Master thesis Industrial Engineering & Management

Optimization of the inbound supply chain for small sized materials with low demand

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Preface

Throughout the writing of this thesis, I have received a great deal of support and assistance.

I would first like to thank my company supervisor, Rob Robbers, who has given me the best introduction in the world of Heineken Netherlands Supply and with whom I have worked together with great joy.

I would like to thank my lead supervisor Matthieu van der Heijden for the great devotion he has helped me with, not only in writing this thesis but also during several courses I have followed during my studies.

I would like to acknowledge my colleagues from the Raw&Pack team for making me feel part of the team and it was great to get experiences from their work, in the turbulent times of the corona crisis.

I also would like to thank my "colleagues" and friends, which happen to be my housemates as well. It was great to have your support and to discuss our thoughts together next to the coffee machine, as most of us were writing our master thesis simultaneously.

Disclaimer

Management summary

When operating in a saturated market, innovation is key to persuade new customers and to keep current customers loyal. One of the many innovative products that Heineken has brought to market are the Blade and Brewlock products. Not only the product itself is unique, but also the inbound supply chain is unique for Heineken Netherlands Supply (HNS). All Blade and Brewlock materials are single-sourced from suppliers all over Europe to several independently organised breweries across Europe. This does not only bring economies of scale for the production of these materials for the supplier, but it also brings a risk in terms of security of supply to the different Heineken breweries. This unique situation including the small size of materials and the production speed of packaging lines result in an unusual and probably inefficient supply chain, as HNS is used to big volumes.

We identify the transfer price being too high as an action problem. Eventually, the price of the Blade and Brewlock products that HNS calculates to Heineken Netherlands Commerce and other Operating Company (OpCo)s will decide if these relatively new products will be a success and profitable to HNS. The quantities shipped (call-off order quantities) to HNS are sourced with lot-size based quantity discounts. The impact of these lot-size based quantity discounts are unknown for HNS as they are used to big volumes. Secondly, this research is focused on the future situation, where a new packaging line is taken into use at different brewery. Inter-brewery transport could be of use to move materials cheaply between the two breweries. This way more lot-size based quantity discounts and lower total cost can be achieved

We have investigated the contracts and mentioned discounts. The demand forecast mentioned in contracts are often very optimistic and the minimum order quantities are not always easily achieved by an individual OpCo, so contracts can be misleading for predicting lot sizes. To get some insights in the potential savings, we have compared the current situation against the situation where all lot-size based quantity discounts are used. The maximum potential savings of using larger order quantities are €66,372 in two years. If we would never use the smallest lot size, already 83% of these savings are achieved. As annual demand increases for a material, the importance of lot-size-based quantity discounts increase as well, as larger demands without increasing order quantities result in a larger number of orders, where discounts are missed more often. Inter-brewery transport could be of use to move materials cheaply between the two breweries, this gives the possibility to merge orders from both breweries to the supplier. The single-source situation of Blade and Brewlock materials makes Vendor Managed Inventory (VMI), where the supplier is in control of distribution material to the breweries, interesting. However, VMI may be hard to implement, because Heineken is a very decentralised organisation, where every brewery can have different working methods. Our research is focused on two breweries in the Netherlands, both part of the HNS.

The problem we are optimizing can be described as a multi-item, multi-location lot-sizing problem. Our problem instances seem quite small, so computation time should not be of the biggest importance. So, we can use AIMMS as our modelling software, HNS is also familiar with this software. A MILP formulation is used for solving our lot-sizing problem, because this is a common formulation and because the model is formulated linearly, this makes it relatively fast to solve. We have extended a standard multi-item lot-sizing problem with quantity discounts, a rolling horizon, multiple inventory locations, with transportation between the locations and the possibility of certain material types to free ride on the quantity discounts of other materials. A rolling horizon is used to simulate the current ordering process. We have built several versions of the model to test different scenario's. A simple one-location model is used to validate the model against the current situation.

We have verified the model and we assume the model to be correct because the model gave logical output given the historical shipping data we have used as input. All of the average order quantities were larger than the average weekly demand quantities, therefore the model bundles demand of several weeks. And the average order quantities increased as the planning horizon is increased, except when all of the quantity discounts are achieved. Also did the total cost decrease as the model was solved with more information, i.e. a longer planning horizon. The effect of incorporating an extra location with more demand has a big effect on the average order quantities and promotes the use of lot size based quantity discounts. When the demand increases (by adding an extra location), the importance of using a

longer planning horizon becomes less important as the maximal quantity discounts are more easily reached.

The result of the scenarios we have tested resulted in significant savings, of maximally €373,714 which can be achieved by increasing the planning horizon and using a two-stop-route with direct delivery for the two materials sourced from the same supplier. Average order quantities for four out of seven have increased by 5% to 33% by the outcomes of the base scenario. So, it would be cost-efficient to make more use of these discounts, in general as these four materials are more important.

To bundle the demand in one order quantity decision we can make use of inter-brewery transport or a direct delivery with two stops. Direct delivery is always cheaper when the average order quantity is above twelve pallets. This can be achieved by a using a two-stop-route. And solve the model with shared ordering cost for the materials that are sourced from the same supplier result in even larger order quantities.

Two material types should not be ordered in larger quantities, holding costs are high and lot-size based quantity discounts are small. So, inter-brewery transportation is also not useful for these material types because inter-brewery transportation is only useful for full pallets and the quantities on a pallet for these materials are too large.

The model proposed in this thesis can be used in future for HNS as well. The model is made as generic as possible and has an understandable user interface that can be used by the procurement department. The model is transferred to the Tactical Supply Chain Planning (TSCP) department and can be adjusted if needed by employees with knowledge of AIMMS. By modifying some constraints and using different input, several interesting scenario's can be tested. The model can be used to investigate the usefulness of inter-brewery transport, maybe for other materials, this can be a really interesting way of dividing inventory across breweries. There does not exist a tool that easily takes into account the free-riding of materials. The model can be used to investigate other materials where free-riding is already happening or possible. Also, the model can be used to make better decisions for the trade-off between groupage transportation and direct delivery. Where you can easily calculate when direct delivery becomes cheaper, the model calculates the expected average order quantities given the prices for groupage transportation or direct delivery. Furthermore, the ordering process itself can be investigated, especially changes in the planning horizon and planning interval. And lastly, the use of warehouse space during the year can already be predicted by the model. However there are other ways to calculate the warehouse space required, the model gives an outcome for each period and can therefore predict tight periods.

In general, the model can be of use for new materials or situations where an alternative way of ordering could be better than the current. A change in demand, costs or space available can trigger situations where the inbound supply chain should be alternatively organised. The model can explore settings and help in decisions to be made to organise this supply chain. We hope the proposed model and the insights found in this thesis do not only help for improving the Blade and Brewlock inbound supply chain but also helps in future situations.

Contents

Abbreviations

3PL Third-Party Logistics provider. 79

CS&L Customer Service & Logistics. 1, 12, 13

DDP Delivered Duty Paid. 10

ERP Enterprise Resource Planning. 15

EXW Ex-Works. 10

FTL Full Truck Load. 2, 8–11, 15, 31, 36, 39, 44, 46, 47, 49, 50, 52, 54, 64

HBBV Heineken Brewery BV. 54

HGP HEINEKEN Global Procurement. 7–9, 64

HNS Heineken Netherlands Supply. v, vi, 1–17, 19–27, 31, 43, 44, 49, 50, 52, 57–59, 61–65, 73, 79, 80, 83, 84, 87, 88

HUSA Heineken United States of America. 1

IB Inter-brewery. 10, 17, 28–31, 35, 37, 38, 43–45, 47–53, 55, 58, 60–62, 64

IRP Inventory Routing Problem. 20, 21

JIT Just In Time. 12

LTL Less Than Truckload. 39, 44, 58, 60

MBP Market Business Partners. 12

MILP Mixed Integer Linear Program. 25, 30, 32, 39

MINLP Mixed Integer Non-Linear Program. 25

MOQ Minimum Order Quantity. 8, 9, 14, 17, 44, 61

MRP Material Requirements Plan. 12, 25, 32, 33, 35, 39–41, 44, 45, 59, 62, 64, 87

MTO Make to Order. 15

OpCo Operating Company. v, 1–6, 8–11, 15, 17, 20–23, 61, 63–65, 73, 79

OPI Operational Performance Indicator. 54

OS Operations Scheduling. 10, 12, 14–17, 26, 31, 36, 39, 43, 44, 54, 59, 60, 64, 84

PO Purchase Order. 14, 15, 59

SKU Stock Keeping Unit. 10

SSCP Strategical Supply Chain Planning. 12

TSCP Tactical Supply Chain Planning. vi, 1, 5, 12, 14, 15, 26, 31, 44, 52, 57, 59, 62

VMI Vendor Managed Inventory. v, 10, 17, 21, 23, 24, 59, 61, 65

WACC Weighted Average Cost of Capital. 13, 17, 24, 26, 61, 62

CHAPTER 1

Introduction

In this chapter, we give an introduction about the company in Section 1.1, we give the motivation for our research, Section 1.2, we give some give context on the problem, Section 1.3, wherein we briefly explain the Blade and Brewlockproducts. These sections are followed by the Problem Cluster, Section 1.4, and in the end we present our plan of approach, Section 1.5, wherein we will present our research questions.

1.1 Company description

The research was conducted within the company Heineken Netherlands Supply (HNS). This company is an independent legal entity, next to the independent legal entities Heineken Netherlands Commerce and Vrumona. This is quite a new and unique structure because it changed at 01-01-2020 and this structure cannot be found in other countries where Heineken operates. In most other countries there is one Operating Company (OpCo) that produces Heineken products and sells Heineken products (mostly) to the market of the country it is situated in (to supermarkets, restaurants, bars, cafes, etc). Only 25-30% of the hectoliters produced in the Netherlands is sold in the Netherlands. Therefore, HNS is a separate company, HNS sells its beer (packaged and ready for consumers) to Heineken Netherlands Commerce and more than 150 other OpCos all over the world.

There is an OpCo situated in a country if there are Heineken products sold in this country. The existence of an OpCo in a country does not say anything about the number of breweries in the country. Typically one OpCo has more than one brewery it can utilize, but for instance, Heineken USA (Heineken United States of America (HUSA)) does not have a brewery in the United States. The OpCo HUSA buys Heineken from HNS, because the customers in the United States value that Heineken beer is imported.

HNS has three breweries under its wing, the biggest one is in Zoeterwoude, this is also where the biggest office is situated. This brewery is the Flexible Global Brewery and is used as a buffer for the world. It is used to produce for emerging markets in countries that do not have its brewery yet or to help other OpCos that have problems to meet their demand, for example. There is another smaller brewery in Den Bosch: the Innovation Brewery. Lots of different recipes can be produced here simultaneously. The third one is the small Brand Brewery in Wijlre, this brewery is used to make craft beers.

Within the company, Heineken Netherlands Supply the research is done within the Customer Service and Logistics department (Customer Service & Logistics (CS&L)), and within the CS&L department the research is done in at two departments: Procurement and Supply Chain Planning.
Within these departments, the research is focused on two teams. Within the procurement department, the research is focused on the Raw & Pack team. The Raw & Pack team is responsible for the procurement of all packaging materials and commodities required to produce and pack the different kinds of beers.
Within the Supply Chain Planning department, the research is focused on the Tactical Supply Chain Planning team (TSCP). The Tactical Planning team makes sure the demand forecast for the coming thirteen weeks can be produced in terms of production line and material availability. My supervisor is

Rob Robbers, he is category specialist pack at the Raw & Pack team. The Blade and Brewlock products are in his portfolio.

1.2 Motivation for research

As the Blade and Brewlock products are at in the growth phase of the product life cycle, optimization of cost for the production of these products is key to make these products a profitable success. Motivation for the thought that the inbound supply chain can be more efficiently organised comes from that inbound supply for the materials required to produce the Blade and Brewlock products is unusual for HNS.

HNS has agreed with their suppliers to send a forecast for the materials required for the coming thirteen weeks, this forecast is updated every week. HNS has agreed with suppliers that HNS will buy the amounts forecast for the coming thirteen weeks, in the coming thirteen weeks. Therefore, the supplier can plan, produce inventories required to supply and produce in bigger batches. This is needed because HNS does not have much space for inventory on location. This means materials sometimes arrive at the brewery only hours before they are used for production, even during the night. This agreement works well for most materials but probably the inventory management, as it is done currently, is not optimal for every material required to produce. Low demand for Blade and Brewlock materials result in small order quantities and small order quantities are relatively expensive because of lot size based quantity discounts. Lot size based quantities are given to promote Full Truck Load (FTL)s. So, if materials take less space in the warehouse than on average and are ordered in smaller quantities than average, then a different way of managing the inventory looks promising.

1.3 Problem context

In this section, we briefly explain about what we mean with Blade and Brewlock materials in Section 1.3.1 and explain what makes these materials unique for HNS in Section 1.3.2

1.3.1 Blade and Brewlock materials

The Blade and Brewlock are similar products that make use of plastic 'Airkegs'. An Airkeg is a keg that is made out of a preform that is inflated on the production line, just before the keg is filled with beer. So, the materials required for producing the Blade and Brewlock are all small in size. All the different materials are two different Preforms, a Valve, a SmartCap (only required for the Blade), a beer tube (only required for the Brewlock), a sleeve (only required for the blade), a box tray (only required for the Brewlock), a temper cap, (only required for the Brewlock), a protective collar (only required for the Brewlock) and two different boxes. More information about the Blade and Brewlock products can be found in Appendix A.

1.3.2 Multiple OpCos sharing the same supplier

Something that makes this inbound supply chain of the Blade and Brewlock materials more complex is that HNS is not the only OpCo that produces the Blade and Brewlock products. In Europe there are nine different OpCos that produce Blade and Brewlock products. In general, every OpCo produces (if they have a brewery) for the demand in the country that they are situated in. Next to this, they can sell to other OpCos if those OpCos do not produce (enough) to meet the demand in their country.
Also, beer brands have to be taken into account, for example, Heineken 0.0 can currently only be filled in the brewery in Zoeterwoude and is sold all over the world. Not every brewery produces every brand, so sometimes do OpCos need to import beer types from other OpCos. Also, packaging and brewing is a separate thing. For instance, the Brewery in Zoeterwoude does not produce Affligem beer. Affligem beer is brought from Belgium to Zoeterwoude to be packed, because the Affligem Brewery does not have a Blade and Brewlock packaging line.
And there is also a difference in packaging lines, the line in Zoeterwoude can produce the Blade and Brewlock products, but the new line in Den Bosch is only designed to produce Blade products, for

example. Global Network Planning allocates market demand to OpCos in a way that capacity restrictions are met.

1.4 Problem Cluster

For the use of identifying the core problem, we use the terminology and structure of the Managerial Problem Solving Method, described by Heerkens and van Winden (2017). In Figure 1.1 we see arrows that go separately into another box or go merged into another box. If the arrows are merged, this means that both factors combined affect the next box. If the arrows are not merged, it means that the factors separately affect the next box.

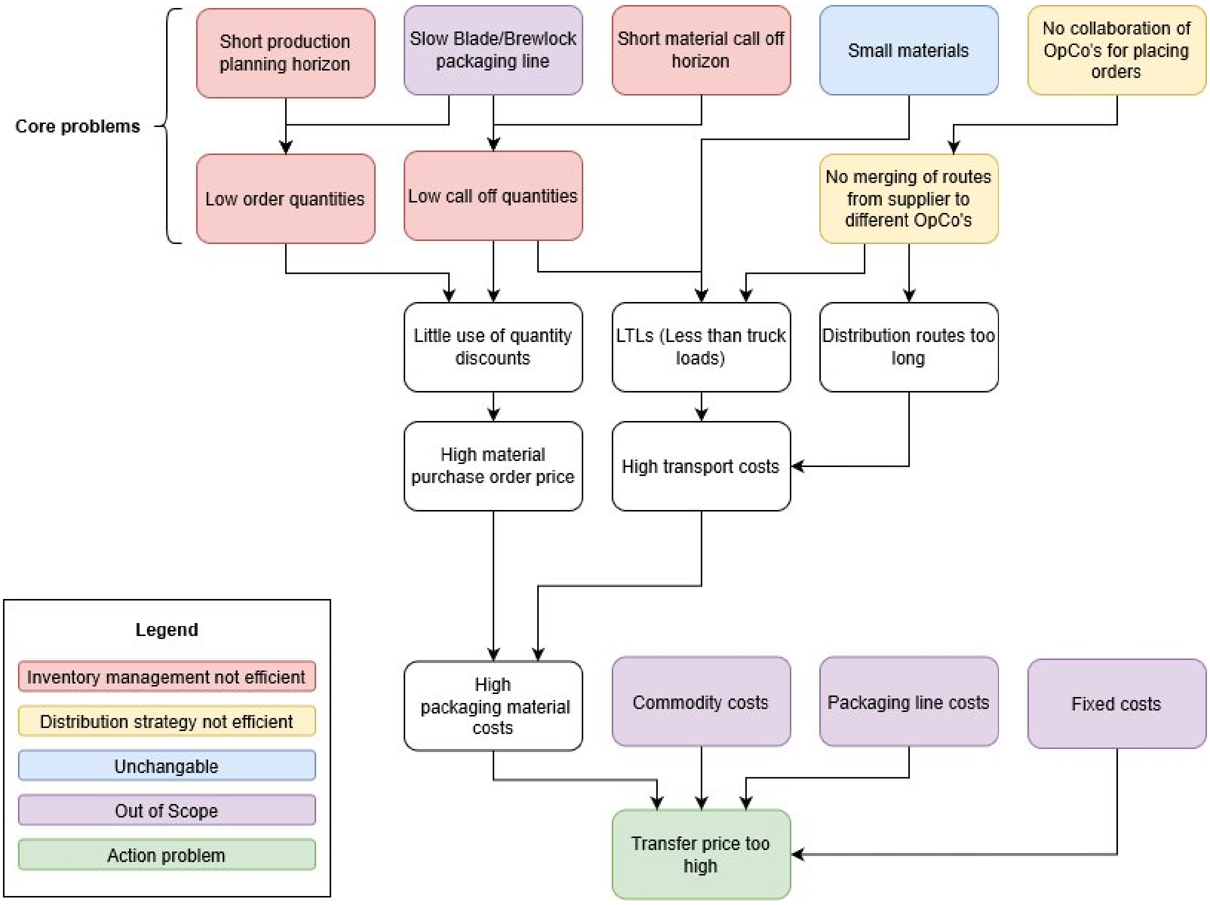

Figure 1.1: The problem cluster

As can be seen in figure 1.1, we identify the transfer price being too high as an action problem. Eventually the price of the Blade and Brewlock products that HNS calculates to Heineken Netherlands Commerce and other OpCos will decide if these relatively new products will be a success and profitable to Heineken. This price is currently high and should be lowered to make the Blade and Brewlock a real profitable success. The transfer price has a fixed component that is allocated over the quantities that are produced. Part of these fixed costs are, for instance, the salary of personnel, depreciation of investments and brewery costs. This is out of scope because we are not able to influence the number of Blade and Brewlock products to be produced and the costs are not able to influence to fixed costs itself.

Commodity cost is, simply said, the cost of beer. These costs are not different from any other product of Heineken, so this is out of scope. Also, packaging line costs are not simply influenced, these costs are completely depended on the packaging line and we cannot change the packaging line easily. The packaging lines of the Blade and Brewlock are still developing a lot, but the packaging itself is considered out of scope as it can be seen as a whole other project.

In case of the Blades around the half of the transfer price comes from packaging material costs, so this is the biggest factor in the transfer price.
The packaging material costs are high because these materials are expensive to buy and expensive to transport partly because they are bought in small quantities. Currently, HNS makes little use of the quantity discounts. The quantity discounts are not available for every material, this differs per material. If there are quantity discounts or not and the height of the discounts should be agreed in the contract.

1.4.1 Two different kinds of quantity discounts

The purchase order price is high because two kinds of quantity discount are not optimally used. Depending on the contract between the supplier and HNS there are quantity discounts on the quantities ordered (and not shipped yet) and the quantities shipped (call-off quantities). The production planning horizon is the thirteen-week-forecast, the quantities given in this forecast are bought. The material call-off horizon is one week, because operations scheduling reviews their inventory one time a week and places orders for materials based on this inventory level. We want to research if another way of working for the Blade and Brewlock would have a decreasing effect on the transfer price.

1.4.2 High transportation costs

The transport costs are high because trucks are not always full and distribution routes are long. The combination of small materials and small quantities result in trucks that are not full. There is also no merger of routes to the different breweries, this could save costs because it could help to achieve full truckloads and make distribution routes shorter in total.

1.5 Research questions & plan of approach

In this chapter, we explain the design of our research. Firstly, we define our main research question. After that, we explain our sub research questions and the scope of the research.

1.5.1 Main research question

How can we come to an optimal inventory management and distribution strategy for materials required to produce the Blade and Brewlock products by Heineken Netherlands Supply?

1.5.2 Research questions

1. **How is the current inventory management, distribution strategy and contract management for the Blade and Brewlock organized within Heineken Netherlands Supply?**

   (a) *How is the inventory of the materials required to produce the Blade and Brewlock managed and how does it perform?*
   We need to know how the inventory currently is managed, which departments are responsible for which inventory and why it is organized this way currently, because we need to have interviews with Strategical planning, Tactical Supply Chain Planning and Operation Scheduling to find out who orders, who allocates demand, where is the forecast coming from, etc.
   Data about inventory levels and replacement orders would be useful to get an idea of the flow of inventory. We can get this data from the previously mentioned departments.
   After this research is done, we know how the inventory is managed and by whom and why it is done the current way. We also know what the results are in terms of inventory levels, replacement orders and where the biggest improvement can be found.

   (b) *How is the current distribution of materials for the Blade and Brewlock currently organized and how does it perform?*
   We need to know how the materials are ordered, how the distribution is organized and why the current distribution choices are made.
   Data about the order quantities and transportation routes from the supplier to the OpCos

could give us an idea of how efficient the current way of working is. It is maybe going to be tricky to get all the data from other OpCos, but should be possible to get the data we need. This is because we know how many materials suppliers produce and how much the other OpCos produce in finished products. And if we can convince that other OpCos or Heineken Global can have savings by collaboration between OpCos then we should be able to get all the data without problems. Getting data from suppliers should be relatively easy, given that the Blade and Brewlock products are single-source and HNS shares a lot of information with the supplier. Within HNS, we can get information out of contracts with suppliers and data about the orders placed can we get from the procurement and planning department.
After we managed to get all the data we should have an idea of the potential savings we could have by collaboration between OpCos for distribution routes from the suppliers.

(c) *What do the current contracts and agreements that HNS has with suppliers take into account and how do they influence the inventory management and distribution strategy?*
The current contracts and agreements have a big influence on the performance of the inventory management and distribution strategy because the quantity discounts and transportation agreements are enclosed in those. We need insight into how these contracts and agreements are created and how they perform in the case of the Blade and Brewlock materials.

2. **Which methods can be used for the inbound supply chain of the Blade and Brewlock materials at HNS on the subject of inventory management and distribution strategy?**

   We have to do literature research to find inventory policies suitable for the situation found within HNS. We have to take into account the agreements with suppliers, the way of working within HNS and the thirteen-week-forecast, for instance. After we know how the distribution of materials to OpCos is performing, we know what potential lies in merging of distribution routes. If it has potential, then we have to do literature research on methods to solve this inventory routing problem.

   After answering this question we should know what methods would be best suitable for improving the inventory management and solving the inventory routing problem.

3. **What are the limitations for adapting the methods and how can we model the inventory management and distribution of the Blade and Brewlockmaterials for HNS?**

   After knowing which methods can be used, we have to identify the limitations for HNS. We need to do interviews and discuss what limitations can be found for implementing these methods. We need to know what can be changed in the way of working and whatnot. For the inventory policy, we have to discuss a lot with TSCP and Procurement for instance. We also need to know the capacity of all storage locations, which we can ask in the warehouse. In general, we need to look for limitations that restrict us in choosing a policy. And we need to look for restrictions which we can use in the model itself.

   The result would be a complete model that can be used to improve the current situation, with all the limitations and restrictions we can find included.

4. **What is the best way to improve the inventory management and distribution for the Blade and Brewlock materials in the current situation and what is the expected impact for HNS?**

   Now that we know how the current situation performs and what methods can be used to improve this, we need to combine this knowledge and calculate the results when we implement these improvements. We can use historical data, which we get from Procurement and TSCP, to compare the optimal situation against the current situation. The model should give us results in inventory management decisions and distribution decisions. To do sensitivity analysis, we can use various forecasts and some other materials characteristics.

5. **How can we implement the model within HNS for future use?**

   Since, the Blade and Brewlock products are in the early adopters phase, the demand for the Blade and Brewlock products is probably going to increase a lot. So, we need to make an implementation plan for HNS, so they can keep improving their inventory management and distribution decisions adjusted to the changing demand. We are curious if we could use the model for other materials as well in the future.

1.5.3 The problem scope

The problem scope will mainly include the Blade and Brewlock materials. But in the end, we will try to build the model as universal as possible, so it can be used in the future as well. The main research question is based on improving the situation within HNS but we will not exclude the distribution from the suppliers to other OpCos because collaboration on distribution of materials could be an efficient way of optimizing the distribution to HNS.

