Optimal product allocation with special attention to new product introductions

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By

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I Preface

This research has been executed as master thesis in order to receive the Master's degree in both Operations Management and Logistics and Innovation Management at Eindhoven University of Technology, The Netherlands. This research has been executed at Heineken Nederland Supply (HNS) in Zoeterwoude, The Netherlands.

Since I did not have any prior knowledge of AIMMS it was very challenging to develop a decision support model in this software tool. I am very grateful that I have been given the opportunity to learn this tool and to improve my knowledge in the field of mathematics and research operations.

First of all, I would like to thank Ir. dr. S.D.P. Flapper, my first supervisor of Operations Management and Logistics from the university. Because of his help, experience with and enthusiasm about mathematical models, I have successfully finished the HPA model. Furthermore, I would like to thank him for all the feedback he gave me regarding my master thesis. Additionally, I would also like to thank my first supervisor of Innovation Management from the university, Prof. dr. F. Langerak. I am very thankful for the feedback and help I received during my investigation and the writing of my master thesis.

Thirdly, I would like to take the opportunity to thank my supervisor from HNS, Steven Drenth, for initiating this research and for his help and support. Every week during my internship he took the time to answer my questions and discuss my progress and results. Furthermore, I would like to thank Marjon van Eijndhoven – Pol and Lars Nijland for their contribution to this research. They helped me a lot with understanding the features of AIMMS and with the data of HNS.

Finally, I owe thanks to my family and friends for their continuous support and interest throughout the entire process of conduction and writing the research.

II Abstract

The focus of this master thesis is on the optimization of allocating (new) products to existing production lines. A mathematical model has been developed, the Heineken Production Allocation (HPA) model, with the objective to minimize the total production time including changeover times. The output of the HPA model gives a production plan that assigns products to production lines and determines the timing of these products. The HPA model takes into account sequence- and machine-dependent changeovers between products, product and production line dependent resource speeds, and limited available capacity. AIMMS is the software tool that has been used for the implementation of the HPA model.

III Management summary

Heineken Nederland Supply (HNS) can save 4.4% of the total needed production time by improving the method to allocate products to production lines. In 2019, this amounts to 2635 hours less production time, which accounts for €800.000. This is the result from the Heineken Production Allocation (HPA) model developed in this research. In addition to this result, it is expected that the current NPI allocation process can be improved by adding three elements to this process. The first element that needs to be added is to weight the importance of the NPI, the second is to include changeovers in the process, and the last added element is to compare the allocated NPI to actual production plans.

These conclusions can be drawn from the research presented in this report conducted in collaboration with HNS. HNS is not able to produce the entire demand of 'bottle oneway' products due to the available capacity of the production lines that can produce these products. The current allocation method is based on experience of the resource planner and common sense rather than on a scientific method. This results in the following main question:

> ***'Does a mathematical planning model result in a better allocation of products to production lines in order to save time and costs?'***

Investigating relevant literature showed that there are articles related to a multi-item production process with parallel, non-identical production lines, and sequence- and machine-dependent changeovers. As none of the articles incorporated all requirements of this research, A Mixed Integer Linear Program (MILP) model has been developed for the problem: the Heineken Production Allocation (HPA) model. This model has been based on the elements affecting the production allocation that have been identified from both literature and the current situation at HNS.

The original HPA model could determine the quantities of a product to be produced per production line to achieve the optimal results in theory. Due to the complexity of the problem, it was not possible to solve the model within 12 hours. As a result, the HPA model needed to be simplified. The simplification that has been made is that the entire order of one product has to be produced on one production line and cannot be divided over multiple production lines anymore. This simplified HPA model led to the conclusions that have been drawn. In theory, the solution of the simplified HPA model might be suboptimal, but using this model in practice it shows that the model improved the allocation of products at HNS.

In order to conclude that the HPA model can be used for the intended purposes, multiple validation and verification methods have been used. The results of these methods confirm that the HPA model delivers according promises and thus can be used. HNS has been used as a case study to develop and test the model in the development phase. But the HPA model has been built in such way that it is applicable to all OPCOs of Heineken.

The main recommendation to HNS is to replace the current "common sense" based production allocation method by the scientific HPA model proposed in this research in order to save time and costs. A recommendation in addition to implement the main recommendation would be to first show the model to an AIMMS expert. The expert should investigate the improvements which can be made in the 'hard programming language' of the model, in the settings of AIMMS, and which license fits the needs of HNS and the HPA model best. This is important to find out whether the run time of the model can be reduced. It is also important to investigate whether the original HPA model could be solved in a way to ensure that the model that is used in practice is as close to the theoretically optimal model as possible. Furthermore, it is favored to use the HPA model on a laptop with an i9 processor and with at least 32 GB of memory to reduce the run time of the model. In order to make the HPA model more user friendly, it is recommended that the input data for the model is available automatically in one data file.

To implement the HPA model as tool for the production allocation, it needs to be approved by the Supply Chain Planning (SCP) manager of HNS. For this implementation, a work instruction has been made in which all formulas and features of the HPA model have been explained. Furthermore, an intensive training has been given based on this work instruction to the HNS supervisor of this project and the project leader of Planning Excellence (PLEX). The last will be the owner of the HPA model within HNS. After the HPA model is approved by the SCP manager, an intensive training has to be given to the resource planners of HNS. It is recommended to include a transition period, in which both the current and new tool will be used for five weeks. After this period, the resource planner manager, in consultation with the resource planners, determines whether the HPA model will be used as planning tool in the future.

Furthermore, it has to be determined how the HPA model can be integrated in the weekly planning process, which will be done by the resource planning manager. The recommendation to HNS is to integrate the HPA model after the production plan has been made. This means that three steps in the current production allocation process can be replaced by the HPA model, which are 'allocate products to production lines', 'read production plan into Advanced Scheduling (AS)', and 'OS makes schedule'.

Practice shows that the current way of allocating new products to existing production lines leads to incorrect allocations. Therefore, a second main question has been formulated:

> ***'What steps should be considered to determine the allocation of an NPI to a production line?'***

The review of the NPI allocation process has been based on elements that affect the production allocation identified from literature and the current NPI allocation process. Additionally, this review has been based on the opinion of the employees that participated in three focus groups.

The main recommendation in order to improve the allocation of NPIs is for HNS to use the developed NPI allocation process instead of the current NPI allocation process.

It is strictly recommended to use both the current and developed NPI allocated processes for the next NPIs and compare the solution of these processes to determine whether the developed NPI allocation process is an improvement.

To further improve the allocation of NPIs, it is suggested to introduce the NPI part into the HPA model. Before the HPA model can be used for an NPI, the input data for the NPI has to be determined since these are not known beforehand. The input data can be determined using the copy-from method, which is mentioned in the developed NPI allocated process.

In order to reduce the complexity of an NPI, it is recommended that the customer cannot compile the NPI on NPI level anymore, which is beer type, bottle type, bottle size, secondary pack type, and pallet load, but only on portfolio level, which is beer type, bottle type, and bottle size.

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1. Introduction

Heineken Nederland Supply (HNS) is an operating company (OPCO) of the Heineken company and has three breweries in Zoeterwoude, ‘s-Hertogenbosch, and Wijlre. The production environment of HNS can be characterized as a multi-item production process with multiple production lines.

HNS has been experiencing a changing beer market: an increasing diversification of products, which has been illustrated in figure 1 and leads to a more complex environment for production allocation (HNS historische productie standen, 2019)[1].

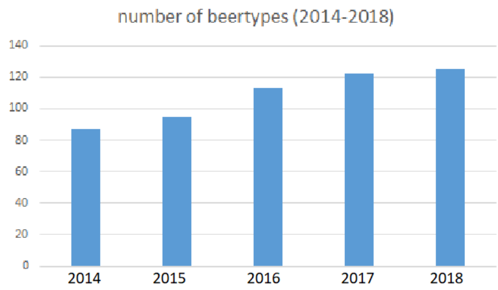

Figure 1. Increasing number of beer types from 2014 to 2018.

Up to now the Tactical Supply Chain Planning (TSCP) department is allocating the products to the production lines with common sense and experience. The increasing product portfolio is making the production allocation more complex which has been resulted in an increasing doubt whether the current production planning and scheduling is optimal. Furthermore, HNS has been experiencing that they are not able to fulfill the demand of the pack type ‘bottle oneway’ each week within the given capacity. Therefore, HNS wants to optimize the output of the production lines, i.e. increase the output beer in hectoliters (hl) in order to meet the demand. To solve this problem a decision support tool has been developed for allocating the products to production lines in order to improve the production allocation.

At the Supply Chain Development (SCD) department, there is one employee specialized in new product introductions (NPI) and is responsible for allocating an NPI to a production line. Within the NPI allocation process of HNS there are three categories considered: 1) an NPI can be assigned to one production line, 2) an NPI can be assigned to more production lines, and 3) and NPI cannot be assigned to one or more production lines. As the focus of this research is on existing production lines, the last category is not part of the scope of this research. At this moment, the NPI Supply Chain (SC) specialist only considers the capacities of the production lines and the capabilities that the production lines have that are the same as the capabilities needed for a certain NPI. The production capability is the technical ability of a production line to produce a certain product. If the NPI requires the capabilities of a production line that already exists, the NPI will be allocated to that production line. Practice shows that this way of making decisions may result in incorrect allocations. An example is given by the following:

NPI Amstel Bright 355 CL is allocated to production line HBLYN08A at ‘s-Hertogenbosch as this was the only production line that was able to produce this beer type, bottle type, bottle size, secondary

[1] Reference derived from the intranet (nonpublic access) from HNS.

pack type, and pallet type. The operators of this production line came to the NPI SC specialist with the comment that this bottle type can technically be produced on this production line, but this production line never produced this bottle type, because it requires a changeover of 4 hours. As a result of this comment, the NPI SC specialist looked if other production lines were also able to produce this NPI. He came to the conclusion that HBLYN16B could also produce this product, only the beer type was not included in the capability list of this line. It turned out that introducing a beer type to other production lines is no bottleneck at HNS as it costs no extra money and it can be implemented easily. This production line was able to produce this NPI with a changeover of less than 4 hours.

Report outline

Following the introduction, the second chapter offers an extensive description of the problem. Chapter 3 describes the purpose, the main questions of this research, and will also present several research questions that need to be answered in order to answer the main questions. Furthermore, chapter 4 provides an overview of the methodology used in this research.

In chapter 5, a literature study is conducted in order to investigate a number of issues. First, the problem posed is investigated in literature, then, the elements which affect the allocation of products to production lines are examined, and lastly, the models that have been used in the past for solving a similar problem are analyzed. The following chapter discusses the current situation of HNS of both the packaging and production allocation process. Chapter 7 explains the model requirements that have been based on both the current situation of chapter 6 and the literature study of chapter 5. This chapter will, therefore, examine the aspects that will be taken into account for the development of the model. Chapter 8 will start off with presenting the assumptions regarding the decision support tool that has been made, followed by the mathematical representation of the Heineken Production Allocation (HPA) model. Furthermore, the verification and validation methods used for the designed HPA model are described in chapter 9. In chapter 10, insights for HNS are given in terms of time- and cost savings over 2019 as well as a representation of the allocation of the HPA model of four random weeks. Chapter 11 describes the steps needed for the implementation of the HPA model at HNS. Chapter 12 initially discusses the current situation of HNS about NPIs, followed by a systematic analysis of whether the elements found in the literature have been used in this current NPI allocation process. This chapter ends with a developed NPI allocation process. The conclusions and recommendations of this research are presented in chapter 13. And lastly, chapter 14 captures the reflection of the research, which includes the contribution to the literature and the limitations of this research with suggestions for further research.

2. Problem statement

In order to track down the actual problem of HNS, a field research has been executed using both qualitative and quantitative research. Qualitative research has been executed first through unstructured interviews with the Sales & Operations Planning (S&OP) manager, the resource planning manager, and the Business Controller Supply Chain (BCSC). The S&OP and resource planning manager have initiated this research at HNS, since they encountered this specific problem in their work. The BCSP was present during the interview for the financial background of the problem. An unstructured interview means that there are no questions prepared before the start of the interview, only the subject of the interview has been formulated. The subject here was thus the problem that HNS encountered and will be investigated in this research. This method has been used because with an unstructured interview, the qualitative data can be generated through the use of open questions, which allows the interviewee to talk in depth in their own words. Furthermore, it has been used as it improves the validity since it gives the interviewer the opportunity to probe for a deeper understanding or ask for clarification (Gorman et al., 2005). When the validity improves, this means that the conceptual definition is closer to the operational definition than before. This qualitative research has been executed to investigate why HNS wants this research conducted and what can be improved within the scope of this research. More details about the unstructured interview can be found in Appendix H.1. Using the outcomes of the unstructured interview, the below problem came to the light.

The main problem which was distinguished during the interviews was that HNS is not able to produce the entire demand for one of their six pack types called the 'bottle oneway' pack type. The six pack types that exist at HNS are shown in Appendix C. Each production line is dedicated to the production of one of these pack types. The bottle oneway pack type has twelve production lines that are able to produce these bottle oneway products. Because HNS is not able to fulfill the entire demand, it is necessary that the bottle oneway production lines are used in a more optimal way. Furthermore, if the demand can be accomplished in less time, fewer employees are needed to answer the demand. But in order to actually save costs, it is important to know if HNS is able to save personnel costs based on the contract they have with their employees, which is the case here. The employees working in the packaging process namely have a standard contract with a partly variable part per year. This means that when HNS decides to put fewer hours in the schedules of the employees in the packaging process, employees will be paid less, enabling HNS to save costs. Additionally, in 2018, HNS hired *211.586* hours of external workers in the packaging process to be able to fulfill the demand, on which they could also save money when the production lines are optimized, see Appendix D.

The second reason that HNS wants this research conducted is to find out whether the current allocation method which the TSCP department uses is still optimal. This method is based on common sense and experience, however, can this still be considered as the best method now that the complexity of HNSs product portfolio increases and the demand is not met? The conclusion from the interview is that in order to fulfill the demand of bottle oneway products, the allocation of products to production lines needs to be improved.

For the quantitative research, the total production process of HNS has been analyzed in terms of costs to see in which part of this process there is an opportunity to reduce costs. The production process of HNS consists of brewing, packaging, and storing. Internal data of HNS shown in Appendix B illustrates that the packaging process within the company is most cost-intensive. The personnel costs within this packaging process are 67% of the total costs in 2018, which is 52 million out of 78 million euros. Using the data of Appendix B HNS decided that the costs of the personnel in the packaging process need to be reduced (HNS TP Slides Total v2, 2019)[2].

Another problem within the production allocation that was encountered by the operators of the different production lines was that the allocation of a new product to a production line leads to disruptions on this particular line. This is confirmed in the article by Gopal et al. (2013) in which they also state that these disruptions may lead to productivity loss. At HNS, the NPI SC specialist allocates an NPI to one production line based on the capabilities and capacities of the production lines. In the unstructured interview, the S&OP and resource planning manager stated that more factors should be considered while making the decision to which production line an NPI will be allocated to. Therefore, research will be conducted in order to review the current NPI allocation process and to investigate what elements have to be taken into account to improve this process.

[2] Reference derived from the intranet (nonpublic access) of HNS.

3. Purpose and research questions

The purpose that will be described in this chapter is based on the problem statement explained in the previous chapter. In order to solve this problem, two main questions have been formulated in this chapter. Furthermore, research questions that need to be answered to answer the main questions will be described in this chapter.

This chapter will describe first the purpose of the research, followed by the two main questions in order to solve the problem of HNS. Lastly, this chapter will describe the research questions that need to be answered to answer the main questions.

3.1 Purpose of the research

The aim of this research is to establish a methodology that determines an improved allocation of (new) products to existing production lines so that time and costs will be reduced. For the allocation of both existing and new products, it is important to identify elements that affect the production allocation. Using these elements, a decision support tool can be created to improve the allocation of products. This will be done by mapping the current situation of HNS, using literature studies and conducting focus groups and interviews with involved employees.

3.2 Main questions

As this research includes the allocation of new and existing products, two main questions have been formulated in order to solve the problem of HNS. The first main question focuses on improving the allocation of existing products.

> ***'Does a mathematical planning model result in a better allocation of products to production lines in order to save time and costs?'***

Besides the first main question, HNS also encounters a problem when deciding which production line will have to produce an NPI. Therefore, an additional main question has been formulated that needs to be answered in this research:

> ***'What steps should be considered to determine the allocation of an NPI to a production line?'***

3.3 Deliverables and research questions

In this section, the deliverables and research questions that are needed to answer the two main questions are formulated. How these research questions will be answered, will be explained in the methodology described in chapter 4.

3.3.1 Deliverable one: Literature review

The first deliverable will provide an overview of the elements that affect the allocation of products to production lines according to the literature. The literature review will also focus on the elements that affect the allocation of new products to production lines.

Research question 1: *What elements affect the production allocation according to the literature?*

3.3.2 Deliverable two: overview of the current situation of HNS

In order to develop a realistic model that can be used by HNS, it is important to understand the restrictions of both the packaging and production allocation process of HNS. Based on these processes, the elements affecting the allocation at HNS can be identified. The research question related to these elements has been described as follows:

Research question 2: W*hat are the important elements that affect the allocation of products to production lines?*

To answer this research question and to gain insights into the elements that affect the allocation at HNS, it is important to understand both processes and, therefore, two sub questions have been formulated.

Sub question 1: *What does the present packaging process look like?*

Sub question 2: *What does the present allocation process of HNS look like?*

Based on these sub questions and the first research question, the elements can be identified that affect the allocation of products to production lines.

3.3.3 Deliverable three: HPA model

The third deliverable is the HPA model, which is a decision support tool for the allocation of products to production lines. To create the HPA model, the model requirements have to be elaborated in order to avoid misunderstandings. After this, the model will be compared to practice to see if this model is successful.

The following research questions have been prepared for the third deliverable:

Research question 3: *What elements will be taken into account as starting points for the HPA model?*

Research question 4: *What does the HPA model look like for existing products?*

3.3.4 Deliverable four: review of NPI allocation process

The fourth deliverable is a review of the NPI allocation process. First, the current NPI allocation decision process needs to be reviewed in order to understand the process and to see what improvements can be made. Comparing the elements that have been found in the literature with those of the NPI allocation process will lead to the development of the current NPI allocation process.

Research question 5: *What are the elements that are taken into account at the moment for the allocation of an NPI?*

Research question 6: *What does the developed NPI allocation process look like?*

3.3.5 Deliverable five: answering the main question

The goal of the last deliverable is to investigate whether the HPA model improves the allocation of products to production lines in order to save time and costs. Therefore, the last research question is the following:

Research question 7: *Which product has to be produced on which production line to fulfill the demand in lowest possible time at lowest possible costs?*

3.4 Summary of problem statement

In this chapter, the research questions have been described that will help to solve the problem of HNS. The goal of this research is to solve this problem by developing a decision support tool that determines to which production line a product will be allocated to at which moment of time.

4. Research methodology

This chapter describes the