measures of the customers separately from the rest.

The remainder of this section explains how to measure the impact of an increased frozen scheduling interval on the service levels. Section 4.3.1 explains the forecast accuracy measures for the order policies MTO and replenishment. Thereafter, Section 4.3.2 highlights the measurement for the safety stock levels.

4.3.1 Customer Forecast Update Flexibility

The customer demand forecast is the quantity that a customer forecasts for a certain product for a given time period. The customer shares, based on a rolling horizon, a 16-weeks demand forecast with HNS. The customer determines what to forecast to HNS based on their own sales. Based on this customer demand forecast, HNS creates a 13-weeks production plan. Section 2.3 explains the relevance for HNS to receive an accurate forecast and explains that HNS measures the customer's demand forecast in week X-4, week X-6 and week X-13.

Forecast update flexibility is the ability for customers to send their orders as late as possible. When the moment between ordering and receiving the order is small, the customer is probably more likely to have a high forecast accuracy, because the customer oversees what demand arises at his customers. When we increase the frozen scheduling interval, the moment between ordering and receiving increases. One of the main disadvantages of increasing the frozen scheduling interval is the decrease in forecast update flexibility. We expect customers forecast update flexibility decreases when customers have to send their orders one week earlier.

Section 2.3 explains that for every order policy HNS measures the forecast accuracy at the same moment in time. However, for the MTO customer, we compare the forecast in week X-4 with the actual order in week X. For the replenishment customers we compare the forecast in week X-4 including the shipment time, because HNS compares the forecast of the customer with the actual sales of that replenishment customer. Since the input data for the determination of the customer forecast update flexibility and the moment at which we measure the forecast accuracy are not the same for every policy, we determine the impact per order policy separately.

We assume for this measurement that the idea behind the planning and scheduling process at HNS remains the same. That means that TSCP knows the orders of all MTO customers and shipment plans for replenishment customers before starting to create a production plan for week Y+1. When we increase the frozen scheduling interval and the MTO orders have to be known before starting planning and scheduling, the MTO customer needs to provide their orders one week earlier. For the replenishment customers, it holds that HNS bases the shipment plans on their forecast in week X-4 instead of week X-3.

MTO customers

To determine the impact of an increased frozen scheduling interval on MTO customer forecast update flexibility, we look at the forecast in week X-4 and the forecast in week X-5. In the current situation, the customer experiences the flexibility to change their forecast between week X-5 and week X-4. When implementing the increased frozen scheduling interval, the customer has to order in week X-5. In the current situation is the customer able to change their forecast in week X-4, but that is not possible in the researched situation. Therefore, we are interested in how often the customer changes their forecast between X-4 and X-5 and what the difference is between those forecasts. When the customer changes their forecast, we want to know which forecasts is closer to the actuals: the forecast in week X-5 or in week X-4?

Figure 4.4 visualizes with blue arrows the moments in time which are going to be compared.

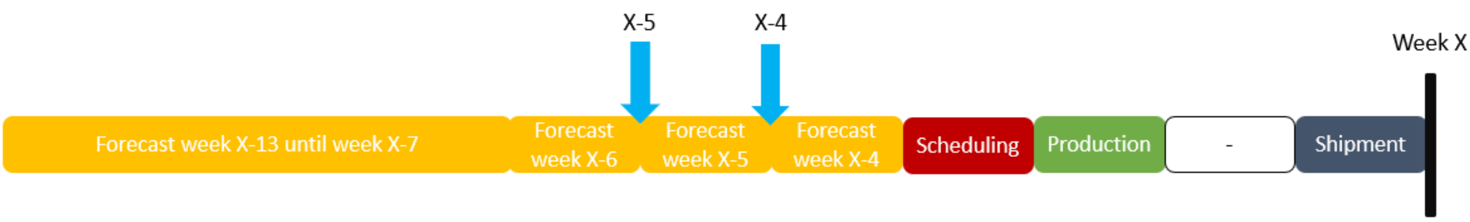

Figure 4.4 – Measurement points in forecasting process for MTO customers

The idea behind this way of measuring is best explained with an example. A customer forecasts 5000 cans of beer in week X-5 and a week later, the customer changes the forecast in week X-4 to 4000 cans of beer. For the current situation it holds that the customer uses the last week to change his forecast. Namely, the customer lowers its forecast from 5000 to 4000 cans, which is a difference of 1000 cans. For this specific case, the last week was important for the customer, otherwise the customer would have received 1000 cans too much, which result in a low forecast accuracy. For the researched situation, the customer orders 5000 cans of beer and observes in the forecast a week later that he only needs 4000 cans of beer. This might have as consequence that the customer increases his stock level, which is not desired, and therefore lowers the forecast for the periods thereafter which he still can change. This results in a higher schedule nervousness.

If for the same example, the customer would order in week X-4, just as in week X-5, 5000 cans of Heineken beer, the customer did not use the last week to change the forecast. When the forecast does not change in the last week, the increased frozen scheduling horizon would not have caused an impact on the forecast accuracy of the customer.

Replenishment customers

We apply the same idea to replenishment customers. However, Section 2.2 explains that replenishment customers have one week extra for updating the forecast. Based on the forecast in week X-3 and the stock levels determines TSCP the to-be shipped quantity in week X. For the researched situation, it holds that based on the forecast and stock level in week X-4 TSCP determines a shipment quantity.

The blue arrows in Figure 4.5 indicate the measurement points. It shows that the current situation is measured in week X-3 and that we compare this with the forecast in week X-4.

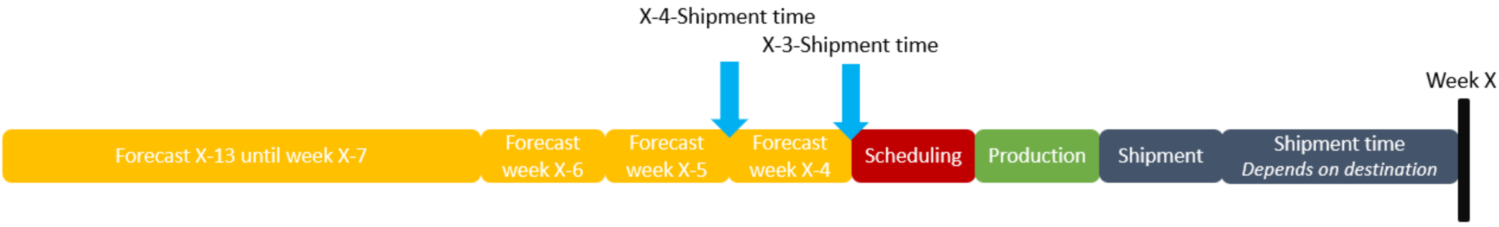

Figure 4.5 - Measurements point in forecasting for replenishment customers

We expect that increasing the frozen scheduling interval might result in a decrease in customer forecast update flexibility, because customers have to forecast over a longer period ahead. A decrease in the forecast update flexibility might result in more rush orders or more cancellations. More rush orders or cancellations impact the players HNS planning and suppliers. When a customer places a rush order, the HNS planning department might have to order more material at the supplier. Or if the customer cancels the other, HNS might also have to cancel some of their orders at the suppliers. This causes extra instability in the HNS' supply chain.

4.3.2 Customer Safety Stock Level

The second measure to determine the impact of an increased frozen scheduling interval on the service level is safety stock. Safety stock is a way to cope with uncertainty in demand during lead time. Customers also hold cycle stock. Cycle stock is the amount of inventory that is planned to be used given a pre-defined period. The period is defined as the time between orders. Since the time between orders does not change and the cycle stock is not depended on the lead time, we only consider safety stock for the service level calculation.

MTO customer keep safety stocks, to prevent themselves of uncertainty during lead time. However, this safety stock is not the responsibility of HNS and has therefore no impact on HNS. When increasing the lead time, the MTO customers might also increase their safety stock levels. As consequence, they might want to charge HNS for some compensation, since the increase in their safety stock levels is due to a decision of HNS. Furthermore, we keep the MTO customers out of scope for the safety stock level calculation.

For the MTS customer (HNC), HNS determines the upper, - and lower bound for the safety stock. For the replenishment customers, HNS received a minimum and maximum level for the safety stock. As for the MTS as for the replenishment customers, we consider seasonality. Seasonality indicates that the quantity depends on the season. In high season (week 20 until week 40), we expect that people volumes go up, since the weather is good outside and people love to enjoy a beer on a terrace or a festival. To prevent customers from stockouts, the safety stock levels during high season are higher than safety stock levels in low season.

To determine the safety stock level for MTS, a safety stock tool is developed at HNS. This safety stock tool determines per season per product what the optimal safety stock level should be, given the current lead time and desired service level.

The following formula is applied to calculate the safety stock level:

$$\text{Safety Stock} = \text{z} * \sqrt{(\text{Lead time} * \ \sigma_{\text{D}}^2 + \ \text{Demand}^2 * \sigma_{\text{LT}}^2} \tag{4.1}$$

in which the z represents the service level. If z = 0.99, it means that given the forecast quality, one can be 99% certain that a stock-out will not occur. The σ_D^2 represents the demand variation and the σ_{LT}^2 represents the lead time variation. From this formula, we expect that increasing the frozen scheduling interval, the lead time variation also increases. This is due to the fact that an increased frozen scheduling horizon results in a longer lead time and longer lead times results in more uncertainty, since the customer does not exactly know what his customers are going to order during the lead time. That results in higher lead time variations.

As the formula shows, the lead time is one of the factors on which we determine the safety stock level. By increasing the frozen scheduling interval, the lead time increases also with one week. Therefore, we expect that the safety stock increases.

Section 2.2 explains that 30% of the total volume is meant for the MTO customer, 30% for the MTS customer (HNC) and 40% for the replenishment customer. We do not consider the MTO customer in the scope for the safety stock, so 70% of the total volume remains. We cannot determine the increase in safety stock due to an increase in frozen scheduling interval for every customer, since some customers determine the safety stock levels themselves. Therefore, a representative group of customers is chosen. The first one that is chosen is the MTS customer, which represents 30% of HNS' total volume. For the replenishment customers we choose the biggest customers, which are HEINEKEN Germany (HGER), HEINEKEN Taiwan (HTW) and HEINEKEN USA (HUSA). These customers represent 80% of the total replenishment volume. Altogether, the replenishment customers combined with the MTS customers totally represent 90% of HNS' safety stock.

For the MTS customer, HNS determines the target safety stock level based on a tool that is developed at HNS. For the replenishment customers, HNS receives the upper, - lower and target safety stock levels, so that HNS ensures that the stock level per product stays between the upper and lower bound. HNS uses a safety stock tool that determines, given a desired service level, the minimal safety stock level to prevent the customer from uncertainty during lead time. This tool is applied for the customers HNC and HGER. For other replenishment markets, it holds that the customers calculate their optimal safety stock level per product by themselves and obtain HNS the optimal safety stock level. Therefore, we determine the exact increase in safety stock level for the customers HNC and HGER and a theoretical increase for the customers HUSA and HTW.

We use this tool to determine the impact of an increased frozen scheduling interval on the safety stock levels for the above-mentioned customers. This tool uses the current lead time as input. Based on this lead time, we determine the current storage costs. After determining the inventory holding costs for the current situation, we use the lead time for the researched situation as input and observe the differences in safety stock levels and inventory holding costs.

Based on equation 4.1, we expect that increasing the frozen scheduling interval results in an increase in customer safety stock level. Increasing the customer safety stock level results in higher inventory holding cost per year that HNS has to pay for the MTS and replenishment customers, but not for the MTO customers. However, increasing the safety stock levels does not influence other players in the supply chain, e.g. HNS Planning.

4.4 HNS Planning

The HNS Planning department has a planning horizon of 13 weeks. The responsibilities of the HNS planning department are creating a 13-weeks production plan based on customer demand forecast and other variables, monitoring line utilization and customer stock levels. Based on this 13-weeks production plan TSCP creates a material forecast for the suppliers. TSCP communicates this forecast with suppliers. From the first non-frozen week, TSCP creates a detailed short-term production plan of one week. This short-term production plan of one week describes how much to produce of which beer on what line. Based on this short-term plan, the OS scheduler creates a production schedule on an hourly basis.

When increasing the frozen scheduling interval with one week, the main difference for TSCP is that they have to create a production plan for the weeks Y+3 until week Y+13 and a detailed production plan for the week Y+2. From literature we learn that changes in the MPS due to an increase in frozen scheduling interval force the MRP to change. Changes in the MRP increase inventory costs and might disrupt production activities. We consider the inventory costs at customer's side as Section 4.3 explains and we measured this with the help of the controllable variable safety stock. We measure the disruption in production activities in the HNS scheduling part, which we explain in Section 4.8. Zhao & Lhee (1993) describe that increasing the freeze portion in the planning horizon might also result in schedule instability. We measure this schedule instability with the help of the controllable variable customer forecast update flexibility, which we also explain in Section 4.3 at the customer's side. The main responsibility of the planning department, which is creating the 13-weeks production plan, is not a measurable variable. Therefore, we conclude that the impact of an increased frozen scheduling interval is mainly measurable on operational level. As consequence, we do not incorporate the HNS Planning module in calculations.

Besides this reasoning, there is another reason not to mimic the impact on TSCP. We determine the impact on the customer demand forecast in Section 4.3. The processes and thus the outcome of the processes will remain the same. The second reason is that the TSCP processes are hard to mimic in a model, because it partly involves human interactions, which cannot be modelled. For example, when a customer sends a forecast with a big increase within 3 weeks, HNS decides to produce in advance, so that no capacity issues arise. That means that the production schedule for the next week contains more of a certain product order than the quantity in the forecast. This is a really hard process to mimic, since these decisions are based on human interaction.

However, there is one important reason why the HNS Planning is mentioned in Section 4.1. We mention that the impact of an increased frozen scheduling interval is mainly measurable on operational level. The production plan that is created by TSCP is used as input for the production schedule. The production quantities assigned to lines stated in the production plan and the material release dates obtained from suppliers are combined at the HNS scheduling department to a production schedule. We explain in Section 4.7 how we combine these several players in the supply chain.

Section 2.3 mentions that the availability of beer is one controllable variable that TSCP considers when creating the production plan. Beer availability is not a measurable variable that is measured within HNS. However, we still expect a change in beer availability when increasing the frozen scheduling interval. Section 2.3 explains the beer planning process elaborately, but for complicity Figure 4.6 repeats the current beer planning process.

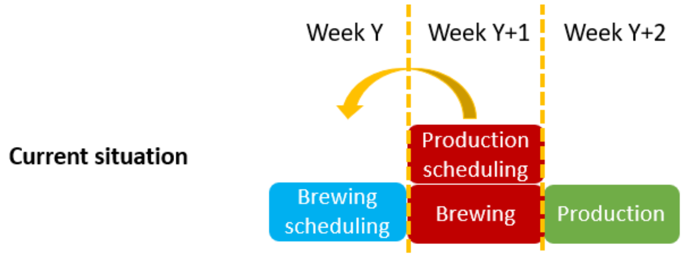

Figure 4.6 - Current beer planning process

From Figure 4.6 we see that the brewing schedule is created in week Y for beers that are needed in week Y+2. In week Y+1, the production schedule for week Y+2 is created. To have all the beers on time in week Y+2, the beers with a brewing time of one week, should be brewed in week Y+1. That means that the beer planner should create a brewing plan for week Y+1 in week Y. However, in week Y, not all orders are known, so beer is brewed according a forecast. This might have as consequence that not all beers are available when needed, since customers can change their forecast. When increasing the frozen scheduling interval with one week, TSCP creates in week Y a production schedule for week Y+2. This might result in a higher beer availability, since beers are brewed according a production plan instead of forecasts.

4.5 Suppliers

The third player for which we determine the impact of an increased frozen scheduling interval are the suppliers. As mentioned in Section 4.2, we identify two uncontrollable variables for the suppliers: supplier material availability and supplier purchase costs. In the current situation, the suppliers receive a first estimation of what HNS is going to order on Monday of week Y for what HNS wants to receive on Monday in week Y+1. The final purchase order is sent on Thursday. Suppliers who work on an MTO basis have little time to produce the ordered quantity. Suppliers that work with a replenishment method, have time to produce the quantity already or deliver from cycle or safety stock. Suppliers need to comply to a predefined service level. This predefined service level is registered in a Service Level Agreement (SLA). An SLA states what the service level should be and what the fines are if the service level is not met. When the supplier does not meet the agreed service level, it can also have big consequences for HNS. Production might be delayed, because materials are not available and that in turn might have as consequence that HNS might not deliver the customer on time. Figure 4.7 visualizes the current and the researched situation.

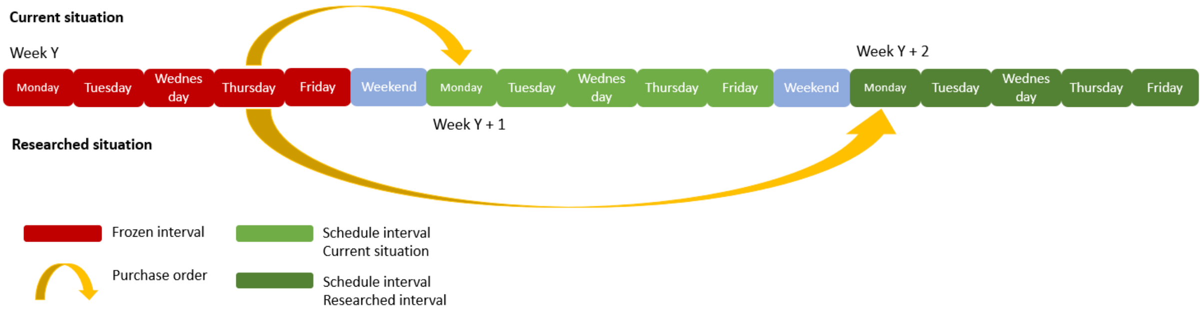

Figure 4.7 - Current and new situation for suppliers and carriers

The figure shows that in the current situation, HNS sends the final purchase order on Thursday in week Y for what HNS wants to receive on Monday of week Y+1. For the researched situation holds that the final purchase order is still sent on Thursday week Y, for what HNS wants to receive on Monday week Y+2. It holds for the researched situation that the suppliers receive the final purchase order one week earlier. Normally the supplier receives in week Y+2 the final purchase order in week Y+1 and now it would receive the final purchase order for week Y+2 already in week Y.

4.5.1 Supplier Material Availability

The first uncontrollable variable that we define for the suppliers is the material availability. Supplier material availability is the percentage materials that a supplier is able to deliver on time for the production schedule. On time for the production schedule is that a supplier is able to deliver the required materials on Monday of week Y+1. If the supplier is not able to deliver the required material on Monday, HNS receives an expected delivery date for later that week. This is a material restriction. We might expect that when suppliers receive the purchase orders one week earlier than the current situation, the supplier is able to more efficiently plan their prosses. A more efficient process might result in fewer material restrictions, since the supplier has more time to produce the required materials. This might result into a higher material availability. Equation 4.2 shows the formula that HNS uses to measure the supplier material availability.

$$SL(\%) = 1 - \left(\frac{\#\, material\ restrictions\ (timing + volume)}{Total\ \#\, planned\ materials}\right) \tag{4.2}$$

This formula is applied to every supplier. So, every supplier has his own service level. As equation 4.2 shows, this supplier service level is based on two variables: the number of material restrictions in timing and volume and the total planned number of materials.

Section 4.2 explains the choice for historical data. Historical data is also used to measure the impact on the supplier material availability. HNS stores all known material restrictions two weeks in advance. In week Y, HNS stores the known material restrictions for week Y+1 and week Y+2 in their database Pluto. Pluto is an HNS database in which all relevant planning and scheduling data is stored. To measure the impact of an increased frozen scheduling interval on the supplier material availability, we count the amount of restrictions in the current situation and the amount of restrictions that would arise for the researched situation.

Figure 4.3 shows that the suppliers are connected to HNS scheduling. When the supplier is not able to deliver the required materials on Monday, but on another day in that week, the production order(s) in which that material is needed, cannot be scheduled before the expected delivery date of the materials. The expected delivery date is used as input for the production schedule as a release date. Materials are released for production after the expected delivery. We expect that an increased frozen scheduling interval results in fewer material restrictions. When there are fewer material restrictions, thus fewer release dates, we expect that the OS scheduler could potentially create a production schedule with less changeover time.

4.5.2 Purchase Costs from Suppliers

The second uncontrollable variable that we define for the suppliers are the purchase costs. The purchase costs are the total price HNS pays to all suppliers to buy the materials needed for production. We expect that when suppliers receive the purchase orders one week earlier than the current situation, the supplier is able to more efficiently plan their process. An efficiently process might result in cost reductions at the supplier side, which in turn might result in lower purchase costs, since HNS caused the lower production costs at supplier side.

One way to find out the potential purchase costs savings is to talk to suppliers. Before talking directly to suppliers, we have a group session with the HNS department Contract Management. This department is responsible for all contact and contracts with suppliers and consist of 6 people, including the manager. During this group session, all employees need to be present and we discuss the current way of working regarding the suppliers and the researched situation. The suppliers are divided into different material types, so that one person is responsible for one type of material suppliers. A group of suppliers with the same material type is called a supplier category for the remainder of this research. To keep things transparent, we apply the same categories in this research as are applied within the department Contract Management. There are five employees at the department, so also five categories, which are: (1) cans, (2) labels, (3) raw materials, (4) carton and (5) draught keg. Per supplier category, we define potential costs savings and summarize the findings with reasons why there would be potential lower purchase costs or not.

4.6 Carriers

The fourth player in the HNS' supply chain are the carriers. For the carriers, we decide to measure the impact of an increased frozen scheduling horizon with the uncontrollable variable transport availability. Transport availability is the percentage of transport goods that are on time scheduled to be at the brewery when needed. To determine the impact on the transport availability, we discuss this topic with the departments Operations Scheduling, who are responsible for the final contact with the carriers so that every transport is one time and the department Customer Service Logistics (CSL), who are responsible for the contracts with all carriers. Based on their experiences for the current situation, we determine the impact for the increased frozen scheduling horizon.

4.7 HNS Scheduling

The last part for which we determine the impact of an increased frozen scheduling interval is the HNS scheduling part. We measure one uncontrollable variable for the HNS scheduling part: the total changeover time per line per week. The breweries 's-Hertogenbosch and Zoeterwoude have 24 lines in total. From these 24 lines, we choose to have 11 in our HNS scheduling scope. First of all, we choose for the can lines, which are the lines HBLYN17, HBLYN24 and ZWLYN06. The demand for can beer is growing every year. This has as consequence that HNS experiences under capacity on the can lines to produce all can beers. To fulfill demand HNS outsources the production of can beer. HNS brews the beer and then produces the beer at another location. Since these can lines are always producing, 24 hours a day, 7 days a week, we expect to achieve high changeover time reductions for those three lines. When we decrease the minutes of changeover time, we expect that HNS has more time to produce cans on their own lines, which results in lower outsourcing costs, thus lower production costs. The other 8 lines are the bottle lines HBLYN08A, HBLYN08B, HBLYN16A, HBLYN16B in ‘s-Hertogenbosch and the lines ZWLYN03, ZWLYN07, ZWLYN21 and ZWLYN22 in Zoeterwoude. There are 4 more bottle lines in Zoeterwoude, but these are left out of scope, since during 2019 one line was most of the times not operating and the other three lines have a small product portfolio. That results in little changeovers during the week, so we do not expect to achieve changeover time reductions for those four lines.

Section 2.3 explains that HNS creates their production schedule in AS. This tool combines the production orders based on beer type and pack type. The tool already needs a few minutes to solve one single line with a few jobs, so solving one year for eleven lines would take too much time. Besides that, we are not familiar with the AS tool, so also takes time to learn the tool. Instead, we select AIMMS as the tool to solve the HNS Scheduling problem. First of all, HNS is already familiar with AIMMS, since some of their planning activities take place in AIMMS. At HNS, they solve every line and every week separately. This is why we cut the production plan into smaller problems in which we solve every line and every week separately. Table 4.1 represents the average number of orders per line per week for the lines that are in the scope of this research.

Confidential table

Table 4.1 – Average number of orders per line per week

From Table 4.1 we observe that the average number of production orders per line per week is around 13. We assume that AIMMS is able to solve an average of 13 products in a reasonable time window. This is based on previous UT-related projects in AIMMS and previous researches performed at HNS. For a line with a high average, such as HBLYN17, we determine a plausible running length. We determine this running length based on the gap, which is the gap between the current best solution and the optimal solution. The gap should be as small as possible.

Now we select a program, we introduce a Mixed Integer Linear Program (MILP) that is solvable in AIMMS. The idea of the MILP is that the model creates a production schedule for the current situation and that the model creates a production schedule for the researched situation. The outcomes of these two models should be compared, so that we are able to determine what the impact is on the changeover time of an increased frozen scheduling interval.

The uncontrollable variable we select for the HNS Scheduling part is the changeover time per line per week. Changeover time is one of the variables currently measured at HNS for their production schedule. TSCP measures the planned changeover time, OS measures the scheduled changeover time and the realised changeover time. All those changeover times are constantly reviewed, so that the planning and scheduling process gets more efficient every time. At HNS, the scheduling objective is to create a production schedule with as less possible changeover time as required, given all changeover time matrices and restrictions that are known. To determine the optimal sequence, literature describes models that minimize on total costs. However, to mimic the HNS scheduling department, we decide that the MILP model should therefore minimize on the changeover time instead of minimizing costs.

Ponignon and Mönch describe that to control the production in the system, they use Earliest Due Date (EDD) dispatching rule. However, for this research it holds that there are no due dates, since every order that is in the production plan, should be due at the end of the week. Therefore, we conclude that the dispatching rule of Ponignon and Mönch will not result in the desired result. As mentioned before, changeover time is of big importance at HNS, so we need an objective that includes changeover time. The *total changeover time* per line per week is the total time needed to change the line from producing one production order to producing the next production order. The material release dates from the suppliers and carriers might impact the sequence of products. When it is very favorable to produce a product as first, but it can only be delivered after Wednesday, another product should be produced first. As a result, the total changeover time per week per line might be influenced.

As Section 4.5.1 explains, the input for the HNS Scheduling part are the release dates from the suppliers and the production quantities per production order per line per week. Since the production orders are already assigned to lines, we break down the problem into a problem that is solvable per line per week. Schutten (1998) describes the classical job shop scheduling problem. This is a problem whereby a shop is given consisting of *m* machines $M_1, M_2, \dots, M_m$. On these machines a set of *n* jobs $J_1, J_2, \dots, J_n$ needs to be scheduled. The objective is usually to find a schedule that minimizes the makespan, which is the total time to process all jobs. The classical job shop scheduling problem assumes that all jobs become available at the same time (start of the week). This is rarely true in practice and therefore, material release dates are introduced. The idea of release dates introduced by Schutten, overlaps with the idea of restrictions from the Suppliers and Carrier parts. Schutten proposes an objective that minimizes Maximum Lateness, which is a generalization of the objective minimize makespan.

The total makespan of a line is the sum of all processing times, changeover times and idle times on a line. *Processing time* is the time a line needs to process all the whole order. The *changeover time* is the time a line needs to swap the line from a product to another product. The length of changeover time depends on the product specifications. Changing only a product specification, such as the height of the bottle takes less time than changing from beer type, since that involves also cleaning time. We define *idle time* as the time a line is standing still. This might be due to maintenance or that there is not enough demand to produce every minute of the week. For example, the Draught Keg line in Zoeterwoude is not producing every minute of the week, since there is not enough customer demand.

We choose the minimal makespan as objective, since it incorporates different aspects. Most important, it contains the changeover time, which is the main variable for this part. Besides that, it also gives us the option to incorporate material release dates. Material restrictions are important to incorporate, because it gives us the opportunity to combine the supplier and carriers' parts with the HNS scheduling part. We expect that with a higher material availability, the OS scheduler is able to create a production schedule with less changeover time. However, we assume that material availability increases with an increased frozen scheduling interval. Therefore, we want to examine this assumption.

The processing time per order is input from the HNS Planning part. It is known upfront what the production quantity per product is. The resource speed indicates how much a certain line can produce of one product per hour. Dividing the amount by the resource speed gives us the total processing time per order. This processing time is a constant for the MILP, since it cannot change. However, for completeness, we use the processing time in the objective.

The changeover times come from changeover matrices, obtained from HNS. The changeover time differs per change of product size, beer type, pack type and secondary pack type.

The idle time differs per line per week and is not known upfront. Therefore, the idle time needs to be calculated. The idle time is the time between two products in which a changeover does not occur. Figure 4.8 represents an example of idle time.

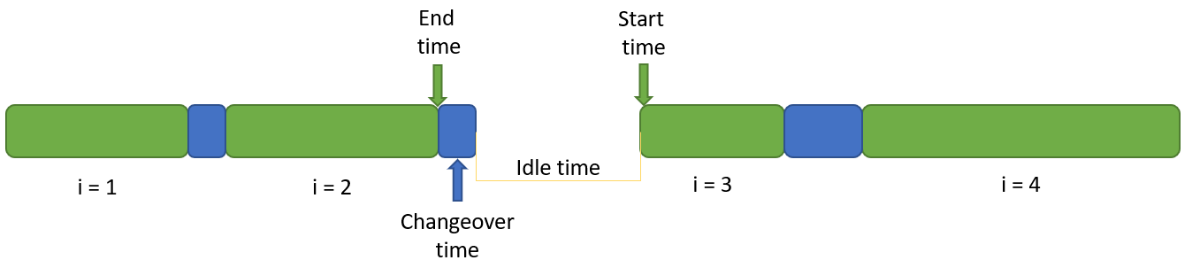

Figure 4.8 - Representation of idle time

For example, if a product ends at 18:00 hour and the next one starts at 20:00 hour and the changeover time between the products is only 1 hour, the idle time can be calculated as 20:00 – 18:00 – 1:00 = 1:00 hour. That means, for the calculation of the idle time, the end time, start time and sequence of products on a certain line is needed. This gives the following definition of *idle time:* the start time of a product minus the end time of the previous product minus the changeover time between those products.

In order to know the sequence of products, Meyr (2000) introduces the idea of order positions. Order positions are ascending, whereby a product is assigned to an order position. If product p is assigned to the first order position, that product p is produced first, if product q is assigned to the second order position, product q is second and so on. Since we know how many products are going to be produced on a line, we also know how many order positions there are on a line in a week.

Table 4.2 represents all sets, parameters and decision variables needed to mimic the OS process of creating a production schedule.

Sets		**Parameters**		**Decision variables**	
$\boldsymbol{p, q \in P}$	Number of products	r_p	Material release date of product p	S_i	Start time of order i
$\boldsymbol{i \in I}$	Number of order positions	$c_{p,q}$	Changeover time from product p to q (minutes)	E_i	End time of order i
		t_p	Processing time of product p (minutes)	$X_{p,q,i}$	1 if a changeover occurs from product p to q after producing i, 0 otherwise
		M	Very large number	$Y_{p,i}$	1 if product p is produced in order i, 0 otherwise
				MS	Total makespan of a line
				IT	Total idle time of a line

Table 4.2 - Sets, parameters and variables of the MILP model

We combine the idea of the objective from Schutten (1998) and the idea for order positions from Meyr (2000) into one model. The model is a simplified scheduling model that determines the sequences, based on the minimal makespan:

$$\min z = \ \mathrm{IT} + \sum_{p} \sum_{q} \sum_{i \in I} X_{p,q,i} * \ c_{p,q} \ + p_{p} \qquad (4.3)$$

Subject to.

$$IT = \ \sum_{i=1}^{I} (S_i - E_i - \sum_{p=1}^{P} \sum_{q=1}^{P} X_{p,q,i} * \ c_{p,q}) \qquad (4.4)$$

$$S_i \geq r_p \qquad \forall i, p \qquad (4.5)$$

$$S_i \geq E_{i-1} + \sum_{p}^{p \epsilon P} \sum_{q}^{q \epsilon P} c_{p,q} * X_{p,q,i} \qquad \forall i > 1 \qquad (4.6)$$

$$X_{p,q,i} \geq (Y_{p,i-1} + Y_{q,i} - 1) \qquad \forall p, i > 1 \qquad (4.7)$$

$$\sum_{p \in P} Y_{p,i} = 1 \qquad \forall i \qquad (4.8)$$

$$\sum_{i \in N_w} Y_{p,i} = 1 \qquad \forall p \qquad (4.9)$$

$$Y_{p,i} \ \in \{0,1\} \qquad \forall p, i \qquad (4.10)$$

$$S_i, E_i, X_{p,q,i}, MS, IT \ \geq 0 \qquad \forall i, p, q \qquad (4.11)$$

The objective of this model is to minimize the total makespan. The *total makespan* is defined as the idle time + changeover time + processing time of all products. Constraint 4.4 represents the calculation of the idle time and constraint 4.5 ensures that no product can start before its material release date. Constraint 4.6 indicates that the start time of order i is equal or greater than the end time of the previous order plus the changeover time. Constraint 4.7 ensures that the changeover variable is set correctly when two products are produced after each other. Constraint 4.8 ensures that for every order i a product is assigned and constraint 4.9 indicates that every product has one order. Constraints 4.10 and 4.11 guarantee that the variables are binary and nonnegative respectively.

The output of the model is the total makespan, which is split up in idle time, changeover time and processing time. Since we solve the model per line per week, the total makespan of every line and every week is known after modelling all weeks. To determine the impact of an increased frozen scheduling interval on the total makespan, the model is modelled for two situations: the current and the new situation. The output is a sequence of products with the total makespan. The idea is that the impact of material restrictions can be determined, by comparing the sequence of products and the total makespan per line per week. The current situation is that in week Y, a production schedule for week Y+1 is created, given all material restrictions. The researched situation is that in week Y, a production schedule for week Y+2 is created with all material restrictions that are registered for that week.

The scope of the HNS Scheduling part are the can and bottle lines. First of all, we start modelling the can lines, since we expect to achieve biggest changeover time reductions for the can lines. In the current situation, HNS outsources some parts of their can production, since HNS does not have enough line capacity to produce all requests. Changeover time savings would immediately yield time and thus money for HNS. Secondly, we determine the impact for the bottle lines. We choose the bottle lines second, since we also expect to achieve big changeover time reductions for these lines. Together, we determine the impact for 15 out of the 24 lines HNS owns in the breweries Zoeterwoude and 's-Hertogenbosch.

It is important to mention that we assume the following:

- We assume that all lines are available the whole week. We do not consider planned downtimes of production lines.
- The model is not able to lot size the production orders since HNS lot-sizes based on human decisions. The material release date of a product and line availability are taken into consideration for this decision. Therefore, we assume that every production order that we obtain as input from TSCP, will be produced as one production order. We do not split one production run into several smaller production runs throughout the week.
- The first order starts at Monday 00:00 hour. In reality the exact starting time per week differs, since it depends on when the last order of the previous week ends. This might have as consequence that the model computes idle time, while there was no idle time in reality.

4.8 Validation and Verification

This section answers the sub-research question: "*Is the model valid according the chosen validation method?*"

S. Robinson (2014) states that it is impossible to prove that a model is valid, so verification and validation is a process of increasing confidence in a model to the point that it will be used for decision-making. We learned that modelling is a process of documenting, validating and verification. Figure 4.9 shows that this process is a repeating process in which the model is compared to the paper model and to reality. After running the model, the outcomes of the model should be compared to the expectations and adapt where necessary.

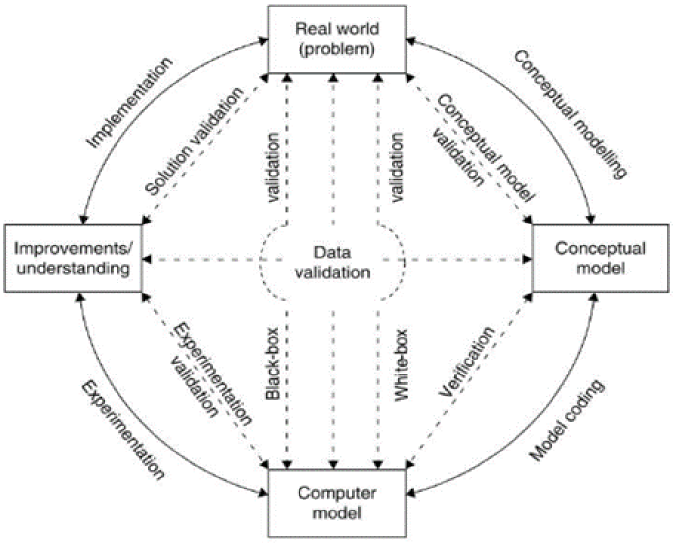

Figure 4.9 - Process of Verification and Validation (S. Robinson, 2014)

The process starts with a model structure. This model structure is explained in the previous sections. The next steps are verification and validation. Verification is the process of checking whether the programmed model coincide with the paper model. Validation is the process of checking whether the model represents reality well enough.

4.8.1 Verification

Verification is the process of checking whether the developed model still complies with the "paper" model. After finishing a part of the model, it is checked if the implemented model in AIMMS still complies with the paper model.

In good cooperation with the supervisors of HNS, the model and logic are discussed and developed. The sequence of the production schedule is discussed with the supervisors to check whether the sequence of products makes sense.

When we found differences between the sequence of the model and the sequence in reality, we analyzed if the logic in the model was wrong or that we made a mistake in the paper model. If the logic in the model was wrong, we adjusted the model.

4.8.2 Validation

Validation is the process of checking whether the developed model complies with reality. According to Robinson (2014) validation is a way to establish credibility. Therefore, it is important to interact with the decision maker. One validation method is black box validation. Black box validation compares the model output to the reality. For this research, we validate the model in two ways: comparing the model sequence of products with the actual sequence that took place and the changeover time that the model calculates with the scheduled changeover time for that week.

First, we compare the sequence of the products from the model with reality. The sequence of the products might say something about the validity at first hand, because the sequence of production orders is what the OS scheduler determines. If the sequence of the model does not comply with the sequence of the OS scheduler, we could argue that the model is not valid, which results in the fact that we cannot say anything based on the model.

After the first validation cycle, we find out that idle time is missing in the model. When there is no idle time, the model determines the optimal sequence based on the minimal total changeover time and the release dates. The processing time is also included in the total makespan, but as Section 4.7 explains, the processing time is a constant. When the model determines the optimal sequence without idle time, the first production order in the week is a production order with the least changeover time to the next production order. When this first production order has a release date, the whole schedule does not change, but starts after the release date of the first production order. This does not comply with reality, since HNS starts the week with another production run. Therefore, we add the variable idle time, such that the model always starts at Monday, even though the most optimal production run is not at the start. With adding the idle time, we give the model the opportunity to start at Monday, because idle time can arise.

The second validation step is to compare the changeover time from the model with reality. When the sequence of the products complies with reality, we also validate if the changeover time complies with the scheduled changeover time. We find that the changeover matrices have changed over time. From this we conclude that comparing the changeover time from the model with reality does not necessarily result in the same changeover time. However, we also observed that there are no big changes in the changeover time, thus that the sequence of the products did not change due to a small difference in changeover times.

4.9 Conclusion on model design

This chapter answers the research question: "*How should the solution design look like?*"

Section 4.1 introduces the five players in the HNS' supply chain: (1) customers, (2) HNS Planning, (3) suppliers, (4) carriers and (5) HNS Scheduling. For these five players, we determine the impact of an increased frozen scheduling interval of one week. An increased frozen interval of one week results in the fact that the planner creates a production plan in week X for week X+2 instead of week X+1.

To determine the impact on the five players in the HNS' supply chain, we define eight variables. Section 4.2 explains these performance measures. For the customers, we define the performance measures forecast accuracy and customer service level. For the HNS Planning we define beer availability. For carriers we measure the increase or decrease in purchase costs and material availability. For carriers, we determine the impact by measuring the transport availability. At last, we determine the impact of an increased frozen scheduling horizon for the HNS Scheduling department on the total changeover time on a yearly level.

We explain in Section 4.3 that for the customers we determine the impact of an increased frozen scheduling horizon for the MTO and replenishment customer by comparing the forecast in week X-4 with the forecast is week X-5. When these forecasts are equal, the customer probably does not notice the difference between the current and researched situation. When these forecasts are not equal, we compare both forecasts with the actuals to see which forecast accuracy is higher. For the customers, we also calculate the expected increase in safety stock level for the customers HNC, HGER, HTW and HUSA.

We explain in Section 4.4 that for the HNS Planning part we only determine the impact on beer availability. The impact of an increased frozen scheduling horizon is mainly measurable at other departments in HNS.

Section 4.5 explains that we identified two uncontrollable variables for the supplier part: material availability and purchase costs. We determine the impact on material availability by calculating the number of restrictions in the current and researched situation. We examine the change in purchase costs with the help of a group session with the department Contract Management and talking to suppliers.

Section 4.6 explains that for the carriers we determine the impact based on transport availability. We determine the impact on transport availability by talking to the HNS' departments CS and OS and talking to carriers.

Section 4.7 describes that the last part that we examine is the changeover time. The changeover time is an uncontrollable variable that is currently used at HNS. We introduce a MILP to determine the impact on the scheduling process. The current and researched situation are both modelled, so that we compare both outcomes and determine the impact of an increased frozen scheduling interval on the sequence of the production schedule and thus the total changeover time per line per week.

Section 4.8 describes the validation and verification of the model. We verify the model through means of conversations and discussions with the HNS supervisors. We validate the model by comparing the outcomes of the model with reality.

Chapter 5 – Solution Results

Chapter 4 introduces the model and the approach to answer the main research question. This chapter presents and analyzes the results regarding all aspects of the research. We answer the last research question: "*What is the impact of an increased frozen scheduling interval per variable?*". We discuss the results in the same sequence as they are introduced in Chapter 4.

Section 5.1 describes the impact of an increased frozen scheduling interval from a customer's perspective. We determine the impact on customer forecast update flexibility and safety stock level. Section 5.2 dives into the supplier's side. We look at the supplier material availability and purchase costs. Section 5.3 determines the impact on the transport availability. Section 5.4 mentions why the beer availability increases and Section 5.5 approaches the problem from the scheduling's side. We determine the impact of an increased frozen scheduling interval on the scheduling process based on the changeover time per line per week. This chapter ends in Section 5.6 with a conclusion.

5.1 Customer

Section 4.3 introduces the two controllable variables customer forecast update flexibility and customer safety stock level to determine the impact of an increased frozen scheduling interval on the customers. Subsection 5.1.1 explains the impact on the forecast accuracy of the MTO and replenishment customers. Subsection 5.1.2 explains the impact on the safety stock levels for the customers HNC, HGER, HUSA and HTW.

5.1.1 Customer Forecast Update Flexibility

To determine the impact of an increased frozen scheduling interval on the controllable variable customer forecast update flexibility, we compare the customer's demand forecast over different weeks for MTO and replenishment customers. We gather the data from Pluto and Blink. Pluto is HNS' database in which all relevant planning and scheduling data is stored. HNS stores actual orders and customer demand forecasts in Blink. The unit in which the customer demand forecast in Blink is stored is in number of boxes. The idea behind the measurement of the impact on the customer forecast update flexibility is for all order policies the same. However, the supply and lead time differ per policy and also the actuals are not the same. The actuals for the MTO customers are the actual quantities that the customer ordered at HNS and the actuals for the replenishment customers are the actual in-market sales that the replenishment customer experienced. In-market sales are the actual quantities that a replenishment customer sells to his customers. Therefore, we describe the impact on the customer forecast update flexibility for the order policies separately.

MTO customers

First, we describe the impact of an increased frozen scheduling interval for the MTO customers. Table 5.1 shows the results.

Confidential table

Table 5.1 - Service level results (MTO)

For the year 2019, the total number of demand forecast points for the MTO customers is X. In X % of all cases, the customer's forecast in week X-4 is equal to the forecast in week X-5. That indicates that in X % of all cases, the customer did not have the necessity to change their forecast. A customer changes their forecast due to new insights they obtained from their own customers. For X % of all cases, the customer uses the last week to change their forecast due to new insights in their own customer forecast, closer to the actuals or further away from the actuals. For X % of all cases, the customer used the last week to change their forecast closer to the actuals and in X %, it holds that the customer forecast was closer to the actuals in week X-5 than in week X-4. Based on historical we conclude that in X % of all cases, the forecast of the customer is closer to the actuals for the current situation, but in X % the customer's forecast is closer to the actuals in for the researched situation. Based on these numbers, we conclude that for the majority of the MTO customers an increased frozen scheduling interval negatively impacts their forecast update flexibility.

However, we cannot ignore the fact that in X % of the cases, the forecast in week X-5 is better than the forecast in week X-4. Therefore, we visualize the absolute difference between the forecast and actuals. Table 5.2 shows the absolute difference between week X-4 and the actuals and between the forecast in week X-5 and the actuals.

Confidential table

Table 5.2 - Absolute difference between forecast and actuals (MTO)

Table 5.2 shows that in the current situation the difference between the forecast and the actuals is between the 0 and 2,000 boxes in approximately X% of all cases. On a weekly basis, HNS produces around 300,000 boxes. The majority of the absolute difference is less than X percentage of the total weekly production quantity. So, the deviation is not of big impact for HNS, since the main deviations are just a half percentage of the total amount produced in a week. When we observe the two most right columns in Table 5.2, we conclude that the deviations are approximately divided in a same way over the buckets in the researched situation as for the current situation. Based on historical data, we conclude that the deviations in customer demand forecast slightly increase when increasing the frozen scheduling interval.

Based on Table 5.1 we conclude that an increased frozen scheduling interval results in a lower service level for MTO customers, since their forecast in week X-4 is closer to the actual than in week X-5. However, based on Table 5.2 we also observe that the absolute difference slightly increases, but that this does not highly impact the production planning of HNS.

When the absolute differences increase, chances on rush orders of cancellations also increase. This is due to the fact that customers forecast either too high or too low compared to their actual order or in-market sales. When increasing the frozen scheduling interval, this could result in more rush orders, because customers need the products or cancellations since customers already have enough on stock. However, when we look at Table 5.2 we conclude that the difference in deviations remains almost the same. As a result, we expect that the increase in cancellations or rush orders is small. Currently HNS does not track the number of rush orders or cancellations.

Based on the same historical data set, we determine the amount of rush orders that could occur when implementing the increased frozen scheduling interval. A rush order occurs in the current situation when a customer did not forecast anything yet in week X-5 but ordered something in week X-4. Based on this method and historical data, HNS would observe in X of the X cases a rush order. Since HNS does not track the number of rush orders, we cannot confirm if this number complies with reality. We expect that there is a chance of rush orders when increasing the frozen scheduling interval. This might be due to the fact that the customer gains new market insights, while the customer already placed an order at HNS. This also holds for the number of cancellations. Since HNS does not track the number of cancellations and cancellations only happen with high exception, we cannot quantify the number of cancellations. However, from literature we learn that an increased frozen scheduling interval results in an increase in cancellations.

Replenishment customers

For the replenishment customers is the shipment plan in the current situation based on the forecast in week X-3-shipment time. For example, if the shipment time to a depot is 7 weeks, then HNS determines what to ship to that depot in week X-3 based on their forecast in week X-10, which is including the shipment time of 7 weeks. Therefore, we incorporate the shipment time in the customer forecast update flexibility analysis for the replenishment customers.

Table 5.3 shows the results for the replenishment customers. In X % of all cases in 2019, the forecast in week X-3 is equal to the forecast in week X-4. That indicates that the majority of the replenishment customers does not use the last week to change the forecast based on new insights in their own customer demand.

Confidential table

Table 5.3 - Service level results (replenishment)

For the other X % holds that the quantities are equally divided. In X % of all cases, the forecast in week X-3 is closer to the actual shipment plan and for the other X %, the forecast in week X-4 was closer to the actual shipment plan. Based on historical data, we conclude that an increased frozen scheduling interval will not impact the forecast accuracy of the replenishment customers.

The results in Table 5.3 are aggregated results from all replenishment customers. Appendix A provides the results per replenishment customer. We conclude from the appendix that the impact differs per customer if the customer uses the last week to fine-tune their customer demand forecast or not. One remarkable relation is that customers who are located in Europe, so customers with a low shipment time (one week or shorter), are more affected by an increased frozen interval than customers who have a long shipment time. This is best explainable with the help of an example. The lead time to France is less than a week, which results in a lead time increase from 3 weeks to 4 weeks, which is an increase of 33%. The shipment time to USA deviates between the 7 and 10 weeks. This results in a supply lead time and shipment time increase from, for example, 9 weeks to 10 weeks, which is an increase of 11%. The increase is relatively lower compared to the increase for France. This relative difference is reflected in the way the replenishment customer is affected by an increase in frozen scheduling interval. This might be due to the fact that HUSA has to forecast for a longer period ahead. Since HUSA has to order that many periods ahead, they will not gain new insights in customer forecast. For France, on that short term, they might gain new insights on the short notice, which cause them to change their forecasts. Therefore, we conclude that the impact of an increased frozen scheduling interval mainly affects replenishment customers with a shipment time less than a week.

Conclusion Customer Forecast Update Flexibility

Increasing the frozen scheduling interval with one week results in a lower customer forecast update flexibility for the MTO customers. Based on historical data, we only observe a change in customer forecast update flexibility for the replenishment customers with a shipment time of less than a week. Replenishment customers with a longer lead time are less affected by an increased frozen scheduling interval.

Bai et al (2002) describe that a high safety stock level could improve the stability of the MPS without degrading the customer service, but incurs high inventory holding cost. Zhao & Lee (1993) describe that a higher freezing portion results in a lower schedule instability, but this results in a decline in customer service level. In this research we split customer service level into customer forecast update flexibility and safety stock levels. Consistent with previous performed researches, we conclude that the forecast update flexibility for the MTO customers declines with an increase in frozen scheduling interval, but this partly holds for the replenishment customers.

5.1.2 Customer Safety Stock Levels

The second controllable variable for the service level is the impact on the customer safety stock level. Chapter 4 explains that HNS determines safety stock levels for the MTS and replenishment customers. For the MTS customer HNC and the replenishment customer HGER determines HNS the target safety stock level. HNS receives the optimal safety stock levels from the other replenishment customers. HNS combines the minimum and maximum cycle stock levels with the safety stock level, so that upper and lower bounds for the stock levels can be determined. This is how HNS ensures that the stock level per product stays between the upper and lower bound.

The safety stock tool that is provided by HNS determines the optimal safety stock per customer per product. Since it is not of interest to know the impact of an increased frozen scheduling interval on product level, products are classified into a pack type. We apply the same pack types which HNS also uses, which are Blade, Bottle one-way, Bottle returnable, Can and Keg. For the safety stock level calculation, a required service level is needed, the z value. We assume that the z value does not change with an increased frozen scheduling interval.

First, we determine the impact of an increased frozen scheduling horizon on the safety stock levels of HNC. Table 5.4 shows the current HNC safety stock levels and Table 5.5 shows the HNC safety stock levels for the researched situation.

Confidential table

Table 5.4 - Current HNC safety stock levels

Confidential table

Table 5.5 - HNC Safety stock levels for researched situation

The storage cost per hectoliter (HL) are obtained by the Business Controller within HNS. These are the storage costs per hectoliter, including all logistic movements. From these tables, we conclude that the blades observe the highest increase in safety stock level. The blade inventory level even doubled. For the other categories, we also observe an increase, but not as much as for the blades. It is remarkable that the safety stock level for the blades should increase with 50%, while for the other categories not.

Therefore, we decide to look at the results on a product level. We observe that some products have a big increase in safety stock level. This is the result of the fact that the tool determines the optimal safety stock level based on historical data. We observe for some products that the customer for the current situation forecasts correctly and that an actual order appears. However, when we increase the frozen scheduling interval, the customer did not forecast anything yet in week X-3. So, when we increase the lead time in the safety stock tool and the customer did not forecast anything yet in week X-3 but the customer placed an order, the deviation between the forecasted quantity and the actual orders is big. The demand variation increases, resulting in a higher safety stock level. For the current situation, the forecast and actuals comply with each other and will therefore not influence the safety stock level in a negative way.

We conclude that for products with a high demand variation, the safety stock level increases the most. For other products with a low variation in demand, the safety stock level almost remains the same while increasing the lead time. The main reason is that safety stock is a method to cope with uncertainty during lead time. When increasing the lead time, the demand variation also increases, which results in higher safety stock level, since the customer have to prevent himself from these variations in demand during lead time.

When implementing the increased frozen scheduling horizon, we expect that the observed demand and supply deviations in the historical data will flatten, since customers have to consider their forecasts earlier. Therefore, we decide to detect and delete outliers from the dataset. Outliers are values above or below a certain threshold.

To detect outliers in the dataset, the interquartile method is applied. The interquartile method splits the data in four quartiles so that it gives an insight into the skewness of the dataset. The interquartile method sorts all values from small to large and divides the values in four quartiles, such that every quartile contains the same amount of numbers. The median is the number in the middle. We determine the median for quartile one (Q1) and quartile three (Q3). Now we determine the thresholds. The lower threshold are all values smaller than Q1 – (1,5 * (Q1-Q3)) and the higher threshold are all values higher than Q3 + (1,5 * (Q1-Q3)). Using the interquartile method results in 15 out of 324 products as outlier. Table 5.6 and Table 5.7 show the results after removing these outliers. Table 5.6 shows the safety stock levels for the current situation and Table 5.7 shows the safety stock levels for the researched situation.

Confidential table

Table 5.6 - Current HNC safety stock levels after removing outliers

Confidential table

Table 5.7 - Safety stock levels HNC after removing outliers for the researched situation

After removing the outliers from the dataset and comparing Table 5.4 and Table 5.5 with Table 5.6 and Table 5.7, we conclude that the safety stock level for the blades is not doubled anymore. For the other categories we observe a slightly lower increase in inventory levels. We verify these findings among employees of HNS. These employees agree on the removal of outliers, such that the results give a better identification of the safety stock levels.

For HNC, there is distinction between low and high season. Appendix B contains the tables for which the safety stock levels are split up in high and low season. From these tables, we conclude that the biggest impact of an increased frozen scheduling interval is during high season. This is the season in which HNC sells most of the beer volume, which also involves uncertainty. When increasing the lead time, the uncertainty is spread over a longer time period which results in an increase in safety stock levels.

Based on Table 5.5 and Table 5.7, we conclude that the increase in safety stock level for HNC on a yearly basis results in an increase in inventory holding cost of approximately € X.

We apply the same method for HGER. First, we determine the increase in safety stock and check for outliers. For HGER, we detect 3 outliers based on the interquartile method. For HNC, the storage costs per pack type are known. We obtain one storage price per pallet from HGER. Table 5.8 represents all safety stock levels for the current situation and Table 5.9 shows all results for the researched situation.

Confidential table

Table 5.8 - Current safety stock levels for HGER

Confidential table

Table 5.9 - Safety stock levels HGER for the researched situation

From these tables, we conclude that the increase in safety stock level for HGER is lower compared to the increase in safety stock levels for HNC. The increase in inventory holding costs is therefore relatively low: € X. This is explainable, because the increase in safety stock levels is much lower than for HNC.

Since HUSA and HTW determine their own safety stock level, we only theoretically approach the increase in safety stock level. To do so, we apply the same method as we applied for HNC and HGER. There are 9 depots in USA, which we sum up for this calculation. Appendix C shows the results of these calculations. We conclude from this appendix that the increase in safety stock level for the customers HTW and HUSA is relatively smaller than the increase for HNC or HGER. This might be due to the fact that when HNS increases the frozen interval with one week, the lead time for HNC increases from 2 weeks to 3 weeks. Which is an increase of 50%. For HGER, the lead time increases from 3 weeks to 4 weeks, which is an increase of 33%. The increase in lead time for HUSA is 17% and for HTW only 11%. So, the lead time for HNC increases relatively the most, which we also observe in the calculation for the safety stock level.

Conclusion Customer Safety Stock Level

For the controllable variable customer safety stock level, we conclude that the inventory holding costs increase with € X euro for the customer HNC. For the other markets, the increase is relatively less compared to HNC.

Section 4.3.2 debates that given the safety stock formula, the customer safety stock level increases with an increase in frozen scheduling interval. Zhao & Lee (1996) already mentioned that an increase in frozen scheduling interval results in higher inventory holding costs. Bai et al (2002) prove in their study that total costs decrease with an increased frozen scheduling interval, mainly due to lower change costs. Change costs are costs for changing the MPS. Their study also showed that even though the total costs decrease, the inventory holding costs increases due to an increase in safety stock level.

V. Sridharan & Laforge (1994) show that an increased frozen scheduling interval does not result in a major loss in customer service but results in higher inventory. We conclude that the observed results comply with previous performed researches found in literature.

5.2 Suppliers

We identify two uncontrollable variables for the suppliers: purchase costs and material availability. We explain in Section 5.2.1 the potential savings regarding the purchase costs. Section 5.2.2 explains the impact of an increased frozen scheduling interval on the material availability from suppliers.

5.2.1 Supplier Purchase Costs

To determine the impact of an increased frozen scheduling interval on the uncontrollable variable purchase costs, we organize a group session with the department Contract Management. Section 2.1 identifies five categories for the suppliers: Carton, Can, Bottes, Draught Kegs and Raw materials. We define per category if there might be any improvement regarding purchase costs.

The first category carton has two main suppliers: supplier A and supplier B. Supplier A delivers most of the carton for HNS and works on an MTO basis. That means that supplier A only starts producing the ordered quantity when HNS definitely orders. Since carton is a spacious product, supplier A does not keep safety stock. Based on the final purchase order on Thursday, supplier A starts producing. The production process of RRK is partly organized in such a way that they are able to deliver most of the orders on time, because HNS is one of their biggest clients. However, they state that their production process is not efficient due to the fact that HNS sends the final purchase order on Thursday of week Y for week Y+1. When HNS increases the frozen scheduling interval with one week and supplier A also receives the final purchase order one week earlier, they are able to more efficiently plan their production process. This results in a cost saving of €400,000 just once at the side of supplier A. Supplier A states that when they realize this cost saving, they return the saving to HNS. This saving for supplier A results in a lower material price for HNS, so lower purchase costs.

Supplier B also indicates that they are able to more efficiently plan their production schedule when they receive the final purchase order one week earlier. Due to the fact that the current prices are based on total yearly volume and that the total yearly volume does not change with an increased frozen scheduling interval, the purchase costs would not decrease. However, we might argue that when supplier B is able to more efficiently plan their production process, they would save costs. It might be the case that supplier B does not pass these cost savings on to HNS or that the tender price for the next tender would slightly decrease. Supplier B states that even though they would not decrease the purchase costs, another result of obtaining the final purchase order are fewer material restrictions, since they have more time to produce the required materials. We discuss this in Subsection 5.2.2.

The can suppliers do not experience any difference when increasing the frozen scheduling interval, due to the current way of working. Capacity reservations are made far in advance already. That means that HNS and the suppliers already align what to produce when based on the medium-term production plan. When the cans suppliers receive the final purchase order one week earlier, it would not influence the capacity reservations.

The category bottles mainly consists out of label suppliers. Labels are a product of which many can be stored on one pallet. There is not a lot of space needed in a warehouse to store labels. HNS and the label suppliers agree on the method to produce the Minimum Order Quantity (MOQ). The *MOQ* is an agreed quantity that should be ordered every time HNS places an order. Since it is cost efficiently to have more labels on stock than produce in small batches, HNS and the label suppliers agree to produce the highest MOQ in the 13-weeks production plan. The label suppliers produce the highest MOQ to prevent the suppliers from producing in small batches. The combination of sufficient safety stock levels and the production of the highest MOQ in the 13-weeks production plan, results in the fact that that the process of producing labels does not change with an increased frozen scheduling interval. This will not result in lower purchase costs for the category bottles.

For draught kegs the main supplier is supplier C. Supplier C is a company based in Germany. Companies in Germany have to arrange the work shifts two or three weeks in advance. Currently, supplier C arranges the work shifts based on the HNS demand forecast, because supplier C knows the exact production quantities just one week in advance, which is too late to arrange the work shifts definitely. Since the HNS demand forecast is fluctuating a lot, it occurs that supplier C arranges too much or too less work shifts. When supplier C receives the purchase order one week earlier, they are able to arrange the work shifts based on actual orders. On a yearly basis, this could save supplier C up to €5 X. They state that when HNS increases their scheduling interval with one week, supplier C will lower their purchase price. Which results in a yearly purchase costs saving of € X.

For the last category raw materials, no improvement in material availability or lower purchase costs are achievable. Raw materials are strategic products. That means that these materials are only ordered a few times a year. When increasing the frozen scheduling interval, the ordering process for raw materials does not change.

Conclusion Supplier Purchase Costs
We conclude that increasing the frozen scheduling interval with one week results in a potential one-off saving of € X and a yearly saving of € X regarding the purchase costs.

Sahin et al (2008) state: "*determining the best frozen interval length requires balancing the manufacturer's need for scheduling flexibility versus the vendor's desire for order visibility*." They introduce the idea of Advanced Order Commitment (AOC), whereby the manufacturer places purchase orders in advance of the vendor's minimum replenishment lead time to improve supply chain integration. When HNS sends their final purchase order one week earlier to the suppliers, we observe similar advantages as to the AOC policy. Sahin et al describe that increasing the frozen scheduling interval, decreases the suppliers schedule instability. A lower supplier schedule instability results in a more optimal production schedule, which complies with the findings at HNS. We conclude that an efficiently production schedule results in lower purchase costs.

5.2.2 Supplier Material Availability
The second uncontrollable variable we define for suppliers is the supplier material availability. We determine the supplier material availability based on the number of material restrictions and the total planned materials. Section 5.2.1 explains that one supplier states that receiving the final purchase order one week earlier would result in less material restrictions.

Section 4.5 explains that HNS stores all material restrictions in their database Pluto. We obtain all known material restrictions of the year 2019 for the 11 lines that are in the scope of the HNS scheduling part. We choose to only look at those lines, since we expect that the number of material restrictions would influence the changeover time, which we determine in the HNS scheduling part. Figure 5.1 is a graphical representation of the number of restrictions per day throughout the week for the bottle and can lines combined.

Confidential figure

Figure 5.1 - Number of material restrictions for the current and researched situation

Figure 5.1 shows that most of the restrictions arise on Tuesday and Friday. A material restriction on Tuesday implies that a product can only be scheduled from Tuesday onwards. The blue bars represent the current sitauation and the orange bar represent the reserached situation. From this figure, we observe that the blue bars are always higher than the orange bars. From that, we conclude that increasing the scheduling interval results in fewer material restrictions. In the current situation, we observe 662 material restrictions for the 11 lines per year. For the researched situation we count 365 material restrictions. This is an improvement of almost 50%. However, this does not directly result in an material availbility improvement of 50%, because the number of total planned materials remains the same, since this does not depent on the frozen interval.

$$SL(\%) = 1 - \left(\frac{\#\ material\ restrictions\ (timing + volume)}{Total\ \#\ planned\ materials}\right) \quad (5.1)$$

Based on the material availability formula in Equation 5.1 and the fact that the number of material restrictions decrease, we conclude that the material availability and thus the supplier service level improves due to an increased frozen scheduling interval. This is a theoretical improvement, since this improvement is based on historical data.

In the current situation, if the material planner observes a shortage for a certain material what might result in a material restriction for the production schedule, the material planner calls the supplier. In this call, the material planner asks if the supplier is able to deliver the required materials earlier in the week. Most of the times, this is paying off and the supplier delivers earlier in the week. The material planner does not call suppliers if he observes potential material restrictions in week Y+2. Therefore, we expect that when increasing the frozen scheduling the actual number of restrictions will be lower and thus results in a higher material availability than we observe based on historical data.

Conclusion Supplier Material Availability
We conclude that an increased frozen scheduling interval of one week results in a higher supplier material availabilty.

Nedaei & Mahlooji (2014) describe that when the manufacturer deals with an inflexible vendor, considerable advantages are gained from extending the manufacturer's planning horizon and gathering a larger set of demand data in the MTO supply chain. Moreover, they conclude that while the vendor's instability decreases by lowering the frozen scheduling interval length, the manufacturer's schedule instability decreases with longer frozen time intervals. Our findings comply with the findings of literature. We observe for both uncontrollable variables for the suppliers that the suppliers profit from an increased frozen scheduling interval.

5.3 Carriers

We define the uncontrollable variable carrier transport availability to identify the potential savings for the carriers. To determine the impact of an increased frozen scheduling interval on the transport availability, we apply the same method as for the suppliers: we interview employees of the department OS and Customer Service and Logistics, since those two departments are responsible for the contracts and contacts with carriers. The department OS indicates that transport availability does almost never impacts the sequence of the schedule. That indicates that there is always transport available when needed. This is due to the fact that the trucks are ordered only a few days before the production starts. This process is captured in contracts between the carriers and HNS. We verify this process at the department Customer Service and Logistics, who is responsible for the contracts with carriers. Both employees acknowledge that an increased frozen scheduling interval of one week does not result in a better transport availability, because the process is arranged in a day-to-day process which does not change with an increased frozen scheduling interval. An increased frozen scheduling interval does also not result in financial savings, since HNS pays the carrier per ride. The number of rides is not correlated to the frozen interval and thus does not change with an increased frozen scheduling interval. We conclude for the transport availability that it will not change due to an increase in frozen scheduling interval.

Conclusion Carrier Transport Availability

We conclude that the carrier transport availability does not change due to an increased frozen scheduling interval.

Literature does not describe the impact of an increased frozen scheduling interval specifically on the transport availability. However, if we consider the carrier under the same supply chain channel member as suppliers, we would state that increasing the frozen scheduling interval, also increases schedule stability for the carriers. Our findings do not comply with this assumptions, because the transport availability is a process that is captured in a day-to-day process.

5.4 HNS Planning

The only variable for HNS Planning is the beer availability. Every beer type has its own brewing time. The beer planner determines how much to brew per beer based on customer demand forecast in the current situation. Figure 5.2 shows the current and researched beer planning process.

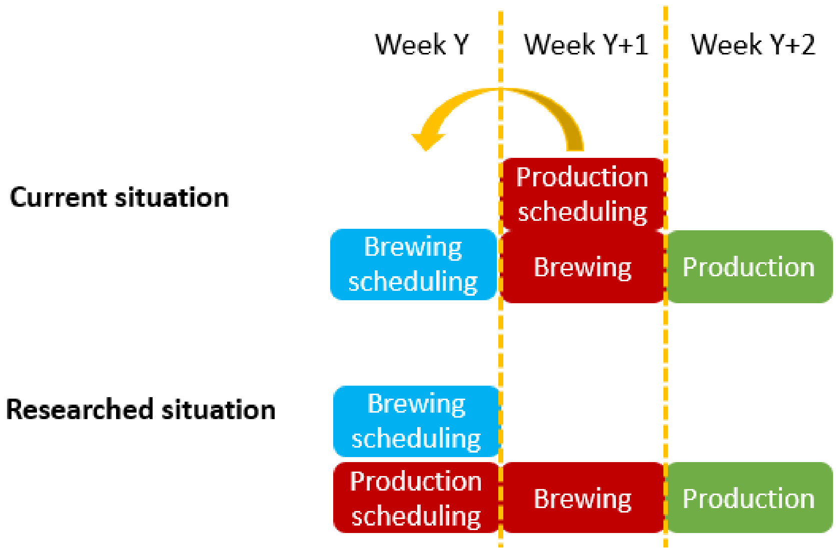

Figure 5.2 - Beer availability

When increasing the scheduling interval, TSCP creates in week Y the production plan for week Y+2 and the brewing schedule for week Y+1. For beers with a brewing time of one week or less, it is possible to brew the beers in week Y+1 so that these beers are on time for production in week Y+2. This results in the fact that for the researched situation, TSCP schedules beers with a brewing time of less than a week based on actual orders or shipment plans instead of scheduling the beers based on customer demand forecast. The result is that beers with a short brewing time should always be available in the researched situation, since it is known how much beer we need. In the current situation, it might occur that there is not enough beer available on time for production because the brewing plan is created according a customer demand forecast. Therefore, we conclude that the beer availability slightly increases with an increased frozen scheduling interval.

Conclusion HNS Beer Availability
We conclude that beer availability slightly increases due to an increased frozen scheduling interval. Since the process of beer planning is a specific process within HNS, nothing can be found in literature about the impact beer availability. However, the beer availability is a process of planning and scheduling. Literature describes that increasing the frozen scheduling interval results in a decrease in schedule instability. This also holds for the beer scheduling processes, because the beers are brewed according actual orders or shipment plans instead of customer demand forecast, which reduces uncertainty.

5.5 HNS Scheduling

Section 4.7 describes the MILP that we use. This section describes the results from the MILP. Subsection 5.5.1 describes the input and output data. We describe in Subsection 5.5.2 the choice for the AIMMS running length and Subsection 5.5.3 describes the limitations of the model. This section ends with Subsection 5.5.4 in which we describe the results of the model and thus the impact of an increased frozen scheduling interval on the HNS Scheduling department.

5.5.1 Input and Output Data

Before introducing the results of the MILP, we describe the used input parameters and output data. Section 4.7 explains that the objective of the MILP is to minimize the makespan, which consists of the parameter processing time and the variables changeover time and idle time. The changeover time is based on the current changeover matrices available at HNS. The changeover time from one product to another product is based on the following input parameters:

- *Beer type*. The beer type describes which beer should be produced, if it is a HEINEKEN or an AMSTEL. There are 77 different types of beers for the breweries Zoeterwoude and 's-Hertogenbosch.
- *Product size*. The product size indicates the size of the product. There are 31 different product sizes in use.
- *Product type*. The product type indicates the type of product in which the beer will be packed. This differs from cans, to draught kegs to bottles. There are 44 different product types.
- *Secondary pack type*. The secondary pack type indicates how many of one product is packed in one box. For example, the 4x6-pack indicates that one box contains 4 times a 6-pack of beer. There are 16 different secondary pack types.

Every line has a standard product type that it produces. That is why most of the lines have their own changeover matrix or a shared one with a line that produces familiar product types. These changeover matrices combine the beer types, product sizes, product types and secondary pack type to one code. Based on this code, the changeover matrix determines the changeover time.

The other input parameter is the release date per product. If a product is not available on Monday, the production order containing that product obtains a release date. To keep the mathematical model linear, the week is divided in time buckets. A release date indicates after which time bucket the production order can start.

One of the outputs of the model is the objective, the total makespan. The total makespan is split up in total changeover time on the line, total idle time and total processing time. We mention in Section 4.7 that the processing time is a constant. Therefore, it is not of main interest for the main goal of the HNS Scheduling part, since the main goal of the HNS Scheduling part is to determine what the impact is of an increased frozen scheduling horizon on the production schedule. We use the idle time and the changeover time to determine the impact. The other output is the sequence of products. We use the sequence of products for validation of the model, as Section 4.8 describes.

5.5.2 AIMMS Running Length

We explain our choice for AIMMS in Section 4.7 and expect that for some lines and weeks the AIMMS running length has to be restricted. After running the model for several weeks and lines, we conclude that the AIMMS running length should be limited for weeks with more than 10 products. We limit the running length based on the gap. The gap is a percentage that indicates the difference between the best LP bound and the best solution. The higher the gap, the further away the best LP bound is from the best solution.

We observe that for weeks with less than 10 products on the line, AIMMS is able to solve the problem in less than 5 seconds. However, for weeks with more than 10 products on a line, AIMMS needs more time to solve to optimality. Since we want to determine the impact of an increased frozen scheduling interval on the production schedule and not change the way of scheduling, we accept that the model does not always find an optimal solution. To test as much weeks and lines as possible, we first test the model and outcomes for a time limit of 30 minutes.

After running the model several times for different weeks and different lines, we compare the sequences of products of the model with the realized production schedule to see what the influence of a gap is on the optimality of the schedule. We conclude that a gap larger than 10% results in a sequence of production orders with lots of space for improvement. A good example of this is week 24 at HBLYN08B in 's-Hertogenbosch. The number of products for that week is 23 with 2 material restrictions for the current situation and 0 restrictions for the researched situation. After running the model for 30 minutes, the gap was still 15%. We observe that this specific week contains 5 different beer types all with different pack types. The diversity of beer types and pack types results in complexity for the model, because a lot of changeovers are possible.

Another consequence and prove that a gap of 10% or larger does not result in the desired outcome is the following. In week 24 the model places a Desperados production order in the middle of the production schedule, while that is not desired given the objective, because changing to Desperados and then changing to another beer is changeover time costly. When increasing the AIMMS running length to 60 minutes, we observe that the Desperados production order is at the start of the week. Which is better for the changeover time.

We conclude that the main reason for a high gap is the diversity of beer types in a week. When there are more than 4 beer types in a week, the gap remains above the 10% in 30 minutes running time. Therefore, we decide to run the model for weeks with more than 4 beer types for 60 minutes, so that we obtain more reliable outcomes.

5.5.3 Limitations

During the implementation of the model, we validate the model. Validation is done by comparing the sequence of the products and the total changeover time with reality. Section 4.7 describes the assumptions we make for this research. During this validation, we find several limitations, which are the consequence of the assumptions or other small aspects that we do not consider during this research:

- The model determines the optimal schedule for ever week and line separately. This might have as consequence that the production schedule for week Y is optimal and the production schedule for week Y+1 as well. However, the last order in week Y and the first order in week Y+1 might be completely different, which in reality results in a high changeover which is undesired. In reality, the scheduler tries to start the week with the beer type or pack type the previous week ended with, since this results in less changeover time for both weeks. Since 's-Hertogenbosch produces different beer types, the scheduler tries to combine the same beer type over different lines. This is more efficient for the beer and filtration scheduler. However, the model does not consider scheduling the same beer types at the same day in the week.
- We do not consider efficiency loss after a changeover, because efficiency losses are not registered at HNS. The model switches between pack types and returns to pack types that are already assigned to a production order in the week, since the changeover time between the production orders is equal. However, after changing the pack type of a product, the line experiences efficiency loss. The consequence of not incorporating this efficiency loss, is that the sequence of products from the model deviate from reality, since the OS scheduler keeps this efficiency loss in mind while scheduling. The changeover time in that week remains the same.
- Input parameters are based on the current efficiency rates and changeovers matrices. During the year, new insights force the changeover matrices or efficiency rates to change. When we compare the current model results with results from the previous year, it might be the case that for some products the efficiency rates have changed. This has as consequence that the model calculates idle time, but in reality, this idle time would not have occurred since the line was not finished yet due to lower efficiency rates at that time.

5.5.4 Results

Section 5.5.1 describes that we use the idle time and changeover time to determine the impact of an increased frozen scheduling horizon on the HNS production schedule. We conclude in Section 5.2 that an increased frozen scheduling interval results in less material restrictions in production scheduling, thus in a higher material availability. We expect that less restrictions gives the OS scheduler more freedom to create an optimal schedule, thus resulting in a lower changeover time per line per week for the researched situation.

We run the model for the can lines, because we expect to achieve the biggest changeover time reduction for those lines. HNS own three can lines: HBLYN17 and HBLYN24 in 's-Hertogenbosch and ZWLYN06 in Zoeterwoude. In the current situation, HNS observes lots of restriction on the can lines and with the expectation that less restrictions result in less changeover time, this is a good way to test our hypothesis.

Changeover time reduction is especially an important topic for the can lines, since HNS currently outsources a part of their can production. When saving changeover time, HNS has to oursource less can line production, which results in high production and outsource cost reductions.

Table 5.10 provides an overview of the results.

Confidential table

Table 5.10 - Changeover time savings for can lines

From the results in the table we conclude that an increased frozen scheudling interval results in less changeover time per week for the can lines. The biggest savings are realized for the can lines in 's-Hertogenbosch. The brewery in 's-Hertogenbosch produces lots of different beer types, which cause lots of changeovers and longer changeover times, since the complete line should be cleaned between changing the line from one beer type to another beer type. From the savings in Table 5.10 we calculate that an average saving of 14 minutes per line per week can be realized due to less material restrictions after implementing the increased frozen scheduling interval. From the Business Controller of HNS, we obtain that a minute of changeover saving is equal to 60 euro financial savings. These costs include the cost reduction for savings a part of the volume that HNS outsources. This results in a production cost savings of €131,400 on a yearly basis.

Table 5.10 shows a total idle time of 18,216 minutes. It is important to find out where this idle time comes from. One of the main reasons is that the model assumes that a week always starts on Monday at 00:00 hour. However, in reality, the week starts when the last production order of the previous week ended. This could be at 09:00 hour in the morning. When there is a week with lots of restrictions, the orders in the model are finished 9 hours earlier than in reality. This has as consequence that idle time arises. Therefore, we accept idle time as a theoretical residue. That means that the idle time that occurs does not result in any potential positive or negative changes for HNS when implementing the increased frozen scheduling horizon.

In this research, we assume that fewer material restrictions result in less changeover time per line per week. We examine this assumption for the can lines. Table 5.11 shows the total number of restrictions for the year 2019 for the can lines.

Confidential table

Table 5.11 - Number of restrictions can lines

The number in the table confirm the finding for the material availability, the number of material restrictions decrease. However, it is insightful to know if all these restrictions occur at the start or at the end of the week, since this might influence the freedom of the OS scheduler for creating a production schedule. Figure 5.3 shows how these restrictions are spread throughout the week.

Confidential figure

Figure 5.3 - Number of restrictions for the can lines for the current and researched situation

Figure 5.3 shows that the number of material restrictions in the current situation is higher than for the researched situation. Table 5.10 shows that fewer material restrictions result in a schedule with less changeover time. However, in the results we observe that a decrease in material restrictions does not necessarily result in lower changeover time. The results show that some weeks have for the current situation several material restrictions and for the researched situation zero material restrictions and that both weeks have the same changeover times, the only difference is the sequence of products.

A good example is week 37 on the line ZWLYN07. This line produces SOL in the odd weeks. In this specific week, there are 14 products in total of which 12 have a material restriction for the current situation. This was due to the fact that 12 production orders should produce SOL and the label supplier for the SOL label was not able to deliver the labels on time. For the reserarched situation, the number of restrictions was zero. At first sight, we expect that the total changeover time for the researched situation would be much better than the total changeover time for the current situation, due to the amount of restrictions.

All the 12 material restrictions were on Tuesday. So, the OS scheduler had to choose one of the two remaining produciton orders as first. The processing time of the first two production orders is long enough to start the third production order at Tuesday. In the end, this results in exaclty the same schedule for the reserached situation (without any restrictions).

When looking at other weeks, we observe that it is more beneficial when there are more material restrictions at the start of the week, then just a few at the end of the week. Material restrictions at the end of the week give the OS scheduler less freedom to schedule optimally. While most material restrictions that occur at the start of the week cause less trouble, since there is enough choice for an optimal sequence with the remaining production orders without material restriction.

Now we know that the impact of an increased frozen scheduling interval results in an average saving of 14 minutes for the can lines, we examine the impact on the bottle lines. The bottle lines have the most material restictions in the current situation after the can lines. HNS has 12 bottle lines: HBLYN08A, HBLYN08B, HBLYN16A and HBLYN16B in 's-Hertogenbosch and the lines ZWLYN03, ZWLYN07, ZWLYN21, ZWLYN22, ZWLYN51, ZWLYN52, ZWLYN81 and ZWLYN82 in Zoeterwoude. The other four bottle lines are not in scope of this research. We do not choose the last four lines, because the line ZWLYN51 was most of the times not operating in 2019. The other three lines, ZWLYN52, ZWLYN81 and ZWLYN82 have a small product portfolio. This results in long production runs and less changeover time. That is why we expect not to achieve big changeover time savings on these four lines.

Table 5.12 provides an overview of the results for the bottle lines.

Confidential table

Table 5.12 - Changeover time savings for bottle lines

We observe in Table 5.12 that there are more restrictions for the researched situation than for the current situation. There are two possible explanations for this. The first explanation is that in the current situation TSCP contacts the supplier in week Y to ask if the supplier is not able to deliver the required materials earlier. Sometimes it happens that the supplier indeed can deliver earlier in the week. This only happens for the material restrictions in week Y+1, since the restrictions in week Y+2 are not in the scope yet. Therefore, we state that the number of restrictions for the researched situation might even decrease further when HNS implement the increased frozen scheduling interval, because TSCP then calls in week Y the suppliers with material restrictions for week Y+2. The second possible explanation might be that for the bottle lines, some materials are used on multiple orders. For example, the SOL front label that is used in multiple production orders throughout the week. When there is a restriction on that SOL front label, multiple orders obtain that release date in one week. If this problem is solved in week Y for week Y+1, this restriction does not show up in the number of restrictions for the current situation, but still in the column for the number of restrictions in the researched situation. Another possible explanation might be that HNS observes lots of restrictions for a certain week and decides to move that production run to the next week. However, it is not included in the data set when TSCP decides to move the production run to the next week.

We conclude from the results that for the bottle lines, one week increased frozen scheduling interval does not result in substantial changeover time saving. This might be due to the fact that the number of restrictions is already lower than for the can lines, so the OS scheduler is less restricted on the bottle lines than on the can lines.

Conclusion Changeover Time per Line per Week

We conclude for the changeover time per line per week that it decreases with an average of 14 minutes per can line per week but does have significantly changes for the bottle lines. For the other production lines, we do not expect considerable advantages due to an increased frozen scheduling interval. Section 5.2.2 describes that an increased frozen scheduling interval results in less material restrictions. We conclude in this section that less material restrictions not necessarily result in less changeover time per line per week. The impact of material restrictions on changeover time is noticeable when the timing of material restrictions moves from the end of the week to the start of the week.

Sahin et al (2008) and Nadaei & Mahlooji (2014) both describe that an increased frozen scheduling interval results in less schedule instability for the manufacturer. For this case, we consider HNS as the manufacturer. In the current situation is the production schedule for one week frozen. The consequence that we observe from a decrease in schedule instability is that the total changeover time per line per week decreases for certain lines. This complies with the findings from Bai et al (2002), in which they conclude that increasing the frozen scheduling interval decreases total costs, mainly due to the decrease in change costs and set-up costs. Change costs are cost that occur when the production schedule has to change due to new insights and set-up costs are costs for setting up the line for a production order, which at HNS is called changeover time. We conclude that our findings comply with previous researches performed, because the total amount of changeover time per line per week decreases with an increased frozen scheduling interval.

5.6 Conclusion on Experimental Results

This chapter answers the main research question: "*What is the impact of an increased frozen scheduling interval on the controllable and uncontrollable variables in production planning of HNS and the consequences for the supply chain*?". Each section describes a part of the research question.

Section 5.1 gives insight in the impact of an increased frozen scheduling interval from a customer's perspective. We use two controllable variables to determine the impact: the customer forecast update flexibility and the customer safety stock level. We determine impact on the forecast accuracy for the MTO and replenishment customers. We conclude that for the MTO customers the forecast accuracy decreases when HNS implements an increased frozen scheduling interval. In X % of all cases the customer uses the last week to adapt their forecast closer to the actuals, but in X % of all cases, the forecast in week X-5 is closer to the actuals. We conclude for the replenishment customers that an increased frozen scheduling interval would not impact their forecast accuracy. The forecast is in X % of all cases in the current situation equal to the forecast in the researched situation. For the other X % it holds that it equally divides if the forecast in week X-5 or week X-4 is closer to the actuals. Regarding the controllable variable customer safety stock level, we conclude a yearly inventory holding costs increase of circa € X.

Section 5.2 highlights the research from a supplier's perspective. For the suppliers we determine the impact based on the uncontrollable variables purchase cost and material availability. The only suppliers that indicate to benefit from an increased frozen scheduling interval are the carton and draught keg suppliers. These suppliers state that receiving the final purchase order one week earlier would result in a more efficiently process. That results in a yearly saving of € X and a one-time saving of € X. The suppliers state that they will lower the purchase costs. For the uncontrollable variable material availability, we observe that the number of restrictions lowers when we increase the frozen scheduling horizon. This results in a higher material availability.

Section 5.3 explains that an increased frozen scheduling interval does not change the carrier transport availability. The process of arranging transport is captured in a day-to-day process and does not change with an increased frozen scheduling interval. We conclude in Section 5.4 that the beer availability slightly increases with an increased frozen interval. Due to the fact that HNS can determine the beer planning for beer types with a brewing time of less than a week based on actual orders instead of a forecast.

We conclude in Section 5.5 that we realize an average changeover time reduction of 14 minutes per line per week when implementing the increased frozen scheduling interval. This results in a yearly saving of € X. We conclude for the bottle lines that an increased frozen scheduling interval does not result in substantiate changeover time savings. We also conclude that the idle time is just a theoretical residue of the model and that less material restrictions do not directly result in a production schedule with less changeover time. It is more beneficial for HNS to have more restrictions at the start of the week than at the end of the week.

Chapter 6 - Conclusion and Recommendations

This final chapter contains the conclusions and recommendations of this research. Section 6.1 provides all conclusions regarding this research followed up by the discussion in Section 6.2. Finally, Section 6.3 explains all recommendations for HNS.

6.1 Conclusion

In this research, we answer the following main research question:
"What is the impact of an increased frozen scheduling interval on the controllable and uncontrollable variables in production planning of HNS and the consequences for the supply chain?"

HNS is known as the flexible HEINEKEN brewery. Therefore, HNS has the goal to produce flexible against low cost. Due to the COVID-19 pandemic, HNS is forced to lower their costs, even if that means giving up some of the service they provide right now to their customers. In the current situation, HNS creates the production schedule in week Y for week Y+1. We research what the impact of an increased frozen scheduling interval of one week is on the supply chain of HNS.

We describe in the current situation analysis that the HNS' supply chain consists of five players for whom we determine the impact of an increased frozen scheduling interval:

- Customers
- HNS planning department
- Suppliers
- Carriers
- HNS scheduling department

The main lesson we learn from literature is that several models are introduced to determine the optimal freezing length. However, HNS is interested in what the impact is of an increased frozen scheduling interval on the supply chain. Therefore, we decide to come up with different variables per player in the HNS' supply chain that might be affected by an increased frozen scheduling interval. We select these variables based on the current situation analysis and literature review. We choose to create the solution design in two parts. The customers at one side and the combination of the players HNS planning, HNS scheduling and Carrier and Supplier at the other side. We combine these players to determine the impact of an increased frozen scheduling interval on the HNS scheduling department.

We define for the customers the controllable variables customer service level and forecast update flexibility. The customer forecast update flexibility is the ability for customers to change their forecast as late as possible. We determine the impact on the forecast accuracy for the MTO and replenishment customers by comparing the forecast changes compared to the actuals. For the MTO customers we conclude that in X % of all cases, customer does not change the forecast between week X-4 and week X-5. We observe that in X % of the cases, the MTO customers use the last week to change their forecast closer to the actuals. For X % of the cases is the forecast in week X-5 closer to the actuals. We observe that the deviation between the forecasted quantity and the ordered quantity slightly increases with an increased frozen scheduling interval for the MTO customers.

We observe for the replenishment customers that an increased frozen scheduling horizon would not have a big impact on their forecast update flexibility. In X % of all cases is the forecast in week X-4 equal to the forecast in week X-3. We conclude that the MTO customers would experience some loss in their forecast accuracy and the majority of the replenishment customer would not experience a difference. The slightly decrease in customer forecast update flexibility might result in more rush orders or cancellations. Especially customers with a short shipment time might gain new insights in their customer demand forecast, which results in rush orders or cancellations. However, HNS does not track the number of rush orders or cancellations. Therefore, we cannot quantify this uncontrollable variable.

The second controllable variable for the customers is safety stock, since safety stock is a method to prevent customers from uncertainty during lead time. When increasing the lead time, we expect to increase the safety stock level. We determine the impact for the customers HNC, HGER, HTW and HUSA, who represent around 90% of HNS in-market safety stocks. Given that the service level per product remains the same, we conclude that the total increase in inventory holding costs due to increase in safety stock for these customers combined is around € X.

We define two uncontrollable variables for the suppliers: the material availability and the purchase costs. We determine the impact on the material availability based on the number of restrictions. We observe that the number of restrictions decreases when we increase the frozen scheduling interval, which results in a higher material availability. We discuss the impact of an increased frozen scheduling interval on the purchase costs with the department Contract Management. Two suppliers indicate receiving the final purchase order one week earlier could result in a more efficiently planning and production produce. That results in savings on the supplier side. The suppliers recharge these cost savings in the purchase cost. One supplier indicate that it could save up to a one-off of € X. The other supplier indicate that an increased frozen scheduling interval saves them up to € X a year.

We determine the impact on the carrier's side with the help of the uncontrollable variable transport availability. The process of arranging transport is captured in a day-to-day process and does not change with an increased frozen scheduling interval. For the HNS Planning part we define the uncontrollable variable beer availability. HNS brews all beers according a customer demand forecast. When increasing the frozen scheduling interval with one week, beers with a brewing time of one week or less can be brewed according actual orders. This increases beer availability for beers with a brewing time of one week or less.

We define the uncontrollable variable changeover time per line per week to determine the impact of an increased frozen scheduling interval on the HNS production schedule. We introduce a MILP to determine the changeover times for the current situation and for the researched situation. We conclude that we realize an average saving of 14 minutes changeover time per line per week for the can lines. The 14 minutes per line per week results in a yearly saving of € X. We observe no improvement achievable for the bottle lines. This might be due to the fact that bottle lines experience fewer material restrictions in the current situation than can lines. This gives the OS scheduler already the freedom to schedule to optimality. Regarding the material restrictions, we observe that it is better for HNS to have more restrictions at the start of the week than restrictions at the end of the week.

Table 6.1 shows the impact of an increased frozen scheduling interval of one week per controllable or uncontrollable variable.

Potential savings		**Potential losses**		**No impact**
Decrease in material purchase costs	€ X	Loss in customer forecast update flexibility (MTO)	€ X	Supplier transport availability
Higher material availability	€ X	Increase in inventory holding costs	€ X	
Decrease in changeover time per line per week	€ X	Higher chance of rush orders or cancellations	€ X	
Higher beer availability	€ X			

Table 6.1 – Positive, negative and no impact summarized

When we compare the savings with the losses, we conclude that the savings are much higher than the losses. However, we should not forget that the negative impact on customer forecast update flexibility cannot be quantified. Due to the COVID-19 pandemic, HNS moves their focus from high service level for the customers to realizing more cost savings, even though this might be at the expense of customer service.

6.2 Discussion

We elaborate in this section more on assumptions and limitations that we made during this research.

The first point of discussion is the choice to look at the impact on the players in the supply chain separately. Supply chain planning dependents on all factors, starting from the customer's side, ending at the supplier's and carrier's side. During this research, we describe the underlying links between the supply chain players. However, we do not incorporate those links in the calculations. When we increase the frozen scheduling interval and the customer has to send their order one week earlier, the customer faces higher uncertainty. Higher uncertainty results in higher safety stock levels. Even though we are aware of the links and we describe them, we still quantify the impact separately and are not able to quantify the impact of several players in the supply chain on each other.

The second point of is the assumption that the service level remains the same. We assume for the calculation of the safety stock levels that the z value remains the same. However, due to the COVID-19 pandemic, HNS changes their focus from high service to saving costs, even if this is at the expense of customer service level. When we calculate the safety stock levels for the customers with a lower service level, the outcome of the safety stock levels might decrease. The other variables, such as the demand variation and supply variation still change due to an increased frozen scheduling interval. So, the safety stock levels would still increase for customers, but the increase would be less high.

The third point of discussion is the choice for historical data. We base our findings and conclusions in this research on historical data, because all needed data is available at HNS. However, we want to discuss the following. When HNS increases the frozen scheduling interval, lots of processes and behaviors require change. For example, we compare the forecast of customers in week X-4 and week X-5. Customers know that HNS measures the forecast accuracy in the weeks X-4 and week X-6. It might be the case that customers do not change their forecast between week X-6 and week X-5, because HNS does not measures. We observe that in X % of all cases the replenishment customer does not change the forecast. When increasing the frozen scheduling interval, customers might behave differently, since they have to send their forecast one week earlier. This might result in a decrease in forecast update flexibility. The same holds for the calculation of the safety stock levels. We base the new safety stock levels on historical data. However, it might be the case that customers would differently forecast for an increased frozen scheduling interval. That results in a lower demand variation than the tool now calculates. A lower demand variation results in a lower increase in inventory holding costs.

The last point of discussion is the model that we introduce in Section 4.7. A model is a theoretical imitation of reality. That means that the model never completely mimics reality. That results in limitations, such as the efficiency rates that we do not consider. Resulting in other sequences than reality. However, the objective still complies with reality for those cases. To approach reality as close as possible, we take several actions of validation and verification. We explain those steps in Section 4.8.

6.3 Recommendations

This final section closes this research with recommendations for HNS and recommendations for further research.

The first recommendation for HNS is to determine the impact of an increased frozen scheduling interval on the processes within the organisation. All processes within HNS are organized based on the current situation in which one week is frozen. Some processes might change quite easily when increasing the frozen scheduling interval from one to two weeks, others require more time and structure. An example of this is when a line stops operating due to failure. In the current situation, the scheduler needs to reschedule only the current week. However, for the researched situation it holds that the scheduler should reschedule the current and the next week. This causes lots of rework.

The second recommendation for HNS is to determine how to convince everyone inside and outside the organization to change. When implementing the increased frozen scheduling interval, processes within HNS require change, but also processes at the customer, supplier and carrier side. Customers need to be convinced of sending their final purchase order or forecast one week earlier. HNS might experience resilience from the customers, since we observe in Table 6.1 that the customers mainly experiences the disadvantages of an increased frozen scheduling interval. HNS decides to keep the costs savings at their side, so the beer prices will not go down with an increased frozen scheduling interval. Besides that, the current cost savings are too low compared to the total year volume for the customer to notice a decrease in the beer price. Processes and the way data is stored within databases also need to change. As a result of this research, HNS already started a workgroup in which they are going to map which processes require change.

The third recommendation for HNS is to determine how to approach the customers. As we explain in the second recommendation, the customer experiences the most disadvantages. During this research, we are not allowed to talk to customers, because we expect resilience against the idea. To not alarm the customers without knowing the outcome of the research, we decide not to have a conversation with a customer about the idea of an increased frozen scheduling interval. Therefore, it is important to determine for HNS how to approach the customers before implementing the increased frozen scheduling interval.

An idea for further research that continues on the third recommendation is the idea of Demirel et al. (2018). Table 6.1 shows that only the customers experience the negative impact of an increased frozen scheduling interval. To reduce the negative impact for the customers, it might be insightful to investigate the opportunity for Flexibility Requirements Profile (FRP). FRP enforces flexibility bounds on production plans so that planned production quantities remain within lower and upper bounds. It also ensures that the deviations in the dynamic planning process stay within the specified ranges while rolling on the planning horizon. We observe in Section 5.1.1 that the most deviation between the forecasted quantity and the ordered quantity is just a half percentage of HNS' total week volume. FRP introduces 1%, 3% or 5% flexible bounds. FRP might seems promising at first sight for HNS, since the customer's deviation is not that large compared to HNS total week volume. Figure 6.1 shows that the amount of flexibility that is permitted will be higher in distant future periods considering higher degrees of uncertainty in the demand compared to the near future.

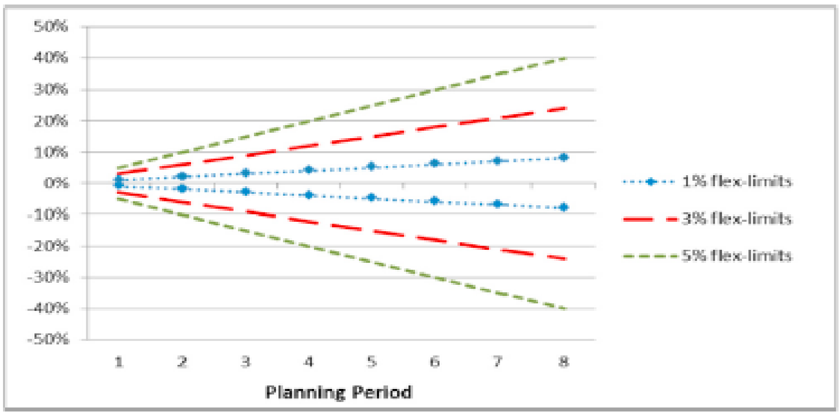

Figure 6.1 - Illustration of the flex-limits in the planning horizon (Demirel et al, 2018)

To satisfy the customers when HNS decides to increase the frozen scheduling interval, HNS might consider the Flexibility Requirement Profile. This is a solution whereby the customer does not lose the full customer forecast update flexibility, but it also gives HNS more certainty about what the customer is going to order, such that HNS can already order at the suppliers. This gives the suppliers still the advantage of knowing the orders one week earlier. However, it might be the case that the quantity can change with just a small percentage. It would be insightful to know what the impact is of combining an increased frozen scheduling interval in combination with the Flexibility Requirement Profile.

For literature we recommend describing the supply chain as one system. In the current literature, the biggest supply chain for which the increased frozen interval is determined, consists of two stages. The supply chain consists of a manufacturer and a vendor or a customer and manufacturer. However, we enrich literature with a three-stage supply chain, since we conclude that all players in the supply chain are equally important and all experience advantages or disadvantages of an increased frozen scheduling interval.

The second recommendation for literature is to evaluate the impact on the short-term planning process. Literature mainly describes the impact on the medium-term planning process, by evaluating the impact on the schedule instability or nervousness, vendor's flexibility or safety stock levels. However, what is missing in literature is an elaborate description on the short-term impact. This research proves that when increasing the scheduling interval, the production schedule changes in a positive sense. The total changeover time decreases per line per week and the OS scheduler obtains more flexibility to schedule the production orders.

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We removed all appendices due to confidential reasons.

Appendix A – Forecast Update Flexibility

Appendix B – Safety Stock Levels HNC Low and High Season

Appendix C – Safety Stock Levels HUSA and HTW