CHAPTER 2

Current situation

In this chapter we give an overview of the problem context by giving answer to the research question:

- ***How is the current inventory management, distribution strategy and contract management for the Blade and Brewlock organized within HEINEKEN Netherlands Supply?***

To answer this question we divide this chapter into three parts by answering three sub research questions. Section 2.1 provides context based on the contracts for the Blade and Brewlock materials, Section 2.2 gives context on the different ways of organising transportation from the supplier to HNS and the last part, Section 2.3 gives us more insights on how inventory is managed at HNS.

2.1 Contracts with suppliers

In this chapter we analyze the contracts that HEINEKEN Global Procurement (HGP) has with the supplier that HNS uses to purchase materials for the Blade and Brewlock products. So we answer the following research question:

- *What do the current contracts and agreements that HNS has with suppliers take into account and how do they influence the inventory management and distribution strategy?*

Table 2.1: Location and price break points of Blade and Brewlockmaterials and suppliers

Supplier information		Price break points of lot-sizes (in pallets)	
Material	Country	Mentioned in contract	Mentioned in pricing list
Brewlock Box	Netherlands	-	32, 64
Collar	Belgium	1	1
Boxtray	Belgium	-	5, 10, 15, 20, 25, 30
SmartCap	Belgium	-	5, 10, 15, 20, 25, 30
Protective cap	Germany	1	1
Preform 8L	Luxembourg	1	12, 18, 26
Preform 20L	Luxembourg	1	12, 18, 26
Bladebox	Italy	4, 16, 30	4, 16, 30
Sleeve	Italy	1, 2, 3	10/27, 5/9, 3/5, 20/27, 1
Valve	UK	3	1

We start with this part because this gives us an overview of the different suppliers and quantity discounts that are applicable. HNS has contracts with suppliers that are mostly based on a forecast of the demand and during the contract time they refresh the agreements according to a pricing list. We will discuss the contract and pricing list. The prices paid for materials are reviewed quarterly and can be negotiated and adjusted if needed. The Blade and Brewlock materials are shown in Table 2.1, all of the suppliers are different companies except for the supplier of the SmartCap, Boxtray and preforms. The preforms come from the same supplier and the SmartCap and Boxtray come from the same supplier. The largest lot-size mentioned for the Brewlock box, Boxtray, SmartCap, Preform8L, Preform20L and Bladebox are all FTLs. We see that in contracts there are hardly any price breaks mentioned, mostly only an Minimum Order Quantity (MOQ) of one pallet is mentioned.

2.1.1 Sleeves

The single-source supplier for the sleeves that HNS uses is located in northern Italy, this contract is quite detailed. In contracts are several rough forecasts for the coming years mentioned (The contracts is already a few years old) on the quantities expected to source, as can be seen in Table 2.2. The supplier gives two types of discounts, lot size discounts for calling off one, two or three pallets and discounts on the volume sourced each year. In Table 2.2 we have calculated the expected pallet price if we use a MOQ of one or three pallets. The difference in pallet price (including transportation costs) between using a MOQ of one or three is always €1.82 per 1000 pieces, but as the demand increases the total cost that goes along with a smaller MOQ are getting larger. So, in the early phase of a new product like the Blade a small MOQ is less 'harmful' than when demand rises.

Table 2.2: Costs & prices including transport based on base & high case Sleeve

		Base case total purchasing costs (€)			Price per thousand pieces (in €)		
Year	Forecast	1 Pallet	3 Pallet	Difference	1 Pallet	3 Pallet	Difference
2017	Y	X	X	2,730	X	X	1.82
2018	$2.8 \times X$	X	X	7,644	X	X	1.82
2019	$4.8 \times X$	X	X	13,104	X	X	1.82
2020	$15 \times X$	X	X	18,200	X	X	1.82
		High case total purchasing costs (€)					
2017	Z	X	X	4,004	X	X	1.82
2018	$3.18 \times Z$	X	X	12,740	X	X	1.82
2019	$4.86 \times Z$	X	X	19,474	X	X	1.82
2020	$6.52 \times Z$	X	X	26,117	X	X	1.82

Interesting is that in the pricing list lot-size-based quantity discounts are given based on quantities up to one pallet, instead of the one, two and three pallets mentioned in the contract. Reasons for this could be that the contracts are made by HGP and they make contracts based on the total demand of all OpCos producing the Blade. Therefore, a MOQ of 1 pallet looks very easily reached, but for a particular OpCo this a big lot size. And even if we look at the demand in whole Europe, then there are big numbers mentioned in the non-binding quantities forecast in this contract. The forecast for 2020 in this contract is about 3 times higher than the forecast at the beginning of 2020.

2.1.2 Bladebox

The Blade box is also sourced from northern Italy but a different supplier than the Sleeves. This is a special kind of box because it is water-resistant and made from plastic. The contract is very similar to the Sleeve contract, 2.1.1. The difference in pallet price (including transport costs) between using a MOQ of one truckload or four pallets is always €108.69 and is constant just like in the contract of the Sleeves. And also for the Bladeboxes, using larger MOQs makes more sense when the demand is larger. However, in this case, we are talking about larger numbers. The Bladebox is a lot more expensive than the sleeve and ordering in larger quantities has a bigger impact on the total costs.

In this case, the lot size based quantity discounts are the same in the pricing list. It looks like we can conclude that HGP made a good estimate of the lot sizes OpCos would order. But the contract prices do not match at all with prices that can be found in the pricing list. It is not completely clear why this is the case. A reason could be that the oil price increased a lot (which makes plastics more expensive) but the biggest reason is probably that HGP works with a quite optimistic forecast for the demand in whole Europe. The contract was made at the beginning of 2017 and the non-binding forecast quantities were about three to four times higher than the forecast made this year for 2020.

2.1.3 Other materials

In this section we will discuss other materials, in the contracts of these materials there are lot-size based quantity discounts mentioned. So, we can assume that these discounts were not taken into account when these contracts were negotiated. However, the pricing list does mention lot size based quantities, so these quantity discounts were probable negotiated at a later stage or not considered of great influence on the total costs.

Preform The single-source supplier for the Preforms is located in Luxembourg. The transportation costs are fixed for FTLs and the contract mentions: *'In case HEINEKEN does not order an FTL, the transport cost can be adjusted accordingly. Supplier and Supplier Affiliates will always deliver the exact volume as stated on the Purchase Order.'*. And so has happened, according to the pricing the list the lot size based quantity discounts are based on quantities ranging between 12, 18 and a full truckload of 26 pallets. There is no MOQ for the preforms to be found.

Valves The preferred supplier for the valves for HNS is located in the United Kingdom. The contract gives volume discounts for quantities purchased each year. In the contract is a MOQ of three pallets mentioned, in the pricing list, the price of one pallet is mentioned. So, the MOQ is changed to one pallet, after the contract was made. There are no lot size based quantity discounts mentioned in the pricing list or contracts.

SmartCap & Boxtray These materials are produced in Belgium. There are no quantity discounts for these materials to be found in the contracts. The Boxtray has a MOQ of 1 pallet (6000 pieces) and also the SmartCap has a MOQ of 1 pallet (3450 pieces). But in the pricing list, we found lot-size-based quantity discounts for both materials in the range of 1, 5, 10, 15, 20 and 30 pallets.

Collar, protective cap and Brewlock box For these materials, the contract was not available. But there are also no lot-size-based quantity discounts to be found in the pricing list. There also seems to be no extra cost for transportation, transportation is included in the price, but it does not matter how big the lot size is. So, no transportation cost to be minimized. The Brewlock box is picked up by HNS, combined with other boxes from the same supplier. The Brewlock box is not leading in the decision if there is a transport required or not. So for these materials, we cannot save costs by making more use of the lot-size-based quantity discounts.

2.2 Distribution of materials

In this section, we explain the current situation on the subject of the distribution of the materials. As can be seen in Table 2.1, the materials are sourced from different places in Europe.

- ***How is the current distribution of materials for the Blade and Brewlock currently organized and how does it perform?***

2.2.1 Trade and transportation terms

Materials are transported from the supplier to a brewery by the supplier or by HNS. Ex-Works (EXW) is an international trade term that describes when a seller makes a product available at a designated location and the buyer of the product must cover the transport costs. Delivered Duty Paid (DDP) is a delivery agreement whereby the seller assumes all of the responsibility, risk, and costs associated with transporting goods until the buyer receives them at the brewery. Unlike most materials HNS sources, most of theBlade and Brewlock materials are sourced DDP, so the seller is responsible for the transportation. Only the Brewlock box is picked up by HNS, the truckloads are combined with other carton boxes from the same supplier, so the trucks are (mostly) full. Another possibility for transportation, that is not commonly used, is Groupage. A third party is responsible for the transportation and groups the orders of HNS with orders of other customers, the supplier and HNS both do not influence the transportation.

2.2.2 Inter-Brewery transportation

For HNS there is regular transportation between the brewery in Den Bosch and Zoeterwoude. Both Operations Scheduling (OS) teams can ask for Inter-brewery (IB)-transport. These trucks that drive between the two breweries are usually not full, so if we don't have many pallets, we can take advantages of these trucks. So, this gives an option that one brewery can be leading in the ordering of materials from the supplier and that the other brewery is supplied from the leading brewery that orders the materials. This is currently already happening for one type of material, the Hi-cone. A Hi-cone is a plastic ring packaging to bundle six cans of beer. This material is called off by Den Bosch because they use this material the most and the brewery in Zoeterwoude is supplied from Den Bosch. The reason for choosing IB-transport is that these materials are really small and HNS does not use it that often, but HNS has to order it in big quantities. So, this situation sounds similar to Blade and Brewlock packaging materials if want to make use of larger order quantities. If the materials do not fit in the trucks that are already driving between the breweries we have to use a new truck. Cost for an FTL one way is €205.44 and if we want to drive back immediately, it costs €245.92 in total.

2.2.3 Single source materials

All materials required to produce the Blade and Brewlock products are single sourced, one type of material can only be sourced from one supplier. Only the valve is produced at two suppliers, but we can consider the situation for most OpCos almost as single-source because the assigned supplier for HNS and Greece has limited capacity. And the packaging material specialists at HNS are not convinced that the quality of the valves from the other supplier is good enough to use at the packaging line at HNS. So, a good relationship with the supplier is key to establish a reliable supply chain to the packaging line.

The big advantage of this single source situation is the economies of scale that can be reached at the supplier. Multiple OpCos order the same materials at the same supplier that produces one uniform product. This looks like an ideal situation for VMI. Unfortunately, we are not sure about the suppliers if they are capable of managing the inventory of all OpCos. Also, HEINEKEN is a decentralised company and every OpCo has a different way of working. The supply chains around HNS are much more complex than the standard brewery because of all the different Stock Keeping Unit (SKU)s for domestic and export use. HNS works with the thirteen-week forecast for tactical planning, where other OpCos do not have this. Although, there is a need for controlling the inventory at the supplier because you do not want OpCos to compete against each other for inventory. In the end, the best situation for HEINEKEN company, as a whole, is the most important goal. HEINEKEN Global Network Planning is responsible for this but as we currently know, there is no priority list of OpCos or something similar.

2.2.4 An inventory routing problem

We know it is hard, given the production line speed of the Blade and Brewlock products and the current way of working to order materials in FTL. This could be the case for every other OpCo because their production lines speeds are similar. Since all of the materials are single source and several OpCos are located close to each other, it could be cost-effective for OpCos to bundle their orders placed at the supplier to make a milk run resulting in a FTL. The country of residence of the suppliers can be found in

Figure 2.1: Map of Suppliers and OpCos

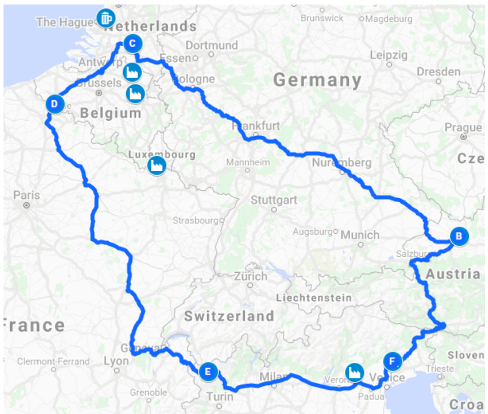

Figure 2.2: Example Delivery route

Table 2.1, the location of the Breweries where Blade and Brewlock products are made can be found in Figure 2.1.

Certainly for the materials transported over a long distance, for example from Italy, should FTLs be desirable. Bundling of orders of the breweries in The Netherlands and France could be a way to achieve FTLs, if they are not achieved at the moment. We can see in Figure 2.2 an example of a route which bundles the breweries in Austria, Den Bosch, France and Italy. By combining the orders of multiple OpCos inventory levels can remain low while the order quantities have increased. Collaboration between OpCos gives challenges but could be worth the trouble if the saving is substantial.

2.3 Inventory management

In this section, we are going to answer the following sub-questions.

- *How is the inventory of the materials required to produce the Blade and Brewlock managed and how does it perform?*

In Section 2.3.1 we give some insights in the warehouse space that is required for Blade and Brewlock materials, Section2.3.2 we explain about the ordering process within HNS. Section 2.3.3 gives insight in warehousing situation of HNS and the costs involved. Section 2.3.4 explains the inventory policy that is used within HNS. Section 2.3.5 gives an elaborate answer to the question if there is potential for cost savings by using more lot-size-based quantity discounts. Section 2.3.6 concludes the insights explained in Section 2.3.5.

2.3.1 Space required and quantities produced

To give an illustration of how much space the materials of the Blade and Brewlock use, we can compare the 8 litre Blade Preform (the Preform itself does not have a volume of 8 litres of course), to a 5-litre Draught Keg. As we can see in Table 2.3, the number of Preforms that fit on a pallet is around five times the number of Draught Kegs and production goes more than 10 times faster for the Draught Kegs. So, this results in the big difference between the number of pallets required for one day of production, for 24 hours of production, 371 pallet Draught Kegs versus 5 pallets preforms.

Table 2.3: Comparison pallets required for production

	5L Draught Keg	8L Blade Preform
Quantity on pallet	324	1440
Nominal production speed (hour)	5000	300
Production (24 hours)	120000	7200
Nr of pallets required (24 hours)	371	5

2.3.2 The ordering process of HNS

At HNS the ordering process is forecast driven. The first forecast is made by Market Business Partners (MBP), they get several forecasts from their markets and merge and validate these different forecasts to one usable forecast for HNS. This forecast is sent to two departments, the Strategical Supply Chain Planning (SSCP) and the TSCP department. These two departments start to analyse the forecast, where Strategical Supply Chain Planning looks monthly at a horizon of at least 1.5 years and Tactical Supply Chain Planning uses weekly a thirteen-week-horizon. Strategical Supply Chain planning takes long term influences like line capacity, workforce size, marketing ideas and promotions into account. TSCP looks at the material availability and production line availability. The TSCP team makes a Material Requirements Plan (MRP) for the coming thirteen weeks, this MRP is in more detail for the coming two weeks. This more detailed two-week plan is sent to Operations Scheduling. The thirteen-week-forecast of materials required are sent to the suppliers and these materials are actually already bought, but not shipped yet. The forecast is sent, so the supplier knows the demand from HNS and can plan their production. This results in larger production batches and savings on changeover costs. The operation scheduling team plans for the coming two weeks and makes call-off orders, so OS decides if the materials are shipped and when they are shipped to the brewery. This process works well to achieve high standards of material availability. Even during the COVID-19 pandemic, scores over 97% were achieved. For a more detailed overview of the Blade and Brewlock material planning process we refer to Appendix B.

It is hard to determine the cost of this ordering process as there are several employees involved in the ordering process. An extensive calculation of these costs are considered out of scope, because it simply to much work. According to Durlinger (2013), ordering cost in the Netherlands are to be found in the range €10 - €150. We choose to use these insights of Durlinger (2013) and investigate the impact of the ordering cost in general.

2.3.3 Warehousing

Packaging materials are stored at the inbound warehouses at the brewery. There is not much space and HNS tries to work as Just In Time (JIT) as possible. As is discussed in the previous section 2.3.2, the inventory management is forecast driven. Suppliers and transporters are given time slots wherein they have to deliver the materials. This optimizes the storage costs at the inbound warehouse and distributes the workload over the day, but could result in higher costs at the supplier/transporter. For some extra information how safety stock is calculated and the concept of line inventory, we refer to Appendix D.1.

There are two warehouses at the brewery, one is rented from the CS&L department of HNS to the brewery, one is owned by the brewery. The inbound warehouses are divided into two parts: ground pallet places and pallet racks. There are about 2500 ground places and 600-700 pallet rack places. There are no fixed places for each material type, which makes it easier to utilize the space more efficiently. All cartons stored at the ground places, depending on the type is it possible to stack two or four pallets high. The ground pallet places are divided into zones of 40 pallet places. Each zone can only consist of one material type, therefore some space is unused. The Blade box, Brewlock box and preforms are stored at the ground places, they usually take up about 250 pallets places, around 10% of the ground places. For the other Blade and Brewlock materials are about 40 pallet rack places used in the other part of the warehouse, so around 6% of the pallet racks. These places are not divided into zones and every rack can be used for every material type. The utilization levels in the own warehouse are not exactly measured but lie according to OS in the range of 80%-100%. So, the warehouse space taken by the Blade and Brewlock materials is quite small, minor increases in warehouse space taken by the Blade and Brewlock products will not affect the total warehouse pace required a lot.

It is also really hard to make a distinction between which personnel belongs to which warehouse and for how much of their time are they working in this warehouse. Also are the warehousing cost for inbound and outbound not separately measured. So, making our calculation about what storage costs for the Blade and Brewlock materials is out of scope because it is really hard to declare each cost in the right way. It is a lot easier to use the fees that HNS needs to pay to a third party for storage. If we want to store material at a third party, we need to pay for transportation to the warehouse and handling costs. For storage at the third party, we need to pay four times handling costs and two times transportation costs. To have an idea of what storage at the own location costs, we can neglect the transportation costs and half of the handling costs. Table 2.4 gives the costs for using the external warehouse.

Table 2.4: Warehouse costs at third party (in € per pallet)

Transportation (one way)	Handling	Storage (each week)
1.92	1.08	1.57

However, this is just the cost of warehouse space. Most of the time the cost of capital of inventory is for expensive materials a larger component. As the materials for Blade and Brewlock products are quite small, we can say that one pallet of materials is quite expensive in terms of capital. According to Durlinger (2013) the Weighted Average Cost of Capital (WACC) can be used for determining the cost of capital of inventory. For HNS the WACC is X.X%, the results of X.X% of the purchase price can be found in Table 2.5.

Table 2.5: Cost of capital for each material per pallet based on WACC

Material	Cost of Capital (pallet)
M1	€ 12.78
M2	€ 5.72
M3	€ 23.70
M4	€ 2.04
M5	€ 9.74
M6	€ 8.69
M7	€ 53.40

Although, the boxes and preforms take some considerable amount of space, warehouse space is not a big restriction for most Blade and Brewlock products. An increase in order quantities will not immediately have the effect of using an extra pallet place at the third party. However, the warehouse space in Den Bosch was initially limited for the Blade materials. The investment for storage facilities was delayed because of a focus on costs due to the corona crisis. And since the Blade packaging line is situated very near to the CS&L warehouse, it does not use the inbound warehouse as warehouse space but a part of the CS&L more compact outbound warehouse. So, initially, the option of using an external warehouse for materials was not completely out of the question. In the appendix D.2, more can be found on the modelling of an external warehouse as an extension of the model presented in Chapter 4. At a later stage during the research a different location has been allocated for the storage of Blade materials, the storage space was not that limited anymore.

2.3.4 Inventory management and policies

Inventory management refers to the process of ordering, storing and using a company's inventory Sharma (2017). These include the management of raw materials, components and finished products, as well as warehousing and processing such items. An inventory policy is an integral part of inventory management. Simply said an inventory policy answers the following questions:

- How frequently should I review my inventory position for an item? (Review period)
- How much should I order? (Inventory position)
- When should I order? (Order point)

The review period in the common working process is each week, as can be read in Section 2.3.2. OS (and TSCP as well) work with a weekly drumbeat. OS does the call-off orders and decides the order quantity. They work with a safety stock level and then manually decide how much to order to have enough for the production of the coming one or two weeks. This safety stock level is calculated according to the formula in 2.3.3. OS generally does round up on the quantities to have been able to order in full pallets, there are no strict MOQs for OS and the lot size based discounts are not always considered. The safety stock level, the material need for production and the warehouse capacity are the main drivers for the call-off order quantities to be delivered at which moment. OS do not only decide how much to order but also schedules time slots for the materials to arrive. The working procedures with time slot makes it easy to optimize the warehouse handling and warehouse capacity but could give transporters and suppliers more hassle, which can result in higher transportation cost.

So, bluntly speaking, we have a period review of one week, a safety stock level and flexible order quantities. The best way to describe this current policy is an (R,s, S) policy according to Silver et al. (2017). However, the order-up-to level is not fixed in the case of HNS. S is manually calculated as material required for production for coming approximately 1.5 week + current inventory. In Chapter 3 we will discuss dynamic order-up-to levels. The time slots make this inventory policy also differs from a standard (R,s, S) system. Lead times can be considered constant in the case of HNS, as they are changeable by HNS.

In practice can a review period of one day be seen as a continuous review system, because there is no uncertainty in demand over one day. We could say the same about our one-week time span, production is fixed and inventory can usually be checked real-time. We prefer to describe the situation at HNS as a periodic review system because the quantities produced always differ a little from planned. A production line always has a small percentage of material loss on the line, so the safety stock may be used or not. And it is really hard to stop a line exactly at the moment you have produced enough. So, there is always a little uncertainty in what you produce each week. Also, the inventory for the Blade and Brewlock material cannot be checked real-time in Den Bosch. The storage location for the materials are not in the regular inbound warehouse because of the different location of the packaging line. So because of the inventory checking in Den Bosch and to take the production uncertainty into account we use the periodic review policy.

2.3.5 Purchase orders & invoices

To review the ordering behaviour of OS and to see if there is potential for cost savings when ordering in bigger quantities, we investigated data of purchase orders and the deliveries at HNS. When looking at the order lines the potential for cost savings look very high because the quantities for one order line do not sum up to large lot size quantities. When looking at the actual purchase orders, we see that purchase orders are mixed in the delivery data. Materials that are received by HNS are not immediately registered. Also, a Purchase Order (PO) can be edited for several days and OS decides when the materials have to be delivered. So, we do not know exactly what materials are ordered at what time and when which materials should be delivered. We had data on the purchase orders and the registering in the warehouse, these are both not the same as the shipment data. So, one truckload can consist of parts of several POs with different material types that are registered various moments in the warehouse. The lesson learned is that is it important to know exactly at what data we are looking at. Eventually, we got data based on the shipping notification, this data is grouped on what is shipped together, so on these quantities are lot-size based quantity discounts given.

We also came across some different prices, the net order price, the goods receipt price and the invoice price. Most of the time, these prices are the same. But prices do quarterly change during a year, so if an order is placed at the end of Q1, this price is seen as net order price, but the invoice price could already be the Q2 price. This is the cause for many differences in values paid and the values ordered. Most of time HNS paid less than they ordered, in value. This makes a good comparison of how much could be saved by using more quantity discounts hard to quantify precisely.

Another practice that influences the values paid en values ordered is that the supplier (sometimes in collaboration with TSCP) bundles orders. The Enterprise Resource Planning (ERP)-system, calculates a net-order-price based on the quantities of a specific material type. For some materials, this is most of the time inconsistent with the price paid, because orders are bundled and the lot size based quantity discounts are given because the supplier fills up to FTLs. We call this behaviour free-riding and we as this influences the use of quantity discounts we should take this into account. In the coming section, we will discuss each material in more detail.

Bladebox The supplier does (in collaboration with TSCP) a good job of merging call off orders into a FTLs. Even if it means that one purchase order is divided over two truck loads. We come to the conclusions that about 10/70 deliveries in the period 2018 - Q2 2020 was not an exact full truckload, which seems an acceptable ratio. The net ordering price that is calculated in the ERP-system is most of the time just misleading because the supplier does make use of FTLs. If we compare the current situation to a situation where only FTLs were ordered, HNS could have saved a considerable but not large amount (around 2% of the total cost on sourcing of the Bladebox), €36,727.- in two years, as can be seen in Table 2.6. One of the reasons that it is possible to bundle POs over several shipments, is that these boxes are an Make to Order (MTO) material. TSCP sends the forecast to the supplier and sends a PO, with a lead time of four weeks. This is not the usual way of working but this way FTLs are reached and the supplier does not need to make to stock for all the different artworks, which can be different for different OpCos. Maybe HNS can use the regular way of working when the Blade line in Den Bosch opens. So, the supplier makes to stock and OS is capable of ordering FTLs because the demand is higher. Disadvantages of the current way of working is that TSCP is doing work, they should not do. The supply chain is less flexible because orders have to be placed at least 4 weeks ahead.

Table 2.6: Potential savings Bladebox

Lot sizes	Quantities ordered	Price difference	Potential saving
less than 12,000	145,200	€250.00	€36,300
less than 24,000	97,600	€4.38	€ 427
24,000 pieces	1,082,000	-	-
		Total:	€36,727

Sleeves The situation for the sleeves is very similar to that of the Blade box. These materials are also sourced from Northern Italy but a different supplier. The biggest difference is are the lot sizes, the biggest lot size for Sleeves is one pallet. We estimate that around fourteen of the 40 shipments were not a full pallet. The potential savings for 2018-2020 were €7,903. Compared to the total spend of €243,000 this is relatively a small amount, which is logical as the Sleeve is mostly ordered in full pallets, 26 of the 40 orders and very few times in the smallest lot size, 5 of the 40 times. The table can be found in Appendix C.2.

Preforms It is hard to have get a clear overview of the shipments that have taken place with preforms. We made an estimation because these two materials free-ride on each other's quantity discounts. In other words, Blade preforms are getting cheaper if we order more Brewlock preforms and the other way around. If there were not more than four days in between two registrations of incoming orders then we assumed it must have been delivered in one shipment. We calculated the quantities that were delivered in loads smaller than 12 and 18. Then we took the same ratio as over the total demand in Blade versus Brewlock materials and used this to calculate the potential savings. The average delivery is about 21 pallets compared to a FTL of 26 pallets. Around 41 out of 114 deliveries consist of less than 18 pallets. These number can be found in table C.3 as well. The preforms for Blade and Brewlock can be bundled in one shipment, but the packaging line in Zoeterwoude will never need both preforms at the same time. The line produces Blade or Brewlock. Still, we see that many shipments consist of Blade and Brewlock materials. OS sees the forecast two weeks ahead, very generally speaking Blade and Brewlock are produced alternately every week. So OS probably orders for one week Blade materials and one-week Brewlock materials. The potential savings are €6,101, which is not a really significant amount as the total spent on both preforms is €3,905,695, logical as quite often large lot-sizes are used.

SmartCap & Boxtray The transportation of these is not arranged by the supplier or HNS but by a third party that merges these materials with deliveries for other customers. But the supplier still gives lot size based quantity discounts. Table 2.7 gives an overview of the potential savings by ordering in full trucks. This is usually not the case for this material, a total potential saving of €6,799 is relatively not that much compared to a spend of €813,072.

Table 2.7: Potential savings Smartcap

	Number of deliveries	Quantities	Price difference	Potential Savings
5 pallets	56	645,600	€ 8.28	€ 5,345
12 pallets	25	600,600	€ 2.42	€ 1,453
18 pallets	0		€ 0.87	€ -
26 pallets	0			
>26	0			
			Total:	€ 6,799

The Boxtray has some similar savings, but the spend is a lot smaller, €179,689.

Table 2.8: Potential savings Boxtray

	Number of deliveries	Quantities	Price difference	Potential Savings
5	66	942,240	€ 8.46	€ 7,971
10	7	228,000	€ 3.82	€871
15	0	0	€ 2.19	€ -
20	0	0	€ 1.27	€ -
25	0	0	€ 0.65	€ -
30	0	0	€ -	
>30	0	0		
			Total:	€ 8,842

There is reason to look at the possibility of transporting these goods directly by the supplier or HNS instead of a third party (groupage transportation). Deliveries are sometimes late, both HNS and the suppliers are not responsible for the transport and cannot influence the transport. Furthermore, hygienic transport for the SmartCap cannot completely be secured. This is important because the cap seals the keg and comes in direct contact with the beer. Especially for Heineken 0.0, a best seller for the Blade, Hygiene is important. Some steps have already been taken, the pallet packaging is recently changed because of instability, the SmartCaps are better protected now. But the wooden pallet is still not hygienic, the Brewery in Den Bosch prefers a plastic returnable pallet because they want to keep the space of the packaging line as clean as possible. We want to investigate if transport without groupage is possible if we merge the demand of the SmartCap and Boxtray from the two breweries into one shipment.

2.3.6 Reaching some quantity discounts

In general, the conclusion can be made that reaching the first price break is a good idea. The first price break always give the largest savings. If we sum all the maximum potential savings, we reach €66,372 in two years, savings reached by never using the smallest lot size will already reach €54,890, 83% of the total. A wish of the OS department is more insight into the financial consequences of their lot size decisions, at the moment of ordering no calculated consideration between holding costs and ordering costs is done. So, we do now that the savings achieved by lot-size based quantity discounts are not huge but also cannot be neglected. Further on in this research, we will focus on the balance between quantity discounts and holding costs.

2.3.6.1 The small example of keg caps

These caps are not used by Blade and Brewlock products but give a good example of savings that can be reached by ordering in larger quantities. Keg caps are a quite standardized material used for all the 'normal' steel kegs. All breweries of HNS, including the Brand brewery order these caps individually. On average about one order each week is placed at the Brewery from either Zoeterwoude or Den Bosch. Every time the transportation costs €190.- The reason for the transport costs to be this high is that they are delivered in a time slot and that it is a direct delivery from Germany. Significant savings can be reached if some of these orders are merged. HNS could make use of the unused capacity in the IB-transport, and for instance place a jointly order once a month. This would bring down transportation costs to around 30% of the original costs.

2.4 Conclusions

- The demand forecast mentioned in contracts are often very optimistic and the MOQs are not always easily achieved by an individual OpCo, so contracts can be misleading for predicting lot sizes.
- The maximum potential savings of using larger order quantities are €66,372 in two years, if we would never use the smallest lot size, already 83% of these savings are reached.
- As annual demand increases for a material, the importance of lot-size-based quantity discounts increase as well.
- IB-transport could be of use to move materials cheaply between Zoeterwoude and Den Bosch, this gives the possibility to merge orders from both breweries to the supplier.
- Every Blade and Brewlock material is single-sourced, this is situation makes VMI look promising but it seems hard to implement because of different ways of working at OpCos and the supplier should be capable.
- The actual warehouse costs for only Blade and Brewlock materials are too difficult to determine, we can use the fees of an external warehouse as reference. The WACC of HNS is used to describe the cost of capital for inventory.
- The Blade and Brewlock materials are not voluminous, an increase in inventory levels for the Blade and Brewlock materials would not immediately have a significant effect on the total warehouse capacity that is used.

CHAPTER 3

Theoretical framework

In this chapter, we will discuss the literature found on the subject of location, inventory and routing problems. Inventory planning for multi-item systems with a joint setup cost, is a well-analyzed area of research of Management Science (Birbil et al., 2006). In this chapter, we will give an overview of related problems to the situation within HNS. The goal of our research is to optimize the inbound supply chain for HNS. By exploring the options to establish a more efficient supply chain we discuss several problems that touch the situation at HNS. We discuss, in this order, the Joint Replenishment Problem, the Inventory routing problem, Locating routing problem and the main subject Lot sizing problems. After this, we will be briefly discussing the Green supply chain and more elaborate Inventory policies. In this chapter we will answer the following research question:

- **Which methods can be used at HNS on the subject of inventory management and distribution strategy?**

3.1 Lot sizing problems

According to Melo and Ribeiro (2016) single-item lot-sizing problems with inventory bounds are extensively studied in literature but multi-item problems not. Most studies assume that the bottleneck in the lot-sizing problem is the production facility, however in some cases the inventory space available is. Melo and Ribeiro (2016) study the case of a bottleneck in the finished goods warehouse. This is, currently, not the case for the warehouse in Zoeterwoude but at the new production line in Den Bosch, there is currently not much space for materials because due to the current corona-crisis the investment in storage facilities is delayed. So for the current situation, the bottleneck can be the materials warehouse in Den Bosch.

Poliakova (2020) gives an extensive overview of the literature about multi-item lot-sizing problems and propose a heuristic for a multi-item lot-sizing problem with remanufacturing. So this is quite different.

Sancak and Salman (2011) describe a multi-item dynamic lot-sizing problem with delayed transportation policy, just like HNS. They propose to intentionally use some of the safety stock to be able to delay the transportation, to have bigger lot sizes that make full truck loads. This model could be of great use, as the situation is very similar. However, the model assumes no lead time, which is of course not the case for HNS. The multi-item lot-sizing problem is often found as a production lot size problem. In Guenther (2014) a block planning approach is proposed. Usually a discrete time scale is used for the multi-item lot-sizing problem. Guenther (2014) uses a continuous time scale where it minimizes the make-span. The modelling approach presented assumes the grouping of product variants into setup families and the production of product variants within a family in a predefined sequence. Numerical results demonstrate the practicability of this approach under experimental conditions which reflect typical settings from a leading company in the European beverage industry. So, the product families for Blade and Brewlock products would be the Blade family and the Brewlock family which both can be produced on the same production line.

3.2 Joint replenishment problem

According to Moon et al. (2008) and Silver et al. (2017), the main issue for a joint replenishment problem is investigating the economies of scale due to the coordination of the replenished items that have a common fixed (ordering/setup) cost. So, in general, this is the same as a lot-sizing problem, the difference is the application. Apart from this major fixed cost, there is an individual minor fixed cost associated with each item. The overall objective is to minimize the total average cost by determining a common basic cycle time along with the ordering frequency for each item. Setting the ordering frequencies to integer values ensures the coordination of replenishment of items. As a result of this coordination, savings on the major fixed cost are obtained. In the case of Blade and Brewlock materials, there can be found small joint replenishment problems at some suppliers. The Boxtray and SMART cap are sourced from one supplier, if we join orders into one shipment, we can see these transportation costs as the common fixed (ordering/setup costs). Although these are costs made by the supplier, this is not like this reflected in the pricing list discussed before in2, the quantity discounts are separately calculated without taking into account that some materials come from the same supplier and can be merged into one shipment.

Moon et al. (2008) goes in detail about quantity discounts, similar as in the situation found of the Blade and Brewlock materials. However, they also include supplier selection as they have the choice to source similar materials from different suppliers. This would only be useful if we decide to use other OpCos as a distribution centre for other OpCos. These joint replenishment problems assume that the ordering costs materials consist of a fixed part (the transportation costs) independent of the order quantity and part that is relative to the quantities ordered. In the case of the Blade and Brewlock materials, this is assimilated into the pricing list.

In Webb et al. (1997) a more production-driven approach is discussed. The major setup costs occur when a product family is scheduled, so this is a similar problem. In our case we can look at finished products as product families, because then a bill of material family is used, e.g. a Heineken Sleeve with a corresponding HEINEKEN box. However, it is possible to use this approach, it is not very promising because we only have two customer-specific packaging materials.

3.3 Inventory routing problem

Bertazzi and Speranza (2012) give an introduction to the Inventory routing problem (Inventory Routing Problem (IRP)), we refer to this for an overview of the pioneering papers that appeared in the eighties and the literature on the single link and direct shipping problems. We can see an IRP as a mix of Inventory Management and Transportation management, where Inventory management tries to answer the question: "How much to replenish?" and for Transportation management: "How to route the vehicles?". The two classes are combined in the question: "When to replenish which customer?". Furthermore, they cite surveys and the tutorials available on this subject.Bertazzi and Speranza (2013) give a tutorial about inventory routing problems. It gives a great introduction in what an IRP is and how you come from a TSP (Traveling Salesman Problem) to an IRP. Baita et al. (1998) give an extensive review about Routing and Inventory problems. They made a classification of different kinds of IRPs. It is interesting to see that mostly there is no restriction on warehouse capacity at the customer and/or supplier.

Mes et al. (2013) study the reverse IRP in the context of waste collection of underground containers with sensors. In the dense network of this context, the container selection becomes more important than the route, this is in total contrast with the situation within HNS. But they gave a clear overview of the decisions in an IRP and their relations.

Silva and Gao (2012) study a distribution centre location model that incorporates joint replenishment inventory costs. The goal of the research is to find the best joint replenishment frequencies at each potential set of locations. This research matches our situation where we want to find out if savings can be reached by joining replenishment with other OpCos. They apply a Greedy Randomized Adaptive Search Procedure (GRASP), which also can be used for the multi-item lot-sizing problem. Savelsbergh and Song (2007) studies an IRP that involves limited product availability and delivery routes that cannot be described as out-and-back tours because they take several days. This reflects the situation of HNS where long lead times are present for materials that are sourced from Northern Italy. They use an innovative randomized greedy algorithm which has similarities to Silva and Gao (2012).

3.4 Vendor Managed Inventory

We refer to Zachariassen et al. (2014) for an explanation about VMI. They focus on the inter-organizational nature of a VMI implementation in practice, most literature looks at the perception from either the vendor or the customer. While to make VMI work, both parties have to collaborate efficiently. In the case of HEINEKEN, a typical situation for VMI seems to be for the suppliers of the Preforms, Sleeve and Bladebox. They are centrally located and have dedicated production lines for Heineken OpCos. Also, the suppliers of the SmartCap, Boxtray and AK03 have HEINEKEN dedicated production lines and could be interesting for VMI.

3.5 IRP combined with VMI

An article that combines an IRP with a VMI policy is Dai et al. (2020) They study three IRP models, a model ending with shortage, a model starting with shortage, and a model with no shortage. These models are composed of a single manufacturer and multiple retailers. To solve these models, a hybrid heuristic algorithm that is developed by combining the cuckoo algorithm with improved Clarke-Wright savings algorithm is developed. In computational experiments, the proposed algorithm is compared with the optimization solver. The results demonstrate the proposed algorithm outperforms the optimization solver. Besides, the results show the average total cost may be reduced by using the strategy of stock out in some cases. Although the proposed heuristic is performing better for larger instances, the optimization solver is also solving small instances, comparable to HNS, in reasonable time. Speranza and Archetti (2015) also investigates the 'integrated approach' (VMI) where the supplier is given information on future orders and can plan their production and distribution more efficiently. They compare two approaches:

- The RMI (Retailer Managed Inventory) policy: Each customer (retailer) decides delivery times and quantities. The supplier organizes the distribution routes, taking delivery times and quantities as constraints.
- The VMI policy: The supplier monitors the inventory levels of the customers and determines delivery times and quantities, in a way to avoid the occurrence of any stock-out, and the routes.

We could describe the current situation for HNS as the RMI policy. The results of this study show that the VMI policies can achieve remarkable savings both in terms of solution cost and number of vehicles used. The savings that can be achieved with an integrated policy are relevant, on average 9.49% in terms of total cost and 9.06% in terms of number of vehicles, even under the condition that the final inventory levels for a VMI policy equal the final inventory levels of the proposed Retailer managed inventory policy. This looks promising for some suppliers that only supply to HEINEKEN OpCos, which is the case for some suppliers. Although it must be said that not every OpCo, at the moment, is sharing their tactical forecast to the supplier and we are not sure if suppliers are capable of applying the vendor managed inventory policy. So, this calls for further research.

Viswanathan and Mathur (1997) consider the commonly described one-warehouse, multi-retailer multi-product distribution system. They present a new heuristic that generates a stationary nested joint replenishment policy (SNJRP) for the problem. A policy is defined to be stationary if replenishment of each item is made at equally spaced points in time, i.e. with constant replenishment intervals. A nested policy means that if the replenishment interval of a given item is larger than that of another item, the former is a multiple of the latter. If OpCos have to merge their ordering strategies, this policy provides a practical approach that should be feasible to implement.

3.6 Optimizing use of own warehouse

Rastogi et al. (2017) study a supply chain with two warehouses, an own warehouse and a rented warehouse. The goal of the inventory model is to optimize the overall costs, so the own warehouse is maximally utilized. So, as less as possible warehouse space is rented. This situation reflects the finished goods warehouse of HNS. For the Blade and Brewlock materials, no warehouse space has been rented. This research could be interesting if warehouse space turns out to be a constraint for the optimization of total cost.

3.7 Taking the lead time into account

Similar to Savelsbergh and Song (2007) do Li et al. (2016) also take into account lead times into the inventory routing problem, which is most of the time ignored. In this study does the lead time depend on the routing decisions made by the vendor. At first, the problem is solved for a small problem instance to create expectations about the optimal policy. As, we also do not want to ignore lead times for our study, these studies can be of use. Especially when we are solving an Inventory routing problem over several OpCo's where the lead time is depended of the route. For the scope of this research, the lead time is not very depended on the different possible routes.

3.8 Location Routing problems

According to Ahmadi Javid and Seddighi (2012) Location-routing problems (LRP) are among the oldest integration issues and have been studied since the seventies. This study investigates a location, inventory and routing decisions in a multi-source distribution network. This network is similar to a network we could create when HNS start cooperating on orders with other OpCos. According to Ahmadi Javid and Seddighi (2012) one key shortcoming in most of the past research on integration is that only two of the three issues of location, routing and inventory are combined. As can be expected, because of the interrelation between these subjects, there is also an interest in investigating ternary integration, i.e. location-routing-inventory problems (LRIPs). For our current situation at HNS, we can extend this problem by mixing it with a lot-sizing problem, although this can become tedious. Our location routing problem is rather simple, so we can evaluate this first before we try to solve the more complex multi-item lot-sizing problem instead of trying to mix all problems into one big problem.

3.9 Green supply chain

The topic of Green supply chains is quite trending and certainly under attention at HNS. However, it is not easy to determine what we exactly mean with a green supply chain. According to Ahi and Searcy (2013), a consensus definition for sustainable supply chains does not exist. They found a total of 22 definitions for a green supply chain and 12 definitions for sustainable supply chain management. So we will not go in detail about this. Bluntly speaking, HNS tries to reduce the CO2 emissions that are a result of their supply chain. This results in that continuously there are taken measure to optimize the transportation moves made by or caused by HNS. CO2 emissions in logistics have decreased by 28% since 2010. Lerhlaly et al. (2016) takes into account environmental considerations into their inventory location routing model. However, the problem is not similar to our situation at HNS, they take into account CO2 emissions for the routing decisions. In our results, we want to take into account a simple way of calculating CO2 emissions and the potential reductions.

3.10 Inventory policies

As we have already mentioned the books of Silver et al. (2017) and in the book of Axsater (2016), there are several 'standard' inventory policies mentioned. In Chapter 2, we discuss that the current situation can be best described using a (R,s,S) policy. In Section 3.10.1 we discuss ways to determine order up to levels, in Section 3.10.2 we discuss the importance of early information sharing with the supplier, In Section 3.10.3 we discuss the subjects of seasonality and uncertainty in price and in Section 3.10.4 we discuss holding costs.

3.10.1 Order up to levels

Silver et al. (2009) propose a simple method for determining s and S in a periodic system. However, Liu and Zhou (2007) propose a dynamic (s,S) policy that looks more like the situation for Blade and Brewlock than the standard (R,s,S) policy. Of course, a difference is that Liu and Zhou (2007) use the situation of VMI, the difference is only here in who decides to ship materials, because HNS has insight in inventory levels of the supplier. Another difference is the supply chain, Liu and Zhou (2007) describe a three-echelon supply chain with an emergency shipment possibility from the manufacturer to the customer bypassing the supplier. The reason for dynamic order-up-to levels is to save on these emergency shipments. Within HNS the reason for dynamic order-up-to levels is to be more efficient in warehouse space usage. They prove that an (s, S) replenishment policy with a dynamic order-up-to-level, similar to the policy at HNS, is significantly lowering supplier cost compared to a reorder point policy, base stock policy and the (s, S) policy with fixed order-up-to-level. Also, Minner and Transchel (2010) show that using dynamic order quantities gives superior results to fixed order-op-to-policies. Keshari et al. (2018) Motivates their order-up-to-policy as a way to mitigate the bullwhip effect in a supply chain network. They use two kinds of order-up-to levels for slow and fast orders of the same item. This situation could be comparable to a situation where HNS orders material from two suppliers(e.g. another OpCo and the supplier). They use the Bacterial foraging algorithm to solve this lot-sizing problem, which could be a promising algorithm.

3.10.2 Information sharing and early order commitments

Reddy and Rajendran (2005) study heuristic settings for dynamic order-up-to levels at different installations in a supply chain. Interesting is that they study the effect of information sharing among the installations in the supply chain, which is already happening within the supply chain of HNS. Altogether Reddy and Rajendran (2005) find that the use of forecast of replenishment lead time and customer demand information sharing, and the proposed safety-stock heuristic settings in the determination of dynamic order-up-to levels, significantly reduce the sum of discounted inventory, shortage and transport costs of the supply chain. Lau et al. (2008) study the effects of information sharing and early order commitment on the performance of four inventory policies. Sharing of future order plans is shown to be the most effective way of reducing the supplier's cost and improving its service level. Early order commitments are to be found beneficial to the supplier and retailers in reducing their total cost.

3.10.3 Seasonality and price uncertainty

The problem of seasonality is very known for a company that sells beer. Certainly, for the Blade and Brewlock seasonality is present. Kawakatsu et al. (2014) study a retailer's optimal replenishment policy products with a seasonal demand pattern. They take into account a finite horizon of one season and research the effect of quantity displayed to demand. For the Blade and Brewlock products this could relate to the situation where there are more draught systems sold, then the demand for Blade and Brewlock materials will eventually increase. Although this could be applicable for HNS, the demand forecast is out of scope for this research. A similar research is done by Giri et al. (2000) but in this study, the demand is not increasing but decreasing. Giri et al. (2000) also show that a policy that considers shortages in every cycle outperforms policies that do not consider shortages in the last cycle, similar to Goyal et al. (1996). Goyal et al. (1996) research a lot-sizing problem with shortages when the there is a trend in demand. Apart from the seasonality in Blade and Brewlock products is there also a probable increasing trend in demand, as we have explained before in Chapter2. The traditional replenishment policy avoids shortages in the last cycle. Each of the remaining cycles starts with a replenishment and inventory is held for a certain period which is followed by a period of shortages. The new replenishment policy, that Goyal et al. (1996) propose, is to start each cycle with shortages and after a period of shortages, a replenishment should be made. This policy shows to be superior to the traditional policy.

3.10.4 Holding costs

As HNS does not know how much holding costs should be allocated for each material, we can take a lesson from studies about holding costs. Azzi et al. (2014) study the structure of holding costs for several industries, unfortunately, they do not mention a very similar industry as for HEINEKEN, but the holding costs they argue are around 25% of the purchase value. Also in the book of D.M Lambert (1993) the percentage suggested in textbooks ranges according to between 12% and 34% of the purchase value, depending on the industry/field. Berling (2008) does propose an interesting new way of looking at holding costs. They take the activities required for holding inventory as there main indicator instead of the cost of capital, which is the more traditional way of looking at holding costs. This could be an interesting way of calculating holding costs for HNS, as they are already implemented activity-based costing in most of there factors in the Transfer price. But for this research, the most straightforward way is to use the WACC. According to Serrano et al. (2017) in operations management literature, the financial risk in an inventory model is usually assumed to be captured by the (constant) WACC of the firm.

3.11 Solution methods

Since our problem instances are relatively small, i.e. 2 breweries to deliver, 8 different materials to order, computation time should not be of the biggest importance. Also, it is easier for HNS to implement our model when we use AIMMS because they are familiar with this software. So, the focus of our research is not on finding the best solution method for our multi-item, multi-location lot-sizing problem. If the computation-times disappoint some promising solving methods seem to be the innovative GRASP of Silva and Gao (2012), the hybrid algorithm of Dai et al. (2020) and the Bacterial foraging algorithm of Keshari et al. (2018).

3.12 Conclusions

- Our problem can be described as a multi-item, multi-location lot-sizing problem.
- The single-source situation of Blade and Brewlock materials makes VMI interesting, however may be hard to implement, as mentioned in Chapter 2.
- Small joint replenishment problems occur at two suppliers if we do not change the routes.
- Supplier selection is not useful, because we have single-source suppliers.
- Using product families as a way to schedule orders is not promising because we can only think of two families.
- Holding costs are hard to determine, the most straightforward way to go is to use the WACC.
- Problem instances seem quite small, so computation time should not be of the biggest importance. So, we can use AIMMS as our modelling software, HNS is also familiar with this software.

CHAPTER 4

Optimization model

In this chapter, we will explain the model this thesis proposes. First, we explain about how the model is built up in Section 4.1 with the goal of the model and problem description. Then we formulate the simple multi-item lot-sizing model with quantity discounts as a Mixed Integer Linear Program (MILP) model in Section 4.2. In Section 4.3 the model is extended with multiple locations with inter-location transport. In Section 4.4, we explain how free-riding in incorporated in the model and Section 4.5 consist of the complete model. Section 4.6 explains how the rolling horizon is coded and Section 4.7 explains how we can use the thirteen-week-MRP as input. Throughout the previous chapter, this chapter and the following chapter we have explained some limitations to our model. In this chapter, we will explain the model we are using and therefore we will answer the following research question:

- **What are the limitations for adapting the methods and how can we model the inventory management and distribution of the Blade and Brewlockmaterials for HNS?**

4.1 Building the extended multi-item, multi-location lot-sizing model

In the first section, we will explain a simple lot-sizing model with quantity discounts. In the following sections, the model will be extended. We work towards a MILP with several inventory locations, inter location (brewery) transportation, a rolling horizon and the use of free-riding on quantity discounts for some material types. We use a simpler one-location model for validation in Chapter 5.

For a quick refreshment in Integer Linear Programs, we refer to Brown and Dell (2007). For an extensive review on the modelling of lot-sizing problem to Jans and Degraeve (2008). Lee et al. (2013b) describes a similar situation which they model with a Mixed Integer Non-Linear Program (MINLP). Although this model is solvable, computation times steeply increase as we add more extensions to the model and increase the planning horizon. To prevent that our model needs a long time to solve, we did stick to a MILP formulation. For starters, we adjusted the quantity discount formulation 'Program 1' from Lee et al. (2013a). The modelling of multiple locations and Inter-brewery did we come up with ourselves. For modelling the rolling horizon we used the documentation and functional examples that can be found on the AIMMS website (`https://www.aimms.com/english/developers/resources/examples/functional-examples/rolling-horizon/`). And also the Free riding on quantity discounts and external warehouse location formulates did we come up with ourselves.

4.1.1 Goal of the model

The goal of the model is to optimize the total costs considering the complete inbound supply chain of the Blade and Brewlock materials. We want to model the future situation of a new Blade packaging line in

Den Bosch and investigate factors that will impact the inbound supply chain. The first step is to consider the quantity discounts when the lot size decision is made and we want to compare that to the current situation. Furthermore, we want to test several scenarios that describe possible future situation for the Brewery in Den Bosch and possible ways to arrange the ordering process for the breweries. These are discussed in Chapter 6.

4.1.2 Problem description and assumptions of the simple multi-item lot-sizing model with quantity discounts

The problem is defined as a multi-item lot-sizing model, the objective is to minimize the total costs, these consist of purchase costs and inventory costs. For our model, we take weeks as periods, because TSCP and OS have weekly drumbeats. We plan for these six materials: Blade box, Boxtray, Preform Blade, Preform Brewlock, Sleeve and SmartCap. For the Blade box and Sleeve several artworks are available, in terms of purchase costs or inventory cost there is no difference between artworks, therefore the demand as input is merged for these artwork types and the different artwork types are treated as one material type. The assumptions, discussed with HNS, are summarized as follows:

- The demand for each period is assumed deterministic.
- All product quantities are expressed in pallets.
- The length of a period is fixed and is one week.
- The entire order quantity of the previous week is delivered at once at the beginning of a period.
- The inventory holding cost consist of a fixed and variable part, the fixed part being the cost of the warehouse space of one pallet, the variable part is the WACC of the purchase cost.
- Planning horizon is finite and known and the duration of each period is the same.
- The prices for materials are considered fixed. For historical data, a weighted average of the historical prices is used.
- Inventory may never be less than the safety stock, where the safety stock is constant and given.

4.1.3 No use of integer variables except for binary variables

We make no use of integer variables except for the binary variables. This is not the most realistic way of representing the current situation. In the current situation are inventory costs related to integer values of pallet places, are orders only placed in integer values (except for the Sleeve) and is Inter - brewery transport only arranged for full pallets. Unfortunately, the demand is not given in whole pallets. We have noticed that using integers, increases computation time a lot. So, for now, no integers are used. We refer to Section 6.4.1 about using integer values in the model.

4.1.4 Notation

All the required notations for the simple model quantity discount model are defined below, we have to add some notations later on to extend the model for multiple locations, inter - brewery transport and free-riding on the quantity discounts.

Indices

p	Planning period (p = 1,2,...,52).
i	Item, (i = 1,2,...,6).
d	Discount level (d = 1,2,..D).

Parameters

D_{ip}	Demand of material i, in period p.(in pallets)
H	Inventory holding costs for one week and for one pallet of material i.
W_i	Weighted average cost of capital of the purchase price, for HNS this is 5,5%
PC_i	Purchase cost of each material i, without transportation cost.
OC	Fixed ordering cost for each order of each material i, at each period p.
S_i	Safety stock of material i.(in pallets)
M	A large number.
B_{di}	The lower bound quantity of material i with discount level d.(in pallets)
C_{di}	The purchasing price of a full pallet of material i with discount level d.

Decision Variables

I_{ip}	Inventory at the end of period p for material i.(in pallets)
O_{dip}	Quantity ordered at discount level d, of material i, at the start of period p.(in pallets), delivered at start of $p+1$
X_{dip}	A binary variable, set equal to 1 if a certain positive quantity is purchased of material i, with discount level d, in period p and 0 if no purchase is made.

4.2 Formulation of the lot-sizing problem into an MILP model

$$\text{Minimize TC} = \sum_{p=1}^{P}(\sum_{i=1}^{I}(\sum_{d=1}^{D}(C_{di} \times O_{dip})) + (\sum_{d=1}^{7} X_{dip} \times OC) + ((H + (W_i \times PC_i)) \times I_{ip})) \tag{4.1}$$

subject to

$$I_{ip} \geq S_i, \quad \text{for all } i,p \tag{4.2}$$

$$I_{ip} = I_{ip-1} - D_{ip} + \sum_{d=1}^{D} O_{dip-1}, \quad \text{for all } i,p \tag{4.3}$$

$$X_{dip} \times M \geq O_{dip}, \quad \text{for all } d,\ i,\ p \tag{4.4}$$

$$\sum_{d=1}^{D} X_{dip} \leq 1, \quad \text{for all } i,p \tag{4.5}$$

$$O_{dip} \geq B_{di} \times X_{dip}, \quad \text{for all } d,i,p \tag{4.6}$$

$$O_{dip} \leq B_{d+1i} \times X_{dip}, \quad \text{for all } d,i,p \tag{4.7}$$

$$X_{dip} \in \{0,1\}, \quad \text{for all } d,i,p \tag{4.8}$$

$$I_{ip} \geq 0, \quad \text{for all } i,p \tag{4.9}$$

$$O_{dip} \geq 0, \quad \text{for all } d,i,p \tag{4.10}$$

The objective is to minimize the total cost, Eq. (4.1), which consist of the purchase cost and inventory holding cost. The operative constraints are as follows: Eq. (4.2) makes sure that the Inventory level I_{ip} of material i is never below the given safety stock level S_i. Eq. (4.3) defines the inventory level at every period. The Inventory for the next period is given by the Inventory of last period, I_{ip-1}, subtract the Demand of the current period, D_{ip} and add the Orders ordered in the previous period, $\sum_{d=1}^{D} O_{dip-1}$. The Eq. (4.4) makes sure that the binary variable X_{dip} is set to 1 if an order is placed of material i, at period p, for some discount some d. The Eq. (4.5) makes sure that for every order O_{dip} only one discount level d is selected. The combinations of Eq. (4.4) and Eq. (4.5) make sure that only for maximally one discount level d, at each period p, for each item i, the order quantity is above zero. Eq. (4.6) and Eq. (4.7) make sure that the right Discount level d is chosen that corresponds with the right order quantity O_{dip}.

4.3 Multi-location and inter-brewery

In this section, the model is extended with multiple inventory locations and the possibility of moving inventory around between these locations by IB-transportation. So, we add an extra index l and we also add two decision variables Inter - brewery In IBO_{ilp} and Inter - brewery Out IBI_{ilp}. The Parameter IBC is a fixed cost per pallet for Inter - brewery transport. It is assumed that the lead time for Inter-brewery transport can be neglected as Inter - brewery transport can take place every day and takes only a few hours.

4.3.1 Extra notation

Indices

l	Inventory location (l = 1, 2).

Parameters

D_{ilp}	Demand of material i, at location l, in period p.
S_{il}	Safety stock of material i, at location l.
IBC	Inter-brewery transportation cost per pallet

Decision variables

IBO_{ilp}	Inter-brewery delivery of material i, at the beginning period p <u>out of</u> location l.
IBI_{ilp}	Inter-brewery delivery of material i, at the beginning period p <u>into</u> location l.
I_{ilp}	Inventory at the end of period p of material i, at location l.
O_{dilp}	Quantity ordered of material i, at discount level d, in period p, for location l.
X_{dilp}	A binary variable, set equal to 1 if a certain quantity is purchased of material i, with discount level d, in period p for location l and 0 if no purchase is made.

4.3.2 MILP formulation with quantity discount, Locations and Inter-brewery

In this section, we merge the first lot-sizing formulation from Section 4.2 and the previous notations from Section 4.3.1.

$$\begin{aligned}\text{Minimize TC} = \sum_{p=1}^{P}(\sum_{i=1}^{I}\sum_{l=1}^{L}(\sum_{d=1}^{D}(C_{di} \times O_{dilp})) + (\sum_{d=1}^{7} X_{dilp} \times OC) + (H + (W_i \times PC_i)) \times I_{ilp}) \\ +(IBI_{ilp} \times IBC))\end{aligned} \tag{4.11}$$

$$
\begin{aligned}
\text{subject to} \qquad\qquad\qquad\qquad\qquad\qquad I_{ilp} &\geq S_{il}, && \text{for all } i,l,p && (4.12)\\
I_{ilp} = I_{ilp-1} - D_{ilp} + \sum_{d=1}^{D}(O_{dilp-1}) - IBO_{ilp} + IBI_{ilp}&, && \text{for all } i,l,p && (4.13)\\
\sum_{l=1}^{L} IBO_{ilp} &= \sum_{l=1}^{L} IBI_{ilp}, && \text{for all } i,p && (4.14)\\
\sum_{d=1}^{D} X_{dilp} &\leq 1, && \text{for all } i,l,p && (4.15)\\
O_{dilp} &\geq B_{di} \times X_{dilp}, && \text{for all } d,i,l,p && (4.16)\\
O_{dilp} &\leq B_{d+1i} \times X_{dilp}, && \text{for all } d,i,l,p && (4.17)\\
X_{dilp} &\in \{0,1\}, && \text{for all } d,i,l,p && (4.18)\\
I_{ilp} &\geq 0, && \text{for all } i,l,p && (4.19)\\
O_{dilp} &\geq 0, && \text{for all } d,i,l,p && (4.20)
\end{aligned}
$$

The objective is to minimize the total cost, Eq. (4.11), which consist of the purchase cost, inventory holding cost and IB-cost. The operative constraints are as follows: Eq. (4.12) makes sure that the Inventory level of every material i is at every location l and every period p above the safety stock level. Eq. (4.13) makes sure that the quantities put into IB-transport, are added up to the inventory level or subtracted from the inventory level, depending on if it's in or outgoing IB-transport. Eq. (4.14) makes sure that the quantities that are sent out of any location by Inter Brewery Transport match the quantities that arrive at the other location. The Eq. (4.15) makes sure that for every order O_{dilp} only one discount level d is selected. The combinations of Eq. (4.17) and Eq. (4.15) make sure that only for maximally one discount level d, at each period p, at each location, l, for each item i, the order quantity is above zero. Eq. (4.16) and Eq. (4.17) make sure that the right Discount level d is chosen that corresponds with the right order quantity O_{dilp}.

4.4 Free riding on quantity discounts

As we have described in Chapter 2, some materials come from the same supplier. The two preforms come from the same supplier and the Smart cap and Boxtray. At the moment do only the preforms make use of the free-riding on their quantity discounts, as the Smart cap and Boxtray are not delivered together. The quantity discounts given for the materials are given based on the total pallet quantity in one shipment. For example, if we have a discounted price for 20 pallets or more, we can order 10 Blade preforms and 10 Brewlock preforms and both materials are bought with the discounted price for ordering 20 pallets. So, the Blade and Brewlock can free-ride on each other's order quantities. To take this into account we need an extra decision variable.

Intuitively, an extra variable is not needed, but if we don't use an extra variables, a disadvantage is that we have to hard-code Constraint (4.17) and Constraint (4.16) for all material types i. The number of constraints to be hard-coded will increase as the number of materials increase. Another option would be adding an extra index for the supplier, but this makes the model more complex than needed. Another problem is that we experience problems if the discount level d for the quantities that free ride with each other is not the same. This happens when the bounds of the order quantities are different for different materials of the same supplier. Usually, this is not the case, but it could be. So, with the use of an extra variable we can use this variable to increase the discount level of other materials, but without making the discount level the same for the two or more free-riding materials.

Decision variable

F_{dilp} Free ride quantity of material i, at period p, for location l and with the discount level d that corresponds with the total pallet quantity

We also need some constraints to make use of the Free-ride quantity variable. For the materials that cannot make use of quantities ordered of other materials for their quantity discount, the variable is set to zero for all locations l, all periods p and all discount levels d of that one material i. In the following table, we will give the materials numbers, this will make the constraint better readable.

Table 4.1: Numbers corresponding with material type

Material type	Number
SmartCap	1
Boxtray	2
Sleeve	3
Bladebox	4
Preform8L	5
Preform20L	6
Valve	7

For the Brewlock preform for example the constraint can be found in Eq. (4.21).

$$F_{d6lp} = O_{d5lp}, \qquad \text{for all } d,l,p \tag{4.21}$$

The quantities ordered of the preform8L will be used for the preform20L to determine the discount level. So the Free-ride quantity will also be used for in the constraint that determines the discount level, as can be seen in Eq. (4.22). Same holds for the upper bound constraint.

$$O_{dilp} + F_{dilp} \geq B_{di} \times X_{dilp}, \qquad \text{for all } d,i,l,p \tag{4.22}$$

4.5 Complete MILP formulation

At this moment all of the extensions that we are going to use are explained and we are merging the extension from Section 4.4 into the MILP formulation from Section 4.3.2. For the use of external warehouse space, we refer to Appendix D. The use of external warehouse space is currently out of the question, but at the start of this research, it seemed a possibility. The total cost function consists of purchasing cost, inventory cost and IB-cost, respectively shown in Eq. (4.23). This is the complete model that is going to be solving with a rolling horizon, explained in Section 4.6. In the following Section 4.7, we explain and extension of the current model that is only used for validation of the model.

$$\begin{aligned}\text{Minimize TC} = \sum_{p=1}^{P}(\sum_{i=1}^{I}\sum_{l=1}^{L}(\sum_{d=1}^{D}(C_{di} \times O_{dilp})) + (\sum_{d=1}^{7} X_{dilp} \times OC) + (H + (W_i \times PC_i)) \times I_{ilp}) \\ +(IBI_{ilp} \times IBC))\end{aligned} \tag{4.23}$$

subject to $$I_{ilp} \geq S_{il}, \qquad \text{for all } i,l,p \tag{4.24}$$

$$I_{ilp} = I_{ilp-1} - D_{ilp} + \sum_{d=1}^{D}(O_{dilp-1}) - IBO_{ilp} + IBI_{ilp}, \qquad \text{for all } i,l,p \tag{4.25}$$

$$\sum_{d=1}^{D} X_{dilp} \leq 1, \qquad \text{for all } i,l,p \tag{4.26}$$

$$\sum_{l=1}^{L} IBO_{ilp} = \sum_{l=1}^{L} IBI_{ilp}, \qquad \text{for all } i,p \tag{4.27}$$

$$O_{dilp} + F_{dilp} \geq B_{di} \times X_{dip}, \qquad \text{for all } d,i,\ l,p \tag{4.28}$$

$$O_{dilp} + F_{dilp} \leq B_{d+1i} \times X_{dilp}, \qquad \text{for all } d,i,l,p \tag{4.29}$$

$$F_{d5lp} = O_{d6lp}, \qquad \text{for all } d,l,p \tag{4.30}$$

$$F_{d6lp} = O_{d5lp}, \qquad \text{for all } d,l,p \tag{4.31}$$

$$F_{d1lp} = O_{d2lp}, \qquad \text{for all } d,l,p \tag{4.32}$$

$$F_{d2lp} = O_{d1lp}, \qquad \text{for all } d,l,p \tag{4.33}$$

$$F_{d3lp} = 0, \qquad \text{for all } d,l,p \tag{4.34}$$

$$F_{d4lp} = 0, \qquad \text{for all } d,l,p \tag{4.35}$$

$$F_{d7lp} = 0, \qquad \text{for all } d,l,p \tag{4.36}$$

$$X_{dilp} \in \{0,1\}, \qquad \text{for all } d,i,l,p \tag{4.37}$$

$$I_{ilp} \geq 0, \qquad \text{for all } i,l,p \tag{4.38}$$

$$O_{dilp} \geq 0, \qquad \text{for all } d,i,l,p \tag{4.39}$$

The objective is to minimize the total cost, Eq. (4.23), which consist of the purchase cost, inventory holding cost and IB-cost. The operative constraints are as follows: Eq. (4.24) makes sure that the Inventory level of every material i is at every location l and every period p above the safety stock level. Eq. (4.25) determines the Inventory at every location l, for every period p of every material i. The Eq. (4.26) makes sure that for every order O_{dilp} only one discount level d is selected. The combinations of Eq. (4.29) and Eq. (4.26) make sure that only for maximally one discount level d, at each period p, at each location, l, for each item i, the order quantity is above zero. (4.27) makes sure that the quantities that are sent out of any location by Inter Brewery Transport match the quantities that arrive at the other location. Eq. (4.29) makes sure that the right Discount level d is chosen that corresponds with the right order quantity O_{dilp}. Then Eq. (4.30) till Eq. (4.36) make sure that the right Ordering quantity is used as Free-ride Quantity.

4.6 Rolling horizon

To simulate the current situation the best, we have to give the model input similar to the input that HNS uses for the decision to call off order quantities. OS makes the call-off order quantity decision using a two-week forecast. To simulate this, we use a variable planning horizon and we roll the model every week. So, when we use a two-week planning horizon, to simulate the call-off order of OS, then each week's problem is solved twice, once as the second week in the planning horizon and once as the first week in the planning horizon. That is similar to reality because in reality OS only plans the start of week two. This way we solve the model for an optimal first week in combination with a feasible second week. When we have rolled the model, the first week(which used to be the second week) is changeable and can be adjusted to be optimal with the knowledge of the new second week. Sometimes the call off decision is made with the use of a longer forecast horizon, this especially done when the demand for the coming two weeks would not be enough to order FTLs. For example, TSCP does decide to call off order quantities for the Blade box and Sleeve using the thirteen-week forecast. The planning horizon is changeable, so we can look at the effect of using different planning horizon. To model this we need to use some more parameters:

Parameters

$MaxPeriod$	The total planning horizon, e.g. one year = 52.
$PlanningLength$	The planning horizon, e.g. two weeks = 2.
$IntervalStart$	Parameter that holds track of the current period.

$Maxperiod$ gives the total planning period, if we simulate a year, this would mean 52 weeks = 52 periods. The *Planninglength* gives our planning horizon for which the model is solved. So, it gives the length of the forecast that is used to determine call off quantities for this horizon, but as the horizon is rolled every week, only the first period is determined. We just solve the same MILP model but now for smaller planning periods until we have reached the total planning horizon. We have a procedure to let the solver run the several problems, sequentially. To give an idea about how the rolling horizon works, we present the following pseudo-code:

```
Solve MinTotalCost ;
while IntervalStart + PlanningLength ≥ MaxPeriod do
    IntervalStart += 1 ;
    Solve MinTotalCost ;
end
```

Algorithm 1: Procedure for Rolling Horizon

So, $MinTotalCost$ solves the goal function (4.40) with the summation over p from $IntervalStart$ til the *Planninglength*.

$$\text{Minimize TC} = \sum_{p=IntervalStart}^{PlanningLength} (\sum_{i=1}^{I} \sum_{l=1}^{L} (\sum_{d=1}^{D} (C_{di} \times O_{dilp})) + (I_{ilp} \times H_i) + (IBI_{ilp} \times IBC) \tag{4.40}$$

4.7 Using the thirteen-week-MRP forecast as input

So, the model uses weeks as periods and input for the model is the forecast for each week. To reflect the historical data the most, the best forecast to use is the thirteen-week-MRP. As this thirteen-week-MRP forecast is used every week to determine the call-off order quantities. For future decisions, however, it's not useful, as this forecast is only made for thirteen weeks ahead. But we can use the historical thirteen-week-MRP forecast to validate the model. However, to use this input we have to change to model a bit to handle the different forecast values of the same period.

Normally there is made an MRP with a planning horizon of thirteen weeks, every week. Unfortunately, this is not completely true, in some weeks there is now forecast made because of holidays or other reasons. Also, it depends on the material and the supplier if it is really necessary and useful to look thirteen weeks ahead, as forecast does change a lot over this time for instance. To have a uniform input for the model we have made one table for each material with all forecast values and zeros if there is no forecast value present. On the horizontal axis, the periods are present. On the vertical axis, the 'IntervalStart' is shown. For each solve, one row is chosen according to from which period the solve starts.

4.7.1 Notation of the thirteen-week-MRP

The index forecast start f is added to the Demand parameter D_{filp}. To determine which forecast start (f = 1, ...,MaxPeriod-1) should be used we use the Parameter 'IntervalStart'.

Indices

f forecast start (f = 1, ...,MaxPeriod-1).

Parameters

D_{filp} Demand of material i, at location l, in period p in forecast start f.

As the model rolls to the next week,i.e. The 'IntervalStart' is increased by one, the following row in the table is used as Demand Forecast.

4.8 Conclusions

- We use a MILP formulation for solving our lot-sizing problem, because this is a common formulation and because the model is formulated linearly, this makes it relatively fast to solve.
- We have extended a standard multi-item lot-sizing problem with quantity discounts, a rolling horizon, multiple inventory locations, with transportation between the locations and the possibility of certain material types to free ride on the quantity discounts of other materials.
- A rolling horizon is used to simulate the current ordering process.
- The model can be used with the historical thirteen-week-MRP forecast but the lead time has to neglected to handle the fluctuation forecast values.
- We can compare our results from Chapter 2 to our model if we use a simpler version of the model with only one location.

CHAPTER 5

Model Verification and Validation

In this chapter, we will verify and validate the model. Verification is the process to ensure whether the model that is developed is right or not. It verifies whether the developed model fulfils the requirements that we have. Verification is static testing. So, Verification means: "Are we building the model right?" Validation checks what we are developing is the right model. It is a validation of the actual and expected model. Validation is the dynamic testing. Validation means: "Are we building the right model?". Law (2007) describe eight different verification techniques and six steps for validation, from which we used some. Section 5.1 describes how we verified that we have built a correct model. We do verify in two steps, first the one location model, which we then compared with the multi-location model. Then the one-location model is validated by comparing the outcomes to historical outcomes in Section 5.2.

5.1 Model verification

One of the most helpful verification techniques is to build up the model from a minimal working example to complete the extended model. As explained in the Chapter 4, we have done so. Also, the AIMMS environment including the language and function reference does help a lot in debugging the model. Another technique is to run the model under a variety of settings of the input parameters and to check if the output is reasonable. We have done this for the complete extended model as for a more simple MILP model.

In Appendix E the simple one-location MILP model is presented. The model is similar to the extended model in Section 4.5. The difference is that the index l location is removed, as historically there was only one location. So, the IB-transport variables and constraints are removed as well, there is no transportation between locations possible.

5.1.1 Shipping notification data as reference data

As explained more in Chapter 2, data from the actual shipments very not easily found. Unfortunately, the shipping notification data is partly manually filled in and therefore the data is somewhat polluted. There are missing values and incomplete rows and columns. However, this is the only data that describes what has been transported together and there is still enough data to use as reference and input for our model. The idea of this verification step is that we configure the settings of the model in the way that it reflects the historical situation the best and compare the outcomes of the model to the shipping notification data. As a first step, we use the Shipping notification as input as well, this way we check if the model follows logical behaviour. For validation, we use the demand input that is used in the real situation, i.e. the first weeks of the thirteen-week-MRP. In the output, we see which setting for the planning horizon reflects the real situation the best. This is described in Section 5.2.1.

5.1.2 One location model with shipping notification data as input

For the verification of the model, we have tested during the build of the model whether the model is giving logical output. Before we verify the multi-location model, we start with a verification of the one-location model.

5.1.2.1 Average order quantity when changing planning horizon

We are comparing the output of the model against the shipping notification data which we have used as input. We would not expect that the model produced output that would result in lower average order quantities than given in the input. Average order quantities would stay the same if the lot size based quantity discounts are already reached by one demand value. Then bundling of demand values to reach quantity discounts has no use in such a case. In other cases, we would expect that more lot sizes based quantity discount are achieved.

Table 5.1: Average order quantities: Output of one location model with Shipping notification data as input

Planning horizon (weeks)	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L
2	4.7	2.7	1.8	171.0	14.6	1.4	25.1
3	7.2	4.0	2.2	201.5	21.5	2.1	31.6
4	9.2	4.6	2.6	206.0	23.4	2.7	30.5
Shipping notification data:							
Average order quantity	4.4	2.5	1.4	131	13.7	1.2	21.9
Weekly demand	2.5	0.9	0.5	74.7	7.0	0.7	11.7
Increase 2 week	7%	7%	31%	31%	6%	13%	14%

As we can see, the average order quantities in the model are in every case larger than in the input data. In the last row, we see the percentage increase in average order quantity from the shipping notification to the outcomes with a planning horizon of two weeks. In the row above the weekly demand is shown (Total demand divided by the total weeks), we see that in the historical situation average order quantity are always larger than the weekly demand, so OS already bundles demand from several weeks for one order. The solution of the model results in more use of the quantity discounts compared to the historical average order quantities. In general, the average order quantities do increase, as the planning horizon increases, except for the Preform20L. Which makes sense, because then the model considers more demand when deciding on the lot size. So, in more cases, more demand values can be used for one order. This is not true for the Preform20L, because the lot size based quantity discount are already reached by ordering 18 pallets. So in general, we see that model makes decisions to bundle more demand in one call-off order quantity decision, to make more use quantity discounts, which we expected. As the planning horizon is extended, the larger the order quantities become, as expected.

We see that the total number of orders decrease as the planning horizon increases. We see in general a shift from lower discount levels to higher ones, like expected. Especially discount level four is used a lot more. Note that the maximum discount levels depends on the material. For the Bladebox and both types of Preform a discount level of four already an FTL. So, it is also logical that discount level four is used so much.

5.1.2.2 Impact on goal function

Figure 5.2 gives the total cost of the solutions depending on the different planning horizons and the ordering cost of €10, €150 and the average of all runs ranging between €10 and €150 with steps of €10.

We see a similar pattern on this graph as in Figure 5.1. Increasing the planning horizon from two to four weeks, for example, has not only a big effect on the decisions the model makes, but it also results

Figure 5.1: Number of orders placed in discount level with shipping notification data as input

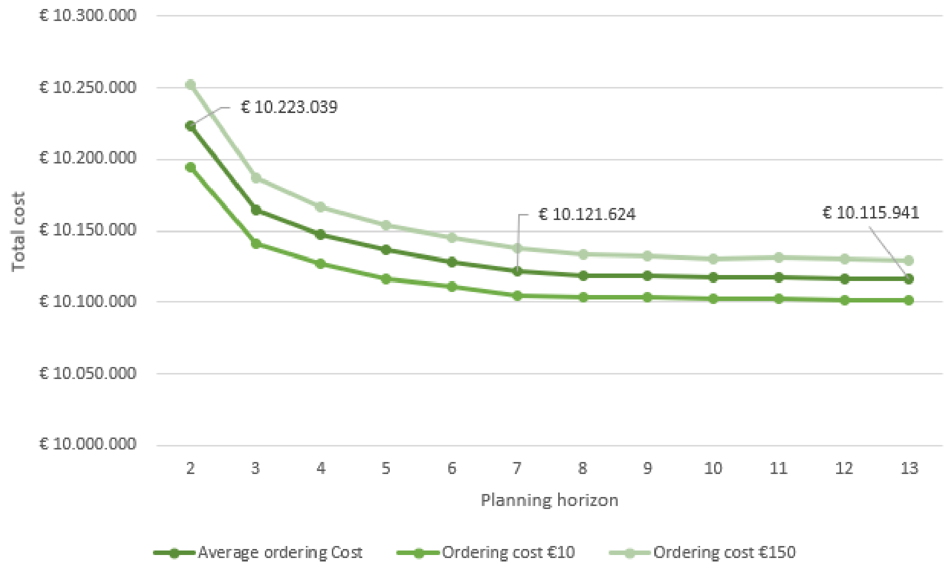

Figure 5.2: Total cost one location model with shipping notification data input

in a big decrease in total cost. Where the effect of a longer planning horizons declines as the planning horizon is longer. So, we assume that the model works correctly, as we only see expected outcomes, a larger planning horizon results in the use of more quantity discounts with result in lower total cost.

5.1.3 Multi-location model with shipping notification data as input

Again, we use the shipping notification data as a reference. Notable, is that we do compare the outcomes of the multi-location model to a one location historical reality, where only Zoeterwoude can produce Blade and Brewlock products. We have used the same demand input for both locations, except for demand of the Preform20L and Boxtray for Den Bosch, as the Brewlock is not produced in Den Bosch.

5.1.3.1 Average order quantities

We do expect that this multi-location model will result in larger average order quantities. The effect of using a longer planning horizon will be smaller, as the demand for one week is already doubled for Blade materials compared to the one location model. However, the demand for one location is not changed, we do expect that the model makes more use of IB-transport and therefore will reach larger average order quantities.

Table 5.2: Average order quantities with shipping notification as input

Planning horizon (weeks)	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L
Outcome multi-location model:							
2	8,9	2,7	3,4	183,9	26,8	2,6	25,1
3	13,5	4,0	4,0	211,0	27,7	4,0	31,9
4	16,6	4,6	4,6	211,4	28,6	5,4	32,0
Percentage increase/decrease compared to one-location:							
2	88%	0%	86%	8%	84%	92%	0%
3	89%	0%	81%	5%	29%	94%	1%
4	80%	0%	74%	3%	22%	99%	5%

In Table 5.2 is shown that the average order quantities of the materials are certainly influenced by the use of two locations. We see that most of the time the average order quantities increase, as expected. Only for the Boxtray this is not the case. The Boxtray is only used in Zoeterwoude, so the outcome is the same as the one-location model, as expected.

5.1.3.2 The use of Inter-Brewery transportation

We expect that IB-transport is used, in both ways. IB-transport is especially useful for short term demands, when the current inventory is not enough to meet demand but also the forecast demand is also not large, so ordering at the supplier would be relatively expensive.

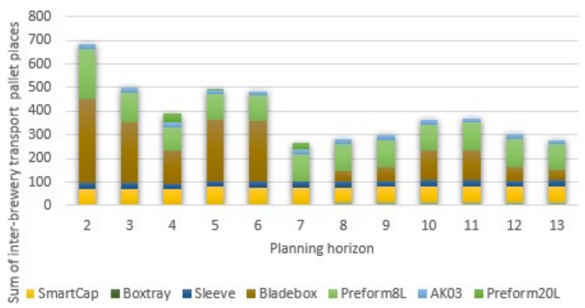

Figure 5.3: Inter-brewery transport Den Bosch to Zoeterwoude

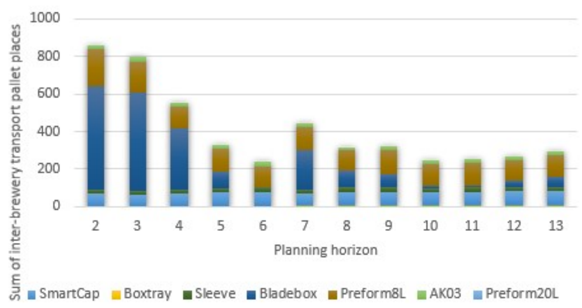

Figure 5.4: Inter-brewery transport Den Bosch to Den Bosch

In Figure 5.3 and Figure 5.4 we see the total pallets transported by inter-brewery transport depending on the planning horizon used. Notable, is that IB-transport is most used when the planning horizon is set to two weeks. When the planning horizon is set to more weeks, the model chooses to order more at the supplier because more demand is known. Which is again logical, when using a short planning horizon, IB-transport is given only a small future demand cheaper than ordering at the supplier.

5.1.3.3 Impact on inventory

In Figure 5.5 and Figure 5.6 the average inventory levels are shown of Zoeterwoude and Den Bosch, respectively. Average inventory levels are shown of multiple runs ranging from using ordering cost of €10 up to and including €150, with steps of €10.

The picture strikes with the used inter-brewery transport, average order quantities and total cost. Especially when the planning horizon is increased from two weeks till 8 weeks, we see a decrease in total cost, decrease in the use of IB-transport, an increase in average order quantities and an increase in average inventory levels. The outcomes when using a planning horizon longer than eight weeks is not shown,

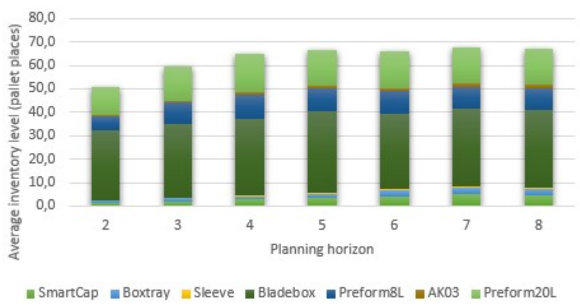

Figure 5.5: Average inventory levels Zoeterwoude

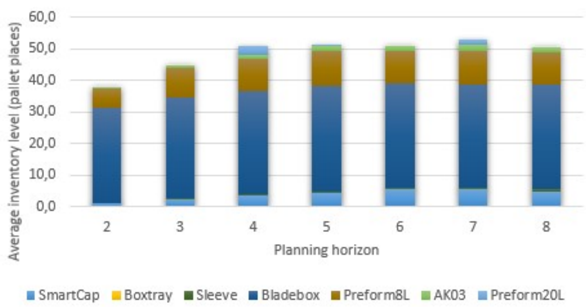

Figure 5.6: Average inventory levels Den Bosch

because the average inventory levels keep constant, this also strikes with the patterns in Figure 5.2, Figure 5.3 and 5.4. The order quantities do increase, but at the same time, the count of orders decrease, which leads to a similar inventory level. So generally, also for the multi-location model, expected outcomes are observed and therefore we can assume the model to work be correct.

5.2 Model validation

To validate the model, we compare the outcomes to historical data. So, as the in the real situation the thirteen-week-MRP is used to determine call off order quantities, the best input to reflect the real situation the best should be this thirteen-weekMRP as well. In Section 4.7, we explained how using the thirteen-week-MRP is incorporated in the model.

5.2.1 One location with thirteen-week-MRP input

As the historical situation does not have two breweries with demand for materials, we use the one-location MILP model, which can be found in Appendix E. We can compare the historical data with outcomes of our model if we use a similar planning horizon. The model optimises with a rolling horizon given the forecast in the planning horizon, similar to what OS does manually.

5.2.1.1 Average order quantities when changing planning horizon

So, when the model was solved with the input of the thirteen-week-MRP different output could be expected, then we saw before. The demand is a lot less spiky than the shipping notification data we have used before and therefore order quantities should be lower. The shipping notification has an extremely spiky demand pattern, logically as the demand is already divided into the size of the order quantities. Also is the demand uncertain, demand disappears out of the forecast, as each roll of the model, the forecast changes. If the model anticipated a large demand for a long time in advance, this could result in large holding costs. So, because of these two reasons we expect the average order quantities to be a lot smaller than we have seen before.

Like expected, is the model much more hesitant of ordering large quantities, as demand is uncertain and fluctuation a lot. We do see for the Boxtray that the average order quantities are a bit larger than currently, however only for the two-week horizon. The thirteen-week-MRP, does not contain the same time-span as the shipping notification data. So the average demand the Boxtray, which is higher in this input explains this difference. In the case of the Bladebox, the order quantities are much smaller because we only used quantity discounts up to and including one FTL, which consists of 60 pallets. In reality are two complete FTLs relatively cheaper than two Less Than Truckload (LTL)s. However in general does the model give logical output, even when using the uncertain demand of the thirteen-week-MRP.

Table 5.3: Average order quantities: Output of one location model with thirteen-week-MRP data vs. Shipping notification data

Planning horizon (weeks)	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L
2	3.1	3.4	0.7	54.4	8.0	0.8	22.2
3	3.7	4.8	0.9	63.7	8.8	1.3	27.8
4	4.7	6.9	1.2	65.8	10.6	1.9	28.2
Shipping notification data:							
Average order quantity	4.4	2.5	1.4	131	13.7	1.2	21.9
Weekly demand	2.5	0.9	0.5	74.7	7.0	0.7	11.7

5.2.1.2 Impact on goal function

In Figure 5.7 the average total cost when using the thirteen-week-MRP are shown when varying the planning horizon. We do expect higher total cost as it is hard to optimize using a fluctuating forecast.

Figure 5.7: Total cost one location model with thirteen-week-MRP as data input

The graph looks quite inconsistent, which is a result of the fact the input demand is fluctuating. We cannot say that a longer planning horizon results in lower total cost, as we have seen in Figure 5.2. However, this is not that strange as the forecast can heavily change over time, as explained elaborately in Appendix F. So, using a longer planning horizon does not give more knowledge about the future demand and can even be misleading in some cases. Also, the effect of the ordering cost is not constant for each planning horizon used. In some cases, larger ordering cost give lower total cost because the model is less encouraged to order and therefore saves money as there were cases where instantly more demand was required and this was already in inventory.

5.2.2 Validation and usefulness of the model

The model is valid when the outcomes of the model are in line with the outcomes of a real situation. We have done an extensive verification of several parts of the model and concluded that the model has logical behaviour. This does not automatically say the outcomes are good enough to base our conclusions on. In the previous section, we have tried to use the model for a changing demand situation, similar to reality. It was hard to model this, as we build the model for assumed deterministic demand and the thirteen-week-MRP gives our model a lot more fluctuation input than is used in reality, as explained in Appendix F. But still, the assumption of deterministic demand can be a tricky one. As we saw in cases where we use a constant demand, the longer the planning horizon used, the better the outcomes of the model are. In these cases, we are also assuming more uncertain demand to be deterministic, so the outcomes become less valid. So, the validness of the model does depend on the planning horizon that is used. However, this does not mean that the outcomes when using a longer planning horizon are unusable or completely unrealistic. Maybe be even, on the contrary, the thirteen-week-MRP has a lot of fluctuations that are not present in reality. When we assume deterministic demand, we probably use values closer to the actual values than if we use the thirteen-week-MRP. It should be noted that, even when using this input, the output was quite consistent and did not result in extreme values. Concluding, the model is certainly valid but we have to take into account that the outcomes become less valid as we use a longer planning horizon.

5.3 Conclusion

For verification of the model, we have used the shipping notification data as input, to see if the output seemed logical. We assume the model to be correct because:

- All of the average order quantities are larger than the average demand quantities, therefore the model bundles demand of several weeks.
- The average order quantities increase as the planning horizon is increased, except when all of the quantity discounts are achieved.
- The total cost decrease as the model is solved with more information (a longer planning horizon).
- The effect of incorporating an extra location with more demand has a big effect on the average order quantities and promotes the use of lot size based quantity discounts.
- When the demand increases (by adding an extra location), the importance of using a longer planning horizon becomes less important as the maximal quantity discounts are more easily reached.

And to validate the model, we have used the historical thirteen-week-MRP data which we compared to the shipping notification data.

- Outcomes of the thirteen-weekMRP input in the one location model look like expected, therefore the model is assumed to be valid.
- Since the 13-week-MRP has a lot less spiky demand pattern and sometimes demand disappears out of the forecast, this causes the average order quantities to be a lot smaller than when solving with the shipping notification data as input.
- The use of a longer planning horizon makes the model less valid, as more uncertain demand is considered deterministic.

CHAPTER 6

Experimental design & analysis of results

This chapter gives an analysis of the results. This chapter answers our main research question:

- **What is the best way to improve the inventory management and distribution for the Blade and Brewlock materials in the current situation and what is the expected impact for HNS?**

First, we explain more about the use of quantities discounts in Section 6.1, then we explain about the use of IB-transport in Section 6.1.1 and in Section 6.1.2 we explain how the ordering process can be changed. Then is explained how what kind of scenario's we will test regarding the SmartCap and Boxtray in Section 6.1.3. Section 6.2 concludes the experiments we are going to do. Section explains why we use the monthly demand as input. In Section 6.3 we set our base scenario to which we compare our other results. Section 6.4 focuses on the use of IB-transport and Section 6.5 focuses on the situation where the SmartCap and Boxtray can be delivered directly to the breweries instead of using a groupage delivery. Eventually, we take a short look on the impact for inventory levels in Section 6.6.

6.1 How to make more use of quantity discounts

In our results, we focus on the use of quantity discounts. A question to be answered is: "What ordering process can be used to make more use of lot size based quantity discounts?" To use more quantity discounts, we have to make our lot size decision based on (more than) enough demand in the planning horizon. There are two ways to have more demand in the planning horizon.

- *Adding more demand in the same horizon.*
  This can be achieved by bundling the demand of Zoeterwoude and Den Bosch into one lot size decision. We can make use of Inter - Brewery transport to deliver to both breweries.

- *By extending the planning horizon.*
  The current ordering process has to be adjusted to reach this. But this is possible as there are examples where the common ordering process is not used. Tactical planning does the call-off order instead of OS for instance.

So, we have to investigate two ways to make more use of lot size based quantity discounts, which can be combined. Bundling the demand of Den Bosch and Zoeterwoude together is only possible if we make use of some transportation between the two breweries. And using a longer planning horizon for the lot size decision is only possible if we change the ordering process. However, we should also be careful with the use of a long planning horizon as we assume more and more stochastic demand as deterministic. We already saw, in Figure 5.2, that the effect of a longer planning horizon to the total cost also declines as the planning horizon is increased. Using a longer planning horizon than eight weeks is considered unnecessary, therefore we will often not show these results as the effect of the planning horizon is small and the assumption of a deterministic is becoming less valid.

6.1.1 The use of Inter-Brewery transport

As described in Section 2.2.2, the Hi-cone is an example of a material that is distributed from one Brewery to the order by Inter-brewery transport. According to OS, this way of working works well for this material. We want to investigate how efficient it will be to make more use of this transportation possibility. Our model gives this option for all materials to be transported within one period, which is realistic because every day half-empty trucks are driving between the two breweries. The goal is to find for which materials the use of inter-brewery transport is useful.

6.1.2 Changing the ordering process

The current ordering process, as described in 2.3.2 works well for most materials. However, it results in LTLs for some Blade and Brewlockmaterials, therefore a change in the process for some materials could be a good idea. At the moment, there is already a specific ordering process in use for some materials, e.g. the Sleeve and Bladebox. The main reason for this change in the ordering process is the longer lead-time than standard, but it also results in FTLs where they were not automatically achieved when using the common ordering process. We see several options for adjusting the ordering process for several materials. For example:

- TSCP makes the call-of order decision (i.e. makes the lot size decision) instead of OS.
  This way the thirteen-week-MRP is used for the lot size decision instead of the two weeks forecast that OS uses.

- OS starts using the thirteen-week-MRP for determining the call-off order quantities, the scheduling could be adjusted as well.

- OS starts using MOQs for some specific materials. These MOQs should be aligned with procurement to determine cost-efficient MOQs.

6.1.3 A more specific case: Groupage transportation of Boxtray and Smart-Cap

As described in Section 2.3.5 the current way of transporting the SmartCap and Boxtray by groupage transportation has its disadvantages. We want to investigate if it is cost-efficient to arrange transportation for HNS only. To be efficient, we need to reach FTLs in shipments from the supplier. By merging the demand of both breweries and the demand of the Boxtray and Smart Cap becomes achieving FTLs easier. We use the Free Ride quantities to test if this is cost-efficient because the SmartCap and Boxtray can free ride with each other because they come from the same supplier, this is confirmed by the supplier. This is currently not yet considered, because both materials are ordered independently and transported by groupage. If with the current planning horizon achieving FTLs is still hard, we can lengthen the planning horizon and see if this is useful. This way we simulate that TSCP does the call-off order instead of OS like is the case with the Blade box and Sleeve, described in 2.3.5 and 2.3.5.

A two-stop route If IB transportation is a useful practice to maintain larger order quantities, then a direct route from the supplier to both breweries could be useful as well. For the SmartCap & Boxtray we will investigate this situation as there are indications for the costs for this type of transportation.

Shared ordering cost In our model, we have assumed ordering cost to be present, for each material, for each location. However, when we bundle orders for multiple locations or multiple materials, we could argue that these ordering costs have to be shared among these locations and/or materials.

6.2 Experimental design

So, to present the result of the mentioned scenarios, we first explain a base scenario, where only the effect of a longer planning horizon is shown in Section 6.3. Then we will continue with Section 6.4 focused on IB-transport. In Section 6.5 we will focus on the SmartCap and Boxtray, as see cost-saving potential for changing the inbound supply chain of these materials. And in this section we will cover the options of a two-stop-route and the effect of shared ordering cost.

6.2.1 Setup of demand input

The Monthly MRP is used as input for modelling future situations. Strategical planning constructs this forecast, they look at a horizon of about 1 to 1.5 years. We did split this forecast into a weekly forecast, simply by division in the number of weeks. We know that this is not completely correct. For example, the packaging line in Zoeterwoude can produce Brewlock and Blade, but will most of the time produce one type in a row to minimize setup times. So one week Blade, one-week Brewlock is more logical demand pattern for Zoeterwoude. But because we do not know which week would be allocated to which packaging type, the weekly averages are the best we got. However, this problem is getting less important over time. When the Blade line in Den Bosch opens, most of the Blade demand will be produced by the packaging line in Den Bosch and all of the Brewlock demand will be produced in Zoeterwoude. This is also visible in the forecast. So this effect will decrease and we do not expect that it will influence the outcome of the model too much.

6.3 Base scenario

The scenario, we identify as the base scenario is a scenario were IB transport is not possible and there is no free-riding for the SmartCap & Boxtray. The two types of Preforms do free-ride with each other, as this is currently already happening. This scenario describes the situation where we do not change the ordering process or way of transporting.

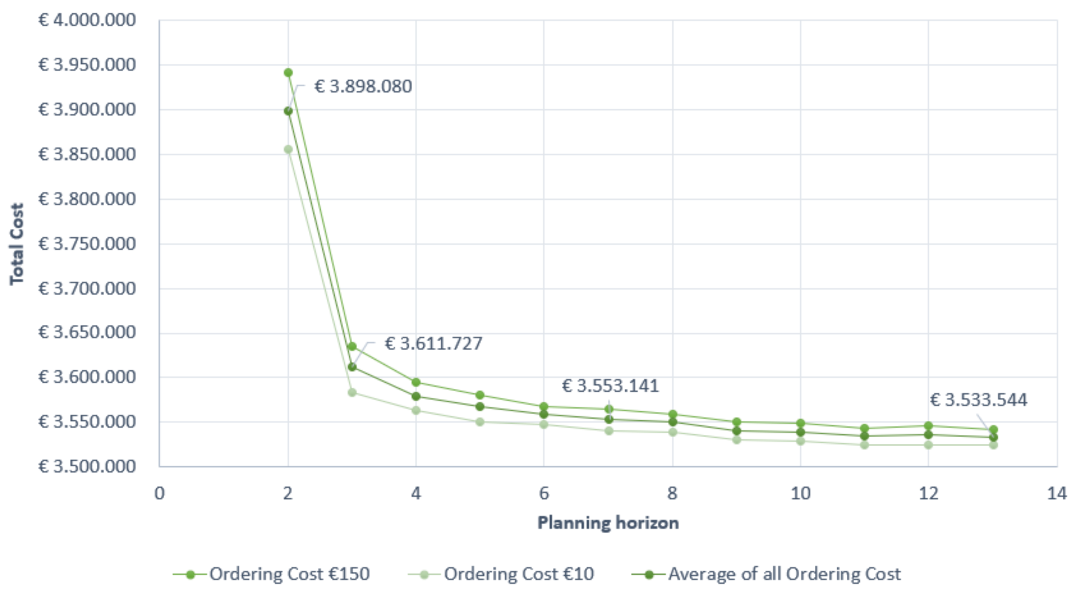

Figure 6.1: Total cost without use of IB-transport and varying planning horizon

We do present varying planning horizons, as these are hard to relate with the current ordering process. The Blade box and Sleeve are ordered with a lead time of four weeks, using the thirteen-week-MRP, the regular ordering process uses a one to two-week forecast. Another reason for presenting the varying planning horizons is that we can already see the effect of lengthening the planning horizon. Total cost is declining as the planning horizon is increased. The effect is declining as the planning horizon is increased, but an average reduction in total cost of more than 9%, €364,536, is quite large. We also already see that the ordering costs do not have a large effect on the total costs.

Table 6.1: Average order quantity based on planning horizon (pallets) average ordering cost

Planning horizon (weeks)	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L
2	1.9	1.1	0.3	20.5	5.6	0.4	8.9
3	3.7	2.2	0.6	37.7	9.5	0.7	11.8
4	4.5	3.3	0.9	46.1	14.4	0.7	26.2
5	6.7	3.7	0.9	42.3	17.2	0.7	33.7
6	7.6	5.0	1.1	45.1	17.2	0.7	33.7
7	9.6	6.0	1.1	47.1	17.8	0.8	26.2
8	9.6	7.5	1.2	46.1	17.8	0.8	29.5
9	10.1	7.5	1.3	56.0	17.8	0.8	29.5
10	9.1	8.5	1.3	54.5	17.8	1.0	29.5
11	9.6	7.5	1.3	56.0	17.8	1.0	27.7
12	11.4	10.0	1.4	54.5	16.7	1.1	27.7
13	10.7	10.0	1.3	54.5	17.2	1.0	26.2
Historical data	4.4	2.5	1.4	131	13.7	1.2	21.9
Increase / decrease week 4	3%	33%	-34%	-65%	5%	-38%	20%

In Table 6.1 the average order quantities are given. This table is the result of the average of the fourteen model outcomes, where ordering cost range from €10 till €150 with steps of €10. We see that using settings that simulate the current situation the best, the average order quantities are sometimes larger and sometimes smaller than currently found. In the last row, the increase/decrease compared to a planning horizon of 4 weeks is shown. The average order quantities for the Sleeve, AK03 and Bladebox have decreased compared to the historical data. For the Bladebox this is caused by the fact that we do not take the second FTL into account, as explained in 5.2.1.1. The Sleeve and the AK03 are historically and in the outcomes of the model ordered in very small quantities. This is partly caused by the relatively small quantity discounts, but is mainly caused by the fact that so many materials fit onto one pallet. This makes these materials relatively expensive to purchase and expensive to hold as inventory, when looking at the unit size of pallets. Table 6.2 shows the capital holding costs of the materials. Here we see that the materials are not especially expensive but the quantities per pallet are large.

Table 6.2: Capital holding costs, price per piece and quantities on a pallet

Material	Holding cost (WACC € ×€ Purchase cost)	Piece price	Quantity on pallet
Preform8L	€ 96	€ X	1,440
Preform20L	€ 85	€ X	864
SmartCap	€ 127	€ X	4,200
Boxtray	€ 49	€ X	6,000
Sleeve	€ 226	€ X	27,000
Bladebox	€ 19	€ X	400
AK03	€ 610	€ X	28,000

As we can see that a pallet of AK03 cost €610 to hold in terms of capital, it is not strange that the average order quantities are smaller in the outcome of the model.

Figure 6.2 and Figure 6.3 give the cycle stock levels, the average pallet places used above the safety stock levels. We see that the inventory levels In Zoeterwoude increase as the planning horizon increases, which is logical as we also already saw that the average order quantities do increase as well. For Den Bosch, this is less clear but still do longer planning horizons result in higher inventory levels in general.

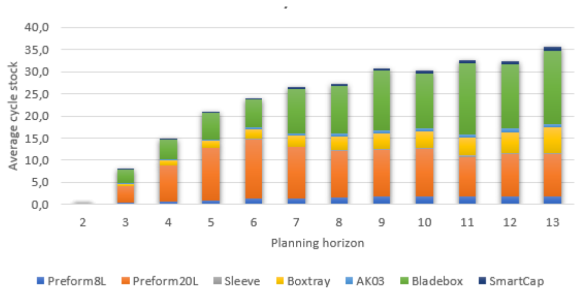

Figure 6.2: Cycle stock Zoeterwoude, No IB

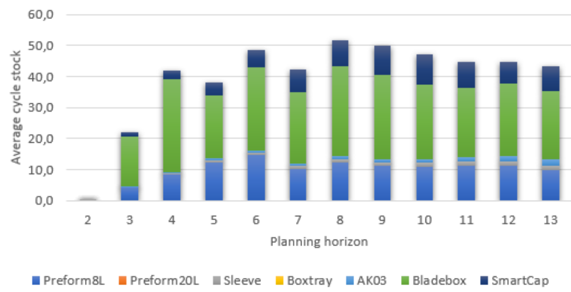

Figure 6.3: Cycle stock Den Bosch, No IB

The effect is declining as we increase the planning horizon, similar to the order quantities and total cost. The count of orders is decreasing as we increase the planning horizon, this is shown in the next Section 6.4, Figure 6.4. So, in general we can say that increasing the planning horizon does have an effect on the average order quantities, number of orders, inventory and is eventually leading to a decrease in total cost. The smaller order quantities of our model for the Sleeve and AK03 are the result of very high holding cost for these materials and indicate that achieving FTLs for these materials is not the right goal. Inventory levels should be kept as low as possible. For other materials seem that using a longer planning horizon has a beneficial effect on the total cost by increasing order quantities, decreasing the number of orders and keeping more inventory.

6.4 Inter-Brewery Transportation

Firstly, we investigate the effect of IB-transport. Both Breweries can order and inter-brewery transport is possible for every material. We used a cost allocation of €8.58 for the transport of one pallet place. In reality, trucks are already driving between the breweries, but the costs are allocated in this way to the load of the truck. For the handling we have used a tariff of €1.08, which we got from Chapter 2, Table 2.4, which is allocated two times for one IB-trip. Figure 6.3 gives the total cost with different settings for the ordering cost and planning horizon.

Table 6.3: Average order quantities and total cost of IB-transportation

Planning horizon	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L	Total cost
2	3.2	1.1	0.6	33.8	9.3	0.7	8.9	€ 3.792.119
3	6.3	2.2	1.0	61.4	17.1	1.4	16.9	€ 3.569.025
4	9.2	3.3	1.6	75.0	22.4	2.0	26.0	€ 3.548.601
5	11.9	4.2	2.0	73.5	30.4	2.4	30.6	€ 3.539.676
6	15.1	5.4	2.5	75.5	25.2	2.7	28.3	€ 3.534.433

The total cost graph looks similar to the Base scenario, 6.1. Again, the use of a longer planning horizon results in lower total cost. The setting of the ordering cost affects the total cost but gives a similar graph for each setting. Also, the difference between a planning horizon of 2 weeks and thirteen weeks is similar to that of the base file, €269,124, a decrease of more than 7% by lengthening the planning horizon. However, for every planning horizon, the total costs are lower than the base file. The difference in total cost ranges from €105.000, using a planning horizon of two weeks till €10.000 using a planning horizon of thirteen weeks. So, the use of IB-transport and the use of a longer planning horizon both result in lower total cost but do not amplify each other. In other words, if we use IB-transport, we do not need to take such a long planning horizon to reach the same total cost.

Figure 6.5 gives the average number of orders placed for all the different runs with different ordering cost. The graph looks very similar to the Figure 6.4. Interesting however is the y-axis: the use of IB-transport has a clear effect on the all of the average number of orders. The average number of orders have decreased a lot compared to what we have seen in Figure 6.4.

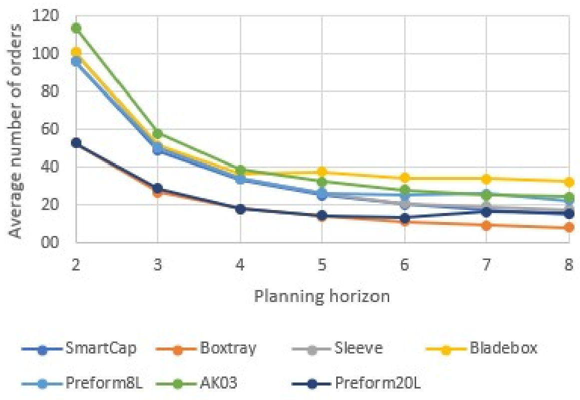

Figure 6.4: Average number of orders base scenario

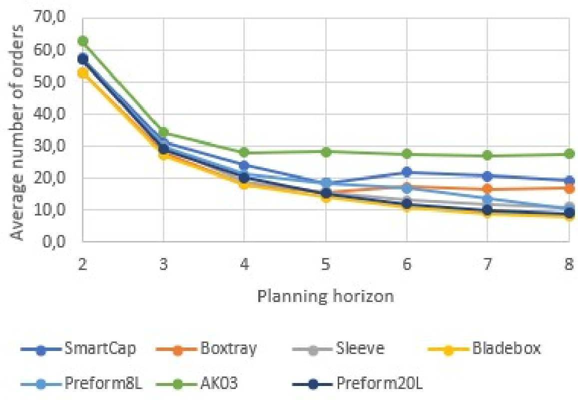

Figure 6.5: Average number of orders IB scenario

Table 6.4 gives an overview of the impact that IB-transport has. These percentages are the average of all outcomes given the varying planning horizon between two and thirteen weeks.

Table 6.4: Impact of IB-transportation compared to Base

Increase/decrease	Preform8L	Preform20L	Sleeve	Boxtray	AK03	Bladebox	SmartCap
Average order quantities	32%	-4%	61%	0%	96%	26%	64%
Number of orders	-22%	5%	-35%	0%	-48%	-20%	-39%
Inventory level Zoeterwoude	-1%	-8%	-68%	0%	-76%	-52%	-44%
Inventory level Den Bosch	-12%	0%	0%	0%	49%	-11%	2%

So, on average we see that number of orders decrease, the average order quantity increases and the inventory levels decrease as inventory us shared among the breweries. Only the number of orders for the Preform20L increase. This is caused by the free-riding among both preforms. As these can free-ride with each other, the Preform 20L is now also ordered by the Brewery in Den Bosch and then delivered at Zoeterwoude by IB-transport, where these materials are required for production. Since Zoeterwoude can also be supplied from Den Bosch or sometimes does supply to Den Bosch, average stock levels can be lowered while the average number of orders are decreased at the same time. So, the decrease in total cost is not only caused by savings on lot size based quantity discounts but also by the decreased inventory levels.

Figures 6.6 and 6.7 shows the on average used IB-transport varying the planning horizon (in pallets). Logically the Boxtray and Preform20L are not transported to Den Bosch, as the Brewlock is not produced in Den Bosch. The Boxtray is never even transported between the breweries, as the Boxtray and SmartCap are not free-riding in the current situation. In general we see that there are more materials moved from Zoeterwoude to Den Bosch than the other way around, this is especially Bladeboxes. But the Bladeboxes are moved to Zoeterwoude quite a lot as well. Maybe this looks like an undesirable situation which results in a lot of unnecessary movement and handling. Although, this way of working does save on total cost because lower stock levels can be achieved at both breweries if sometimes small quantities are distributed instead of larger quantities from the supplier to a brewery. In general, we can say the average quantities that are transported by IB-transport decline when the planning horizon is increased. This indicates that the use of IB becomes less important as more future demand is known.

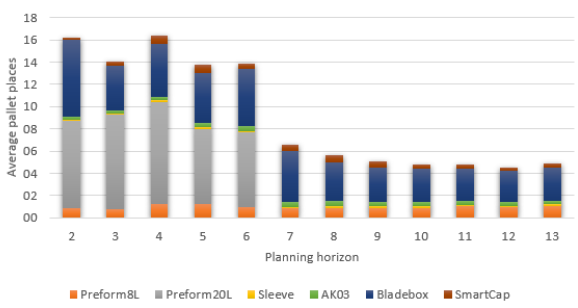

Figure 6.6: Average IB pallet places used to Zoeterwoude

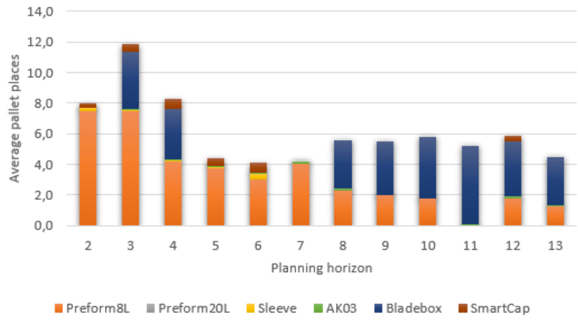

Figure 6.7: Average IB pallet places used to Den Bosch

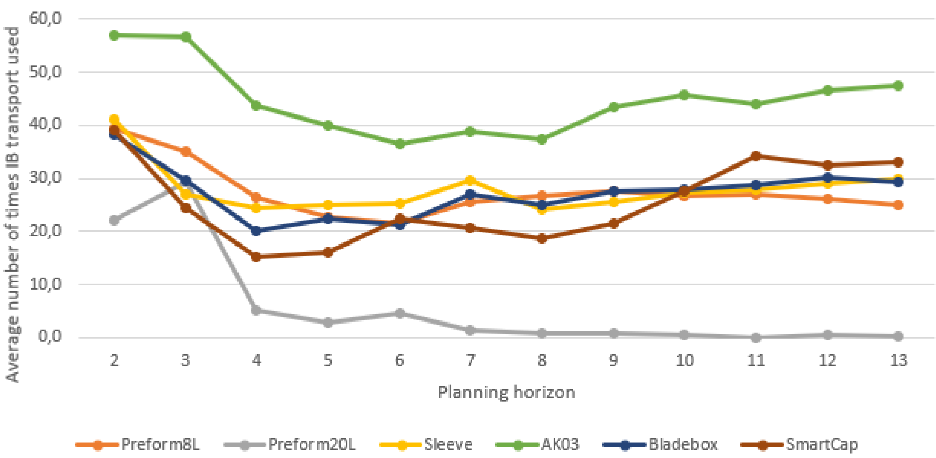

Figure 6.8: Average number of times IB-transport used

In Figure 6.8, we see that in general, the number of times that IB-transport is used is first declining when the planning horizon is increased and later on for some materials increases a little again. This looks like a logical outcome where IB-transport first becomes less important to meet short term demand, when the planning horizon increases. Then when the planning horizon is increased even further into the future, IB-transport is only used for small short term demands, because we already expected some large demands in the future. Also, the preform8L is transported quite often from Zoeterwoude to Den Bosch, quite logically as these materials free-ride with the Preform20L and Den Bosch does not have a demand for the Preform20L. If the demand for Preform20L is not enough for an FTL, some Preform8L can be shipped as well and then be transported to Den Bosch afterwards. The Sleeve and AK03 are transported a lot but in very small quantities, see Figure 6.8. This is not desirable, as HNS only wants full pallets to be moved between the breweries, because of instability issues with pallets that are already partly unpacked.

6.4.1 Integer IB-Transport

In reality, HNS cannot transport half-full pallet because of instability issues. Pallets are mostly unloaded at the packaging line and not at an earlier stage in the warehouse. Therefore, the pallet quantities to be driven around between the two breweries should be integer. A big disadvantage of setting the inter breweries quantities to integer is the increase in computation time. It takes more than a night to solve using only a thirteen-week planning horizon. But to investigate the impact of using integer values for IB-transport, we have solved the model with the restriction of integer values for IB-transport for ordering cost of €10 and for the planning horizon in the range two up to seven.

In Table 6.5, the total cost when using integer values for IB-transport have increased compared to the

Table 6.5: Comparison of average order quantities and total cost, of integer and continuous IB-transport

Planning horizon	SmartCap	Boxtray	Sleeve	Bladebox	Preform8L	AK03	Preform20L	Total cost
	Average order quantities (pallet)							
2	1.9	1.0	0.3	21.4	5.5	0.4	7.1	€ 3.778.068
3	3.6	1.7	0.7	39.9	10.1	0.7	12.7	€ 3.566.744
4	5.5	2.3	1.0	51.8	14.0	0.7	23.6	€ 3.541.978
5	7.0	2.8	1.1	62.8	15.7	0.7	26.2	€ 3.528.967
6	9.1	4.0	1.4	60.9	14.0	0.8	22.5	€ 3.523.705
Continuous output:								
2	3.2	1.1	0.6	22.5	8.3	0.7	8.9	€3,764,144
3	6.3	2.2	1.0	46.0	15.7	1.0	17.5	€3,554,499
4	6.5	3.3	1.6	56.0	17.2	0.9	23.6	€3,541,639
5	10.7	3.7	1.2	69.1	19.7	1.0	26.2	€3,528,764
6	15.1	5.0	1.4	69.1	17.8	1.1	20.5	€3,523,516

continuous setting. However, the total costs do still significantly decrease compared to the base scenario and the difference with the continuous settings is not large. We can even assume that the integer setting becomes less important as the planning horizon is increased and the IB-quantities increase as well, the difference when using planning horizon of six weeks is just €189. In general, the average IB-quantities have decreased or stayed the same. By the given output we can assume that, certainly when using a longer planning horizon, the difference between integer values and continuous is not large enough to significantly influence our results.

6.4.2 Which materials to transport by inter-brewery transport

So, for some materials is inter-brewery more useful than for others. As the Bladeboxes are quite voluminous to use for the empty spaces in the current IB-transport, transporting so many pallets with Bladeboxes between the breweries is not that desirable. For example, the average quantity to be transported between the breweries when using a planning horizon of two weeks is already a FTL (60 pallets). This directly means that we need to arrange more IB-transportation between the breweries. We have covered the cost for this transportation, but driving more trucks between the breweries is not the way to go, we want to make more use of current transportation movements, not creating extra transportation routes. In the context of reducing CO2 emissions, it is already a bad idea to create more transportation movements. For the Sleeve and AK03, the opposite is the case, these are only moved in really small quantities, not even full pallets. Which is not possible, because of instability issues. The AK03 is not transported between the breweries when solved a integer values, so IB is not useful for these materials. The Preform20L is not required in Den Bosch but the move of the Preform20L from Den Bosch to Zoeterwoude does happen. So some inventory is stored in Den Bosch. The preform8L is more often transported to Den Bosch, so for both preforms IB-transport looks useful. The Boxtray is also moved from Den Bosch to Zoeterwoude and the SmartCap is also moved in small quantities to both locations. So, the most promising materials to be moved around by Inter-brewery transport are the two types of Preforms, the SmartCap and Boxtray. Especially if the IB-transportation is used while these materials can free-ride with each other from the supplier.

6.5 Direct delivery SmartCap and Boxtray

Groupage transportation has several disadvantages compared to direct delivery, mentioned in Chapter 2, Section 2.3.5. As the transportation is neither in hands of HNS or the supplier there is less control over the transportation. Lead times are unreliable, groupage deliveries are known to be late. Also, there is a higher risk of damaging the materials, as the pallets can be cross-docked on the way. Even for the SmartCap there is a hygienic risk as this material comes in contact with the beer, a clean and hygienic transportation is very important. For direct transportation to be cost-efficient, larger order quantities have to be achieved. In other words, Groupage transportation is more expensive than direct delivery when the order quantities are larger.

6.5.1 Average order quantities considering SmartCap & Boxtray

So, in previous sections, we saw that increasing the planning horizon and the use of IB transport does result in some overall cost savings and big differences in average order quantities. The break-even-point between groupage transportation and direct delivery lies at twelve pallets. When ordering twelve pallets or more, the transportation price to be paid for each pallet is lower with direct delivery than by Groupage transportation. In Table 6.1, we saw that the average order quantities for the SmartCap and Boxtray were already increasing by increasing the planning horizon and again the average order quantities increased by adding the possibility of IB-transport, as we saw in Table 6.4. However, these average order quantities are not completely correct for the situation of direct delivery, because when these materials are delivered directly then they will free-ride with each other just like the Preforms. In Table 6.6 the average order quantities are given of the SmartCap, Boxtray and these materials ordered per location.

Table 6.6: Average order quantities and total cost for direct delivery of SmartCap and Boxtray

Planning horizon	SmartCap	Boxtray	Zoeterwoude	DenBosch
2	3.2	1.1	1.0	3.3
3	6.2	2.2	1.7	8.9
4	9.5	3.3	2.9	14.2
5	12.1	4.3	2.3	18.7
6	15.1	5.0	3.1	23.5
7	16.8	5.5	4.0	25.3
8	14.6	5.4	6.1	21.5

In Table 6.6 we can see that when the model uses a planning horizon of four weeks or longer, the average order quantity for Den Bosch is larger than twelve pallets. You would not expect that this would be the case if we would look at the current situation. If we let the model use the same settings for the SmartCap and Boxtray except instead of the lot size based quantity discounts for direct delivery, we use the discounts for Groupage. Groupage also gives a discount on larger orders, but these discounts are a lot smaller. In Table 6.7 we see the outcomes of the model.

Table 6.7: Average order quantities for groupage delivery of SmartCap and Boxtray

Planning horizon	Boxtray	SmartCap	Zoeterwoude	Den Bosch
2	1.1	3.2	1.1	3.4
3	2.2	6.3	2.2	6.6
4	3.3	9.6	3.3	9.9
5	4.3	11.8	4.3	9.9
6	5.4	12.9	5.5	6.3
7	6.6	13.8	6.6	11.4
8	7.5	12.0	7.5	12.1

The optimal order quantities given Groupage transportation are much smaller than when the input of direct delivery is given. So, when you optimise the current situation, you would not expect that direct delivery would even be a considerable option given the optimal order quantities.

6.5.2 Free-riding and IB-transportation

As we can see in Figure 6.9 is IB-transport much less used for the SmartCap and Boxtray when they free-ride with each other to one of the breweries. The Boxtray is never transported to Den Bosch.

Logically, because the orders at the supplier consist of both materials, instead of ordering one material and supplying the other material from the other brewery.

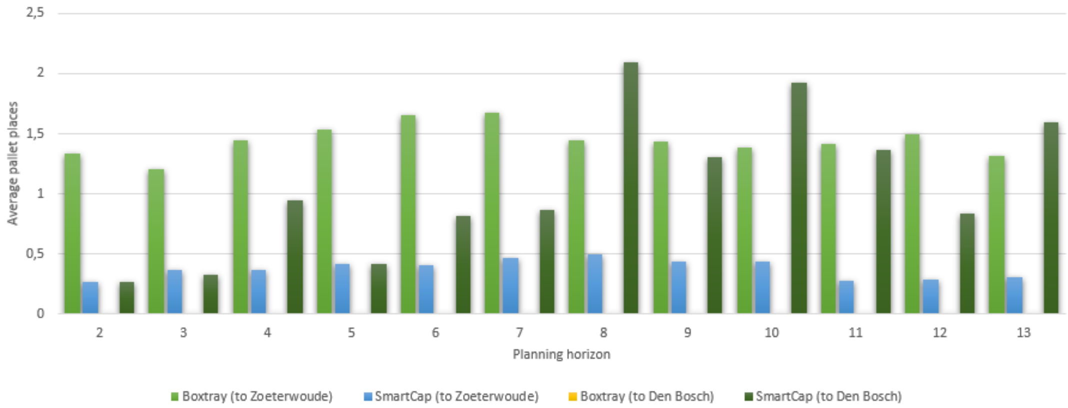

Figure 6.9: IB-transport used for Smartcap and Boxtray with free-riding

6.5.3 Direct delivery transportation by Supplier

When we want to use direct delivery efficiently then the SmartCap and Boxtray have to be placed in one truckload, then these materials will free-ride with each other on the lot-size based quantity discounts. The SmartCap is placed on a standard pallet and the Boxtray on a euro-pallet. So, if we want to merge those materials in one FTL, we have to make sure it fits.

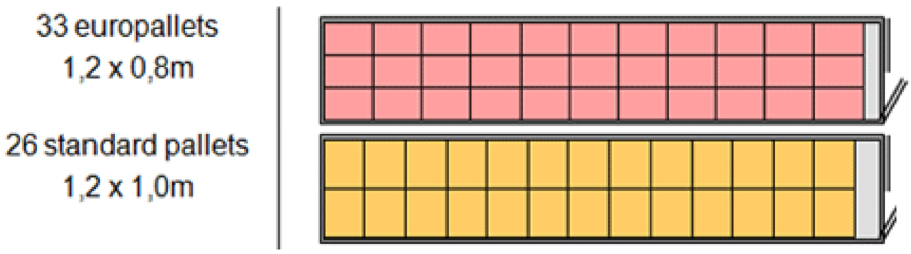

Figure 6.10: Lay-out of pallet types in truck

The euro-pallet can be placed three next to each other over the width of a truck, the standard pallet only two. So, to achieve an FTL, the number of euro-pallets has to be dividable by three and the number of standard pallets by two. An FTL can consist of 18 euro-pallets and 12 standard pallets for example. So, if we compare this layout with Table 6.6, we see based on the average order quantities, FTL are not always achieved. Maybe, if the order quantities are smaller than these FTL smaller trucks can be discussed or TSCP can just round up their call-off order quantities to an FTL.

6.5.4 Two stop route from Supplier to both Breweries

When delivering directly, a two-stop-route would probably be the best option to deliver as we then can merge the orders of both breweries into one truck. In terms of handling (cost) for HNS, this is a lot easier compared to IB-transport, employees do not have to do the unloading and loading of the materials that are transported by IB-transport. However, we already saw, in Figure 6.9, that IB-transport is not used when for the SmartCap and Boxtray when these materials are delivered directly. We have asked several logistics providers for the cost of the route Belgium - Den Bosch - Zoeterwoude. One can provide this route for €310, which is a quite reasonable price. Cost for an IB-transport one way is €205 and if we want to drive back immediately, it costs €246 in total. So, the difference with the previous outcomes is that now the orders of for the SmartCap and Boxtray in Den Bosch will also free-ride with the orders for the SmartCap and Boxtray in Zoeterwoude. In other words: every period an order can be done, to deliver at both breweries for both materials and these materials will all be delivered in one shipment, so will all count for the lot size based quantity discounts. Note that the ordering costs still are calculated for each item ordered, at each location.

6.5.5 Total cost savings

When we compare the three settings we have discussed previously, we see that for all planning horizons and ordering cost savings occur on total cost by allowing IB-transport and even a little more savings occur by simulating a two-stop route compared to the base scenario. Table 6.8 gives an overview of the total cost. For all outcomes, we have taken the average of all ordering cost settings, ranging from €10 up to and including €150 with steps of €10.

Table 6.8: Total cost comparison: Average savings by two-stop route

Planning horizon	Base scenario	Total cost: Possibility of IB	Two-stop-route	Savings by: IB	two-stop-route
2	€ **3,898,080**	€ 3,792,119	€ **3,782,234**	€105,961	€ 9,885
3	€ 3,611,727	€ 3,569,025	€ 3,563,282	€ 42,702	€ 5,743
4	€ 3,579,213	€ 3,548,601	€ 3,540,201	€ 30,612	€ 8,400
5	€ 3,567,108	€ 3,539,676	€ 3,533,824	€ 27,432	€ 5,852
6	€ 3,558,633	€ 3,534,433	€ 3,531,689	€ 24,199	€ 2,744
7	€ 3,553,141	€ 3,527,591	€ 3,524,537	€ 25,549	€ 3,055
8	€ 3,549,853	€ 3,525,032	€ **3,523,366**	€ 24,821	€ 1,666

In Table 6.8 is shown that the use of two-stop-route for the SmartCap & Boxtray does come with quite significant savings. The savings are also depending on the planning horizon that is used in the model. If we say that the planning horizon of the current ordering process comes closest to a planning horizon of two weeks, then savings of around €115,846 occur in a period of 58 weeks, when we switch to a two-stop-route. If it is also possible to use an eight-week forecast for the lot-size quantity decision than even a difference of €373,714 can be found. So, significant savings can be achieved by the use of a longer planning horizon and a two-stop-route.

6.5.6 Shared ordering cost

As we mentioned earlier, the ordering cost were calculated for each item ordered for each location. If we are going to bundle the orders for the SmartCap and Boxtray for both locations, then we could probably bundle these ordering costs as well. In other words, if we order one of these materials, from one of the locations, ordering costs occur. If we order two materials and/or from two locations at the same time, this is still one order, so the ordering cost can be shared among the materials and locations ordered simultaneously. Table 6.9 gives the results when we solve the model with shared ordering cost among both locations and both materials.

So, we do see that if we consider the ordering cost per supplier, per period that even larger order quantities are ordered on average. The average order quantity achieved of 25 pallets means that almost all of the time the maximum lot size based quantity discounts are used. The last price break is reached at 25 pallets. However, the difference is not that big. So, independently of how ordering costs are defined, can we say that achieving efficient truckloads is possible given that we make use of direct delivery.

6.5.7 Implementation of direct delivery of SmartCap and Boxtray

We concluded that combining the demand of the SmartCap and Boxtray into one call-off order quantity decision is a good idea. The first method that came to mind, is to use IB-transportation. However, using a two-stop-route is an easier method that should be cheaper as well. The third and recently available option is to combine the materials with other materials, beer tubes are recently bought from the same

Table 6.9: Average order quantities with and without shared ordering cost SmartCap & Boxtray

Planning horizon	With sharing ordering cost	Without sharing ordering cost
2	4.2	4.2
3	8.3	8.3
4	12.7	12.6
5	16.1	16.1
6	20.1	20.1
7	24.0	22.4
8	25.6	19.0

supplier as well and transported to Heineken Brewery BV (HBBV) in Zoeterwoude. This makes the idea of a two-stop-route even easier to implement. If the truckloads can be filled with tree materials, achieving FTLs becomes even easier. The supply of these beer tubes will be very regular; about once a week a truckload, depending on how fast the production line is up to speed. It should be an easy practice to let the SmartCap and Boxtray free-ride with these beer tubes on the way to Zoeterwoude. This way the largest lot size based quantity discounts are automatically reached as the truck with beer tubes is filled to a FTL by adding some pallets with SmartCaps and/or Boxtrays. The current ordering process can still be used where OS orders based on their forecast. Lead times are the same, and inventory levels do not have to be increased. The only alignment that has to take place is between OS of both breweries of the two slot times wherein the supplier has to deliver at both breweries.

6.6 Effect on inventory

Larger order quantities result in higher inventory levels. As explained in Section 4.5 and Appendix D.2 warehouse space should not be a restriction and therefore is not a constraint in our model. But to get an idea of the extra cost of inventory, the effect on inventory levels is important as well.

6.6.1 Available warehouse space

So, as said the warehouse space should be enough, but is it? There are over 90 square meters in the inbound warehouse of the Blade and Brewlockmaterials. There are two types of pallets, standard and Euro-pallets, A euro-pallet is 1 square meters and a standard pallet is 1,2 square meters. If we look at the outcomes the model with several settings we see that the maximal total required square meters is 105. A part of the inventory (around 20 square meters) is kept at the production line, so this will fit easily. We can also approach the same question from a production perspective. The production line in Den Bosch is planning to produce with three employee shifts, i.e. 120 hours a week and maximal with five shifts, i.e. 168 hours. To produce a full week with 168 hours we need the number of pallets shown in Table 6.10. The Operational Performance Indicator (OPI) is 80% of the nominal speed of 600 blades an hour, which is the norm, but the norm is probably not achieved easily, certainly not in the beginning. The OPI in Zoeterwoude is normally around 60%.

Table 6.10: Maximal required ground places for 1 week of production in 5 shift workweek

	Max Demand (in pallet)	Stackable	SubTotal	Pallet type (m^2)	Total m^2
Preform8L	56	2	28	1.2	33.6
Valves	2.88	1	2.9	1.2	4.46
Sleeve	3	1	3	1	3
SmartCap	19.2	1	19.2	1.2	23
Bladebox	92	2	46	1	46
Total	173		99		$109m^2$

So maximally $109m^2$ is used for a full week of production, with 5 shifts and an OPI of 80% and this will fit in the warehouse space. This situation is very unlikely to happen a lot, so we are sure that the available warehouse space is large enough.

6.7 Conclusions

- Significant savings, of maximally €373,714 can be achieved by increasing the planning horizon and using a two-stop-route with direct delivery for the SmartCap and Boxtray.
- Average order quantities for all materials, except the Bladebox, AK03 and Sleeve have increased by 5% to 33% by the outcomes of the base scenario. So, it would be cost-efficient to make more use of these discounts, in general.
- To bundle the demand in one order quantity decision we can make use of IB-transport or a direct delivery with two stops. Bundling demand is most useful for the Preforms, SmartCap and Boxtray.
- Direct delivery is always cheaper when the average order quantity is above twelve pallets. This can be achieved by a using a two-stop-route. And solve the model with shared ordering cost for the SmartCap & Boxtray even larger order quantities are achieved, see Table 6.9.
- The AK03 and Sleeve should not be ordered in larger quantities, holding costs are high and lot-size based quantity discounts are small.
- By using the model and by using the demand of the production line we conclude that there should be no shortage in warehouse space, see Table 6.10.

CHAPTER 7

Implementation

This chapter provides some discussion for further implementation of the model we have used in this thesis. This chapter is split up into four Sections. Section 7.1 explains how the model is transferred to HNS. In Section 7.2 is explained for what reasons the model could be used for investigating other materials and Section 7.3 gives a shortlist of how we can recognise these materials. Section 7.4 explains how the model can be used to discuss the call-off order quantity decision. This chapter answers the last research question:

- **How can we implement the model within HNS for future use?**

7.1 Using the model with HNS

As explained earlier, has the model been build as generic as possible. So we do hope, the model can be of further use within HNS. In AIMMS an understandable user interface is built, so without knowledge of mathematical modelling can the model be used. The idea is that this model can be used as a tool for the procurement department to get insights into changing inbound supply chains. In the sections before we explained which situations are applicable to investigate, using the model and when alarm bells should be ringing to investigate possible ways of working.

At the end of this thesis, the model was explained and transferred to employee of the TSCP department. This employee is an experienced AIMMS user, so is capable of changing the model for further use, if needed. The model can be used by the Procurement department to get insights in trade-offs like the trade-off between groupage and direct delivery or get insights which can be used for negotiation contracts, etc. Employees of the TSCP and Procurement department will discuss together how to use the model the best and when to use it.

7.2 Use of model for other materials

Blade and Brewlockmaterials are not the only materials that could be described as unusual for HNS, for example, the keg caps can be seen as unusual too in terms of order quantities. The model we propose could be useful for other materials as well, to analyze if the way of working negatively influences the total cost. For example, does Heineken make efficient use of lot size based quantity discounts for these materials? Examples of materials where we expect improvements can be made are aluminium bottles, keg caps of keg stickers. The model has been build as universal as possible, this allows making further use of this model for other situations within HNS (or even other companies). The model can be used for several uses:

- *To investigate the usefulness of IB-transport*
For HNS a standardized way of transporting materials Inter-Brewery could be a good idea, also for other materials that we did not investigate. But also if a similar situations can be thought of in other companies, the model could be useful to investigate the usefulness of dividing inventory between locations to be able to purchase materials more cost-efficient. Note that also the cost of the extra handling should be taken into account and an idea of the ordering cost should be present.

- *Free-riding between materials.*
For the case of SmartCap and Boxtray transported together, they count for each other in the quantity discounts. Similar situations can be found at other suppliers. The model takes this effect into account if the Free-ride constraints are modified for these materials. How big these effects are, mostly depend on the differences of the lot size based quantity discounts.

- *The trade-off between Groupage transportation and direct delivery.*
This trade-off can be investigated by comparing two different price breaks for two types of transportation. It could be that the currently used order quantities are low or high because of the currently used price breaks, so it's not always sufficient to see which price break is the cheapest using the current order quantities. The model can be used to compare the optimal outcomes of both transportation methods, using the corresponding price breaks. With the use of the model, the total cost can be compared.

- *The ordering process (i.e. the planning horizon and interval).*
We saw that the planning horizon has big influences on the optimal ordering schedule reached. The effects of the planning horizon and planning interval can be investigated for other materials as well. The forecast is different for many materials in terms of how reliable it is and how flexible the supplier is. By experimenting with different settings HNS can get an idea of the impact a change in the ordering process would have. Also for other companies, this would be an interesting thing to investigate.

- *The required warehouse space.*
One of the outcomes of the model are inventory levels of course. And especially with the extension mentioned in Appendix D this model could certainly be used to calculate expected inventory levels and to investigate the use of a flexible external warehouse.

7.3 Materials to investigate

It makes sense to investigate every material that does not follow the regular way of ordering, like the Bladebox and Sleeve for instance. What are the reasons that the regular ordering process is not used? And is the current ordering process still suiting for the current situation? Also, every material required for products that are in the growth phase of the product life cycle should be looked at too, Demand often increases a lot. So, economies of scale could be achievable and should not be forgotten under the pressure of the operation. So, to summarize when alarm bells should be ringing:

- When materials are called off in LTLs.
- There is a significant change in demand for materials.
- There is a significant change in transportation cost.
- There is a significant change in total demand (of different materials) at the supplier.
- There is a significant change in warehouse space.

7.4 Who directs the call-off order quantity decision?

As we can investigate the ordering process, especially when looking at the planning horizon and planning interval. We could think of several changes to the process to the current process to be implemented, for example:

- TSCP would place a call-off order based on the thirteen-week-MRP (or will at least set up this call-off order).
- OS will round up to determined quantity without knowledge of future demand.
- OS will use the thirteen-week-MRP for some materials to determine call off order quantities.

Several workarounds could be thought of but the main question remains: who should direct the call-off order quantity decision in this case? Actually, there are three options: OS, TSCP and the supplier.

- When is an order triggered?
  - **OS** A periodic check on a out-of-stock situation triggers one of both OS departments. This OS department contacts the other OS department and together they will align their call off order.
  - **TSCP** A periodic check at both plants has to be arranged by TSCP and triggers the call-off order.
  - **Supplier** The supplier uses the of the thirteen-week-MRP and inventory levels at both breweries to for a periodic check and schedule deliveries at the breweries.
- Advantages
  - **OS** The operational task of calling off orders is fully accommodated at the operational departments.
  - **TSCP** The thirteen-week-MRP is already used by TSCP.
  - **Supplier** Decrease in ordering cost, supplier can align production with demand, no complicated ordering process for simple materials.
- Disadvantages
  - **OS** has to use thirteen-week-MRP and therefore arranges two types of call off order decision processes.
  - **TSCP** The task of making a PO is too operational for TSCP, if TSCP does place a PO it increases the ordering cost.
  - **Supplier** Less control over the supply chain, the supplier has to be capable and to be trusted. Flaws will result in a lower service level.

Giving the supplier more responsibility is something we have discussed earlier in this thesis when we talk about VMI, in Section 3.4 for instance. However, the disadvantages are clear, with good collaboration these could be minimized and we think that giving the supplier more responsibility could result in lower total cost, which are important for products like the Blade and Brewlock. If this turns out to be no option for HNS or the supplier, we suggest that OS should be enabled to look have better insights in longer forecast and tries to experiment with the use of a longer planning horizon. Scheduling of deliveries to the brewery is the core activity of OS, so giving the task of making a PO to TSCP would mean more laboriousness of the ordering process. And laboriousness in the ordering process, makes the ordering process more expensive and unnecessary complex.

7.5 Conclusions

- The model is made as generic as possible and has an understandable user interface that can be used by the procurement department. The model is transferred to the TSCP department and can be adjusted if needed by employees with knowledge of AIMMS.
- The model can be used for different situations, generally when something changes about the way the inbound supply chain can be organised. A change in demand, costs or space can trigger a situation where the model can be used to test alternative options.
- The model can be used to investigate:

    - The usefulness of IB-transport.
    - Free-riding between materials
    - The trade-off between groupage transportation and direct delivery
    - The ordering process (i.e. the planning horizon and interval)
    - The required warehouse space

- Materials become interesting to investigate when they are usually called off in LTLs, or when they are a significant change in demand, costs or warehouse space for these specific materials or supplier.

- The model can also be used as input for the discussion on how to organise call-off orders for small-sized materials with low demand. We suggest to investigate the options for giving more responsibility to the supplier. If that is not possible, we encourage OS to make use of longer forecast and planning horizon so they can make call-off order quantity decision with more information.

CHAPTER 8

Conclusions and Recommendations

This last chapter presents the most important conclusions and insights of this research. The chapter is divided into four sections. Section 8.1 presents an overview of the conclusions of our research. Section 8.2 provides some discussion resulting from our conclusions, Section 8.3 gives the recommendations based on these conclusions and Section 8.4 provides suggestions for further research.

8.1 Conclusions

The inbound supply chain of Blade and Brewlock is considered a unique situation for HNS. Every Blade and Brewlock material is single-sourced from suppliers all over Europe. This causes the inbound supply chain to be inefficient and unusual for HNS, as HNS is used to big volumes. We identify the transfer price being too high as an action problem. Eventually the price of the Blade and Brewlock products that HNS calculates to Heineken Netherlands Commerce and other OpCos will decide if these relatively new products will be a success and profitable to HNS. The quantities shipped (call-off quantities) to HNS are sourced with lot-size based quantity discounts. The effect of these lot-size based quantity discounts are unknown for HNS as they are used to big volumes.

We have investigated the contracts and mentioned discounts. The demand forecast mentioned in contracts are often very optimistic and the MOQs are not always easily achieved by an individual OpCo, so contracts can be misleading for predicting lot sizes. The maximum potential savings of using larger order quantities are €66,372 in two years. If we would never use the smallest lot size, already 83% of these savings are achieved. As annual demand increases for a material, the importance of lot-size-based quantity discounts increase as well, as larger demands without increasing order quantities result in a larger number of orders, where discounts are missed. IB-transport could be of use to move materials cheaply between the two breweries in Zoeterwoude and Den Bosch, this gives the possibility to merge orders from both breweries to the supplier. Every Blade and Brewlock material is single-sourced, this is situation makes VMI look promising but it seems hard to implement because of different ways of working at OpCos and the supplier should be capable. The actual warehouse costs for only Blade and Brewlock materials are too difficult to determine, we can use the fees of an external warehouse as reference. The WACC of HNS is used to describe the cost of capital for inventory. The Blade and Brewlock materials are not voluminous, an increase in inventory levels for the Blade and Brewlock materials would not immediately have a significant effect on the total warehouse capacity that is used. However insights in future use of the warehouse space of the Blade line in Den Bosch are useful as this warehouse space is allocated for Blade and Brewlock materials only.

Our problem can be described as a multi-item, multi-location lot-sizing problem. The single-source situation of Blade and Brewlock materials makes VMI interesting, however maybe hard to implement, as mentioned in Chapter 2. Small joint replenishment problems occur at two suppliers if we do not change the routes. Supplier selection is not useful, because we have single-source suppliers. Using product families as a way to schedule orders is not promising because we can only think of two families. Holding costs are hard to determine, the most straightforward way to go is to use the WACC. Problem instances seem quite small, so computation time should not be of the biggest importance. So, we can use AIMMS as our modelling software, HNS is also familiar with this software.

A MILP formulation is used for solving our lot-sizing problem, because this is a common formulation and because the model is formulated linearly, this makes it relatively fast to solve. We have extended a standard multi-item lot-sizing problem with quantity discounts, a rolling horizon, multiple inventory locations, with transportation between the locations and the possibility of certain material types to free ride on the quantity discounts of other materials. A rolling horizon is used to simulate the current ordering process. The model can be used with the historical thirteen-week-MRP forecast but the lead time has to be neglected to handle the fluctuating forecast values. We can compare our results from Chapter 2 to our model if we use a simpler version of the model with only one location.

We have verified the model and we assume the model to be correct because the model gave logical output given the shipping notification data we have used as input. All of the average order quantities were larger than the average demand quantities, therefore the model bundles demand of several weeks. And the average order quantities increased as the planning horizon is increased, except when all of the quantity discounts are achieved. Also did the total cost decrease as the model was solved with more information, i.e. a longer planning horizon. The effect of incorporating an extra location with more demand has a big effect on the average order quantities and promotes the use of lot size based quantity discounts. When the demand increases (by adding an extra location), the importance of using a longer planning horizon becomes less important as the maximal quantity discounts are more easily reached.

To validate the model, we have used the historical thirteen-week-MRP data which we compared to the shipping notification data. Outcomes of the thirteen-week-MRP input in the one location model look like expected, therefore the model is assumed to be valid. Since the 13-week-MRP has a lot less spiky demand pattern and sometimes demand disappears out of the forecast, this causes the average order quantities to be a lot smaller than when solving with the shipping notification data as input. The use of a longer planning horizon makes the model less valid, as more uncertain demand is considered deterministic. However, we assume that when using a planning horizon of eight weeks or less, the model still can be assumed to be valid, as even with the 13-week-MRP as input, the model gave logical outcomes.

The result of the scenarios we have tested resulted in significant savings, of maximally €373,714 which can be achieved by increasing the planning horizon and using a two-stop-route with direct delivery for the SmartCap and Boxtray. Average order quantities for all materials, except the Bladebox, AK03 and Sleeve have increased by 5% to 33% by the outcomes of the base scenario. So, it would be cost-efficient to make more use of these discounts, in general. To bundle the demand in one order quantity decision we can make use of IB-transport or a direct delivery with two stops. Bundling demand is most useful for the Preforms, SmartCap and Boxtray. Direct delivery is always cheaper when the average order quantity is above twelve pallets. This can be achieved by a using a two-stop-route. And solve the model with shared ordering cost for the SmartCap & Boxtray even larger order quantities are achieved, see Table 6.9. The AK03 and Sleeve should not be ordered in larger quantities, holding costs are high and lot-size based quantity discounts are small. IB-transportation is also not useful for the AK03 and Sleeve because IB-transportation is only useful for full pallets and the quantities on a pallet for these materials are too large. By using the model and by using the demand of the production line we conclude that there should be no shortage in warehouse space, see Table 6.10.

The model proposed in this thesis can be used in future for HNS as well. The model is made as generic as possible and has an understandable user interface that can be used by the procurement department. The model is transferred to the TSCP department and can be adjusted if needed by employees with knowledge of AIMMS. By modifying some constraints and using different input, several interesting scenario's can be tested. The model can be used to investigate the usefulness of IB-transport, maybe for other materials like the Hi-cone and keg caps, this can be a really interesting way of dividing inventory across breweries. There does not exist a tool that easily takes into account the free-riding of materials.

The model can be used to investigate other materials where free-riding is already happening or possible. Also, the model can be used to make better decisions for the trade-off between groupage transportation and direct delivery. Where you can easily calculate when direct delivery becomes cheaper, the model calculates the expected average order quantities given the prices for groupage transportation or direct delivery. Furthermore, the ordering process itself can be investigated, especially changes in the planning horizon and planning interval. And lastly, the use of warehouse space during the year can already be predicted by the model. However there are other ways to calculate the warehouse space required, the model gives an outcome for each period and can therefore predict tight periods. In general, the model can be of use for new materials or situations where an alternative way of ordering could be better than the current. A change in demand, costs or space available can trigger situations where the inbound supply chain should be alternatively organised. The model can explore settings and help in decisions to be made to organise this supply chain.

8.2 Discussion

In this section, we will discuss the effect of the holding, ordering cost and the assumption of deterministic demand, as we are a bit uncertain about these variables and they do have a big impact on the results of our research.

8.2.1 Holding cost

The holding costs are often underestimated within a company. The fact that the costs are mostly hidden contributes to this. How can you determine the size of something you cannot see? The complex warehouse situation of HNS also makes it a great effort to investigate the cost of inventory. Not only do small volumes and small demand result in small order quantities, but they do also result in a slow inventory turnover and high capital cost per pallet. The expectation was that the current order quantities could not be efficient but were an unintentional result of the standard ordering process. But the standard ordering process does take into account inventory turnover, as HNS does not order for demand too far into the future. This way the trade-off between ordering and holding costs is already (unintentionally) guarded quite good.

8.2.2 Ordering cost

The ordering costs are completely unknown within HNS but can also vary a lot within companies. We took the range that Durlinger (2013) found in several companies. The thing we did not take into account is that ordering cost can not only vary between companies, they can also vary within a company for several materials or suppliers. If we bundle orders of one supplier, does that also bundle the ordering cost (partly or completely)? If we have to maintain a different ordering process for some materials, does that influence the ordering cost much?

Already for years do the fixed cost for HNS increase and compared to other OpCos is HNS considered expensive in terms of fixed costs and is getting more and more expensive. The largest part of the fixed costs is the cost of personnel. In my opinion this has a lot to do with the laboriousness of the work HNS does. HNS is, as explained earlier in Section 1.1, considered the buffer of the world. Although this is a great achievement for HNS to have such a flexible and capable supply chain, it comes at a cost. HNS excels at being flexible to produce anything within a very short lead time, but this counters a standardized way of working.

So, with the respect of ordering cost, I think that the ordering cost for Blade and Brewlock materials are quite high. Maybe even higher than the €150 that Durlinger (2013) mentions, especially when employees deviate from a standardized way of working. The material ordering process is focused on high material availability. An interesting point of view would be the cost at which this material availability is achieved. And concerning this research, if the ordering costs are a lot higher than assumed, this has a considerable effect on the number of orders and average order quantities.

8.2.3 Stochastic demand

The demand is assumed deterministic in the model, wherein reality is it stochastic. Although, the forecast for the coming two weeks is used for the scheduling of production and is therefore 'frozen' and can be considered deterministic. The further we look ahead, to more uncertain the forecast gets. This is considered out of scope for the research, but if we want to use a thirteen-week-MRP for the lot-size decisions, we should take into account the uncertainty of this demand. In our results, we saw that using a planning horizon longer than 7 weeks is a lot less useful when looking at total cost. So, for Blade and Brewlock materials we do not expect problems as a result of uncertain demand, also because the demand for Blade and Brewlock materials is quite constant. However, this could be different for other materials.

8.3 Recommendations

Following from the conclusions, we summarize here the main recommendations following our research.

8.3.1 Direct delivery for the SmartCap and Boxtray

As we have shown in this thesis, we do recommend to change how the inbound supply chain for these materials is organized. Making use of direct delivery and IB-transport is already a step in a better direction as we have shown. But a direct delivery to both breweries in one route seems even more promising. We encourage HNS to investigate these two options more and make a decision which way of working is the most practical and preferred way of working for all departments.

8.3.2 Collaboration between OS departments

Not only OpCos are independently organised. Also breweries within HNS are quite independently organised. Both the brewery in Den Bosch and Zoeterwoude have separate OS teams, for some materials at some suppliers they do the same work, by giving these teams more insights in inventory levels at both locations and collaboration on ordering for both locations, a more efficient transport can be arranged and inventory levels can be lowered as both breweries can share their inventory. Required for this is an efficient way of transporting the inventory between the breweries. Transportation routes can be adjusted or IB-transport can be used. However for this to be cost-effective overall, it would mean that this ordering process should be standardized. The pitfall here is that we save time and money on ordering and transportation costs but increase the laboriousness of the process and this can eventually cost even more. So, the best recommendation that we can give is to design standardized ordering processes were the collaboration between breweries is not out of scope.

8.3.3 Use the insights in quantity discounts for contract negotiations

One of the reasons this research was initiated is that there is not so much known about the use of lot-size based quantity discounts and the impact of the transportation costs on the total cost of the procurement of materials. As we have proven that these lot-size based quantities should not be taken outside of consideration when optimizing the inbound supply chain, these discounts should also be taken into account when contracts are negotiated. At least for HNS it is important to have an idea of how frequent and large the transported volumes from the supplier to the brewery are and what the cost of this transportation is. We do understand that the contracts are negotiated by HGP with supplier, given the volumes required for production for all the OpCos in Europe. But this does not mean that the transportation costs for the individual OpCos are outside of the scope for these contracts. They can have big consequences for individual OpCos as for the total costs. The trade-off between the lot-size based quantity discounts for the transportation of materials and the production-size quantity discounts at the supplier is one to keep into mind. The assumption of only using FTLs for delivery of materials from the supplier to the breweries does not hold for these small-sized materials. Inventory costs are often higher than on average, so raising inventory levels is probably not a desirable effect of increasing lot-sizes. So, these more expensive costs for the transportation from the supplier to the brewery should be taken into consideration for the bigger picture that is discussed by HGP and the European suppliers.

8.3.4 Further use of the model

To give insights for designing these standardizes ordering processes the model we presented in this paper can be of further use. Unique for HNS is that it takes into account the demand for both breweries. Also does it calculate the trade-off between ordering and holding costs, which is new for HNS. One of the interesting settings that could be explored more is the use of a different planning interval. Is a weekly drumbeat required for all materials? With the use of the model, the effects on total cost can be investigated, as the result of inventory levels and order quantities.

8.4 Suggestions for further research

Following this research, the conclusions, the discussion and recommendations we also like to do some suggestions for further research.

8.4.1 Investigate ordering cost

The ordering cost is unknown for HNS but are a key variable for this research and can be a reason of high fixed costs within the organisation. Because of the COVID-19 pandemic, which hits the global company Heineken as well as HNS hard resulted an a rapid focus on cost savings. Research on ordering costs would help to find more cost-efficient ways of working. Implementing more and more standardizes ways of working would save a lot in fixed costs for HNS. Finding the ordering cost is a tedious job, but I think it would be of good use to making the high fixed costs more measurable and makes the different parts of the fixed costs to bet better identified. So, what you should do is measure how many employees have to work for how many hours for ordering materials. After this is measured you can categorize by material, by finished end product, by supplier. This way it becomes easier to make the right choices for effective cost savings.

8.4.2 Vendor Managed Inventory

Although, previously mentioned in the recommendations, VMI is not only something we recommend already, especially more research has to be done. As explained earlier in Chapter 2 it is not known if the ways of working differs so much between OpCos that collaboration is not possible and it is also unknown if suppliers and if, which suppliers are capable of managing inventory for Heineken OpCos. Apart from the recommendation, we suggest that further research should not only be done for Blade and Brewlock materials, also for other materials this could be a more cost-efficient way of organised the inbound supply chain. VMI becomes especially interesting if lots of ordering costs can be saved. So, if the ordering costs are measured and it turns out that one supplier is relatively expensive to order then the option of VMI can save relatively high costs. HNS already uses VMI for its customers, so has experience in the implementation of VMI. It would grace HNS, if they would not be passive by neglecting the option of VMI if the supplier has no experience, but if they would help in implementing VMI.

8.4.3 Production based quantity discounts

Not in the scope of this research are the quantity discounts given for bigger production batches. The bigger the production batch, the less setup times and less idle time. Also do suppliers sometimes give discounts on total year volume, probably because fixed are divided over much more materials. We do recommend to look into this because there is a lot unclear at this subject. For most suppliers, there is not much transparency in the cost calculation for the production of materials. This is required to see if the supply chain can be more cost-efficient end-to-end. As we speak a lot about dedicated production lines, a good supplier relationship is very important for the security of supply. I would say that transparency in cost calculation is a sign of a good supplier relationship. And because of these dedicated production lines, the supplier as Heineken do reach for the same goal. They want to produce as cost-efficient as possible, this way Heineken can keep the product prices low, which can result in more demand, which can result in the production of more materials. Key to this is to keep in mind the helicopter view of the supply chain to be cost-efficient end-to-end, from 'grain to tap'.

Also for the future, this is important to look into. We did not see much mentioned about lot-size based quantity discounts in the contracts. So, we do not know if the trade-off between the lot-size based quantity discounts for the transportation of materials and the production-size quantity discounts at the supplier is consciously taken into account. And more importantly, as the demand for Blade and Brewlock products is expected to increase a lot, when does the trade-off shift? It would be interesting to know when it would be a good idea to switch from a single-source organisation to more suppliers, closer to the breweries. Not only could this be a cheaper solution, but also security of supply can be improved this way. Probably, the supplier has information about their production batch-based quantity discounts, as the discounts given probably are constructed quite similar to lot-size based discounts, our model can even be extended by adding the production batch discounts as well.

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Appendices

APPENDIX A

How the Blade and Brewlock work

The Blade and Brewlock systems are targeted for small business, so not for consumers at home. Both systems can be used in small restaurants or small canteens for instance. The 20L Brewlock system can be seen as an alternative for the 20L steel kegs and the 8L Blade systems are targeted for businesses that currently do not sell enough beer to have a draught system installed.

The Blade system is shown in Figure A.1, it is a small draught beer system that uses 8-litre plastic kegs as refill kits, a keg is shown in Figure A.2. HNS call this the hardware and software. The hardware is the draught system, these draught systems are not produced or sold by HNS. Heineken Nederland Commerce and other OpCos buy and sell these systems. HNS produces the software: the 8 liter filled plastic keg in a box, ready to sell to Heineken Netherlands Commerce or other OpCos all over the world. The packaging materials required to produce the Blade finished product for HNS is a plastic preform, a valve, a SmartCap, a sleeve and a plastic box.

Figure A.1: The Heineken Blade

Figure A.2: Heineken Blade keg

The Brewlock works generally the same but uses a different draught beer system and bigger kegs. The draught beer system is installed in the bar or a movable draught beer system as can be seen in Figure A.3 is used. The plastic kegs are placed on the ground behind the bar or inside the refrigerator (in the David draught system). The packaging materials required to produce a 20-litre Brewlock product are:

a plastic preform (a different one from the Blade product because of the bigger size), a valve (same as required for the Blade product), a temper cap, an optional disposable tube, a protective collar, a box tray and a water-resistant carton box.

One of the unique things about these draught systems is that they do not need a separate CO2 tank. Regular draught systems with steel kegs use non-carbonated beer and by pumping CO2 inside the keg, carbonated beer comes out. In the plastic kegs used by the Blade and Brewlock systems there is already carbonated beer inside, like in a bottle or can. The beer in the Blade and Brewlock kegs is coming out because the compressor blows air between the inner and outer wall, as can be seen in Figure A.5. The Brewlock needs a bigger compressor because the keg is standing on the ground and the beer is pumped upwards. The smart cap for the Blade is used for bleeding the Blade keg with air and to prevent the tube with beer from freezing. The Blade system includes a cooling system at the bottom of the keg. The Brewlock uses a disposable tube or a special coupler that is already attached to the draught system, like in the David draught system.

Figure A.3: Brewlock

Figure A.4: David draught system

Another unique thing is that the kegs are made out of preforms. The preforms are materials that are required for production and these preforms are inflated on the packaging line, just before they are filled with beer.

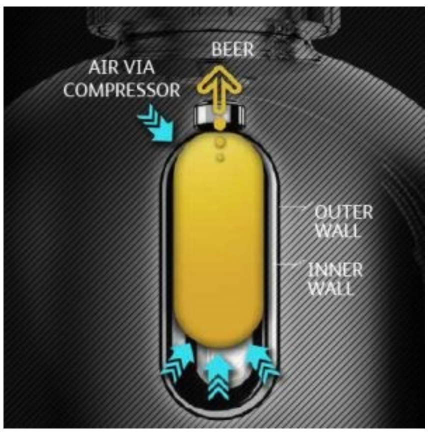

Figure A.5: How the Brewlock works

So, when we talk about the Blade and Brewlock materials, we talk about the two different preforms, a valve, a SmartCap (only required for the Blade), a beer tube (only required for the Brewlock), a sleeve (only required for the blade), a box tray (only required for the Brewlock), a temper cap, (only required for the Brewlock), a protective collar (only required for the Brewlock) and two different boxes. More information about the Blade can be found on: `https://www.blade.nl/`. And more information about the Brewlock can be found on: `https://smartdispense.heineken.co.uk/smart-systems/introducing-brewlock/`.

APPENDIX B

Blade and Brewlockmaterial planning process

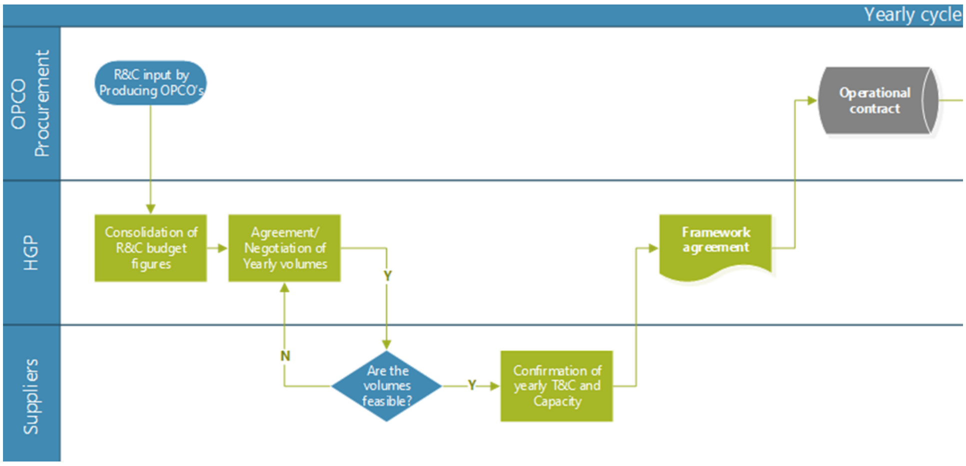

Figure B.1: Yearly Brewlock & Blade material planning process

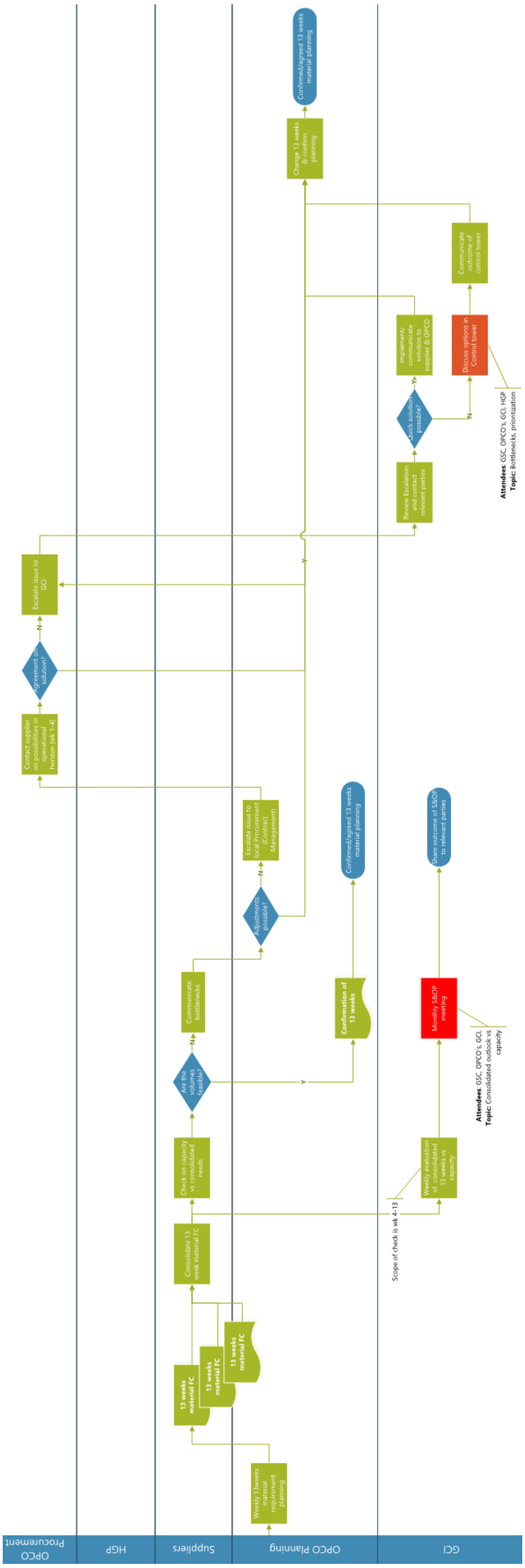

Figure B.2: Weekly/Monthly Brewlock & Blade material planning process

APPENDIX C

Transfer price, warehousing and savings

C.1 Transfer price

The transfer price is the price that HNS asks for the products they sell to HEINEKEN Nederland Commerce or other OpCos all over the world. Every cost that HNS incurs is translated into the transfer price. The transfer price has a variable and a fixed component, in general, are about 60% of the costs are variable and 40% are fixed costs. The fixed costs consist of the salary of personnel, depreciation of investments and fixed brewery costs such as repair and maintenance. The variable costs consist of: cost of commodities, cost of packing materials and production line costs. Every OpCo calculates its transfer prices, this creates a competition between the OpCos. Because HNS is focused on export (and also sells its products to HEINEKEN Netherlands commerce according to transfer price) every cost needs to be declared in the transfer price. For most other OpCos this is generally not the case, they only transfer a small percentage of their production volume to other OpCos and therefore do not declare all fixed costs in the transfer price (which is logical). How much of the fixed costs can be declared in the transfer price is governed by HEINEKEN global, they try to do this as fair as possible but sometimes strange things happen. It can be cheaper for OpCos to buy from other OpCos instead of producing by itself and sometimes OpCos are forced by HEINEKEN global to buy from certain more expensive OpCo because of capacity reasons. Also, the allocation of production is governed by HEINEKEN global. Also, this is done as fairly as possible, taking into mind what is best for the HEINEKEN N.V., which is necessarily not the same as the best for a certain OpCo.

C.1.1 Warehousing cost in transfer price

In C.1, more is explained about the transfer price. Primary warehouse costs are a small component (around 2-3%) included in the transfer price, Table C.1 gives an example of how these costs are divided per HL. In this example, we use fictional numbers. The total warehouse costs are 3000 and we have used 145 pallet places used in total. One pallet place costs 3000/145 = €20.69. So, the total cost is simply the number of pallets required times the pallet price and cost per HL are the total cost divided by the number of HLs.

HNS tries to work as much as possible according to Activity Based Costing (ABC) Raab et al. (2007). Unfortunately, this calculation of the warehouse component of the transfer price is not activity-based, but it is the only warehouse cost calculation we have at the moment. Also, we are now talking about the total warehouse costs, including the inbound warehouse. Warehouse costs are currently seen as a fixed cost component that can be declared in the products that make use of the warehouse. This is more and more untrue today because HNS uses more and more a third-party logistics provider for the storage of their finished products. To this Third-Party Logistics provider (3PL) provider, they pay a fee for the storage space they use. So by using the warehouse of the 3PL, you transform fixed costs into variable

Table C.1: Primary Warehouse costs in transfer price (in €)

SKU	HL Volume (market demand)	HL per pallet	Pallet places	Total cost	Cost per HL
1	1000	100	10	206.90	0.21
2	5000	150	33.33	689.66	0.14
3	3000	100	30	620.69	0.21
4	10000	150	66.67	1379.31	0.14
5	1000	200	5	103.45	0.10
Total	20000	700	145	3000	

costs. This looks like a more robust way to handle the changing demand for products, but it is more the opposite. When demand decreases unexpectedly to the forecast, then the production cannot follow immediately. So, finished products will just end up longer in the outbound warehouse and warehouse costs go up. And because the warehouse costs component in the transfer price is fixed at the beginning of the year based on the forecast, HNS will end up with undeclared costs at the end of the year.

The current distribution of cost is based on the HL per pallet and the number of pallets that are used. We assume that every pallet place costs the same, which is certainly not true. The place in the warehouse, size of the pallet, environmental requirements, stacking possibilities and handling, for example, are not taken into account and can differ for each pallet place. In this calculation, the total warehouse costs are taken and as we saw in Table 2.3 finished goods take a lot more space in the warehouse. So, the inbound warehouse takes up less of the cost than the outbound warehouse. Activity-Based Costing for the warehouse costs would give a fairer overview of which product types are more expensive than other in terms of storage costs and can give us insights in the storage costs of the Blade and Brewlock materials in the inbound warehouse.

C.2 Extra tables of potential savings

Table C.2: Potential savings Sleeves

Sleeves	# Deliveries	Quantities	Price difference	Potential saving
0-9999	5	29640	134.4	€ 3,984
10,000-14,999 pieces	3	32570	44.8	€ 1,459
15,000-19,999 pieces	3	50729	22.4	€ 1,136
20,000-26,999 pieces	3	75247	17.6	€ 1,324
27,000 pieces	26			
			Total:	€ 7,903

Table C.3: Potential savings Preforms

Pallets	Number of deliveries	Blade price difference	Brewlock price difference	Potential saving
12	6	€ 21.50	€ 35.84	€ 1,289
18	35	€ 8.19	€ 13.65	€ 4,812
>18	75			
			Total:	€ 6,101

APPENDIX D

Limited Warehouse capacity

In the beginning of the research it looked like the inbound warehouse capacity for Blade line in Den Bosch was limited. Halfway during the research, the conclusion was made that the warehouse space was too limited to be able to order in FTLs. Therefore, HNS chose to use another warehouse space for the materials required for the Blade packaging line. So, capacity is not a restriction anymore. In case warehouse capacity becomes a restriction, this chapter explains how we could include the option of using external warehouse space in our model.

When the available warehouse space becomes limited, the option of using an external warehouse is not out of the question. However, this way of storing inventory is a lot more expensive because of the extra handling and transportation. We use two more parameters for the holding and handling cost(includes transportation) and three more decision variables, one to determine the quantities that go into the external warehouse, one to determine the quantities that go out of the external warehouse and one to determine the quantities that are in the external warehouse. The first period p there is no inventory stored externally, $ES_{il0} = 0$. In principle does every brewery have their external warehouse. Every brewery has a third-party logistics provider nearby which can be used for storing materials.

Extra Parameters

W_l	Maximum warehouse capacity, expressed in pallet locations, at location l.
HO	External warehouse holding cost of a pallet with materials in one period
HA	External warehouse handling cost of a pallet with materials in one period

Extra Decision variables

EI_{ilp}	Quantity entering external warehouse from location l, at the beginning of period p of material i.
EO_{ilp}	Quantity leaving a external warehouse to location l, at the beginning of period p of material i.
ES_{ilp}	Quantity in an external warehouse from location l, at the beginning of period p of material i.

Extra Constraints

$$\sum_{i=1}^{I} I_{ilp} <= W_l, \qquad \text{for all } l,p \tag{D.1}$$

$$ES_{ilp} = ES_{i,l,p-1} + EI_{ilp} - EO_{ilp}, \qquad \text{for all } i,l,p \tag{D.2}$$

$$I_{lip} = I_{lip-1} - D_{ilp} + \sum_{d=1}^{D} O_{dilp-1} - IBO_{ilp} + IBI_{ilp} + EO_{ilp} - EI_{ilp}, \qquad \text{for all } i,l,p \tag{D.3}$$

Eq. (D.1) makes sure that the sum of all materials i in inventory will not exceed the Warehouse Capacity at each location l, at every period p. Eq. (D.2) determines the inventory levels at the external warehouse locations, every inventory location l has it's own external warehouse stock level ES_{ilp} for each period p, for each material i. This is the level from the last period $ES_{i,l,p-1}$ added with what is moved to into the external location EI_{ilp} and subtracted with what goes back to the Brewery EO_{ilp}. The inventory constraint Eq. (D.3) is also adjusted accordingly, so subtracted with what goes into the external space EI_{ilp} and added with what comes out of the external warehouse EO_{ilp}

$$\begin{aligned} \text{Minimize TC} = \sum_{p=1}^{P}(\sum_{i=1}^{I}\sum_{l=1}^{L}(\sum_{d=1}^{D}(C_{di} \times O_{dilp})) + (\sum_{d=1}^{7} X_{dilp} \times OC) + (H + (W_i \times C_{7i})) \times I_{ilp}) \\ +(IBI_{ilp} \times IBC) + ((EI_{ilp} \times HA) + (EO_{ilp} \times HA) + (ES_{ilp} \times HO))) \end{aligned} \tag{D.4}$$

Eq. (D.4) gives the adjusted goal function, where the costs for external warehouse are given in the second row. Every time inventory is moved, these quantities are multiplied by handling cost (including transportation), HA and for every period the external warehouse inventory level ES_{ilp} is multiplied with the holding cost, HO.

D.1 Safety stock and line inventory

Safety stock is used to compensate the material loss on or before the packaging line. Materials go through quality tests (depending on the material type) and can be rejected if they are out of tolerance. Also, for most materials, there is some material loss on the line itself. For example, a can is stuck on the line and gets dented. The formula to decide the safety stock to handle the total material loss is:

$$(MaxLoss - AvgLoss) \; * \; ((use\ in\ plan\ orders) \; / \; \#\ weeks\ plan\ orders)$$

The loss of per production line is continuously measured, the *MaxLoss* gives the highest loss that ever has occurred and *AvgLoss* gives the average loss. *Useinplanorders* is the amount that is required for the production of the coming two weeks, so *#weeksplanorders* is two.

Not all inventory can be found in the inbound warehouses, also some of the inventory can be found at the production line, we call this line inventory. For most materials this is just some leftover material, that is left over after a production batch. For most products that HNS produces this line inventory is not significant in inventory levels, for the Blade and Brewlock products this can be a significant amount. If, for example, half-a-pallet of valves is left over after a production run, this is a significant amount (roughly enough for half a week of production) that could have an impact in the decision if OS wants to place a call-off order or not.

APPENDIX E

Simple MILP model for comparison with historical data

For verification of the model, we use a simpler version of the complete model in Chapter 4, Section 4.5. The number of locations is one, so also no Inter-brewery transport is possible.

$$\text{Minimize TC} = \sum_{p=1}^{P}(\sum_{i=1}^{I}(\sum_{d=1}^{D}(C_{di} \times O_{dip})) + (\sum_{d=1}^{7} X_{dip} \times OC) + ((H + (W_i \times C_7 i)) \times I_{ip})) \qquad \text{(E.1)}$$

subject to

$$
\begin{aligned}
I_{ip} &>= S_i, && \text{for all } i,p && \text{(E.2)}\\
I_{ip} &= I_{ip-1} - D_{ip} + \sum_{d=1}^{D}(O_{dip-1}), && \text{for all } i,p && \text{(E.3)}\\
\sum_{d=1}^{D} X_{dip} &\leq 1, && \text{for all } i,p && \text{(E.4)}\\
O_{dip} &\geq B_{di} \times X_{dip}, && \text{for all } d,i,p && \text{(E.5)}\\
O_{dip} &\leq B_{d+1i} \times X_{dip}, && \text{for all } d,i,p && \text{(E.6)}\\
F_{d5p} &= O_{d6p}, && \text{for all } d,p && \text{(E.7)}\\
F_{d6p} &= O_{d5p}, && \text{for all } d,p && \text{(E.8)}\\
F_{d1p} &= O_{d2p}, && \text{for all } d,p && \text{(E.9)}\\
F_{d2p} &= O_{d1p}, && \text{for all } d,p && \text{(E.10)}\\
F_{d3p} &= 0, && \text{for all } d,p && \text{(E.11)}\\
F_{d4p} &= 0, && \text{for all } d,p && \text{(E.12)}\\
F_{d7p} &= 0, && \text{for all } d,p && \text{(E.13)}\\
X_{dip} &\in \{0,1\}, && \text{for all } d,i,l,p && \text{(E.14)}\\
I_{ip} &\geq 0, && \text{for all } i,p && \text{(E.15)}\\
O_{dip} &\geq 0, && \text{for all } d,i,p && \text{(E.16)}
\end{aligned}
$$

The objective is to minimize the total cost, Eq. (E.1), which consist of the purchase cost and inventory holding cost. The operative constraints are as follows: Eq. (E.2) makes sure that the inventory level of every material i is at every period p above the safety stock level. Eq. (E.3) determines the inventory for every period p of every material i. The combinations of Eq. (E.6) and Eq. (E.4) make sure that only for maximally one discount level d, at each period p, for each item i, the order quantity is above zero. Eq.

(E.5) and Eq. (E.6) make sure that the right discount level d is chosen that corresponds with the right order quantity O_{dip}. Then Eq. (E.7) till Eq. (E.13) make sure that the right ordering quantity is used as Free-ride Quantity.

APPENDIX F

Incomplete data and large forecast fluctuations in thirteen-week-MRP forecast

Although a weekly drumbeat is used and every week a thirteen-weekMRP is made, this is not necessarily the case for Blade and Brewlock materials. In the last few years the production line was not constantly in use, so sometimes several weeks no demand was present. During holidays the thirteen-weekMRP is also not always made. Altogether the data is lacking lots of thirteen-weekMRP forecasts, as it was not required to forecast. This sums up to that in the 183 weeks we have used, only 60 thirteen-weekMRP forecasts are made of all materials, only the Boxtray has 101 thirteen-weekMRP forecasts in the 183 weeks.

The model is given weekly input, where there is no difference between a forecast value of zero and no forecast value. In general this is correct, if a week number is missing in the thirteen-weekMRP, this means no usage is expected in that week. However, in a week where there is no forecast made, this "empty thirteen-weekMRP" is also not shared with the supplier. This means that the old thirteen-weekMRP could be still valid. This is hard to exactly trace-back, but is by looking at the data generally not the case. We saw many cases where the demand slowly disappeared and after a while, no forecast was made. So we do expect that demand does much demand disappears this way. Unfortunately, the opposite does happen a lot more.

Especially in the way that demand pops up in the forecast after in some weeks no forecast was made. When this happens, this does generally not happen for only one week in the newly made forecast, it happens for several weeks in the new forecast. This is because the material need is most of the time not given 13 weeks ahead in the 13-week-forecast. Most of the time, depending on the material, only a forecast value for the coming 3 to 10 weeks is present. So, when after some weeks of no forecast, the first 13-week-forecast is given, it contains several values that should have been present in the 13-week-forecast that could have been made earlier. This causes huge fluctuations in forecast values of certain weeks, a fluctuation that is equal to the forecast value, which are not seen as fluctuations in reality.

The model is not capable of handling these fluctuating forecast values. A problem instantly becomes infeasible as suddenly forecast values change over a period. A way to deal with this is to neglect the lead time when using this thirteen-week-MRP. In general, the effect on the outcomes of the model should not be that big because the forecast of the current and coming week should generally not change a lot.

In reality, actual forecast fluctuations are easier dealt with, the tactical planner or operational scheduler can arrange emergency shipments or the production plan can be adjusted because of material availability. This does not happen a lot, HNS has managed with its suppliers a very high material availability. Even during the COVID-19 pandemic, overall material availability stayed above 97%, which is the target level. However, this availability is not reached automatically, of course, lots of alignments have taken place between suppliers and HNS to be able to supply on time. The splitting of ordering and calling off of materials makes an impact on the material availability, in this way tactical planning takes away a lot of the material restrictions before they are called off. But sometimes, some last minutes changes are present and in real life, people would manage, the model cannot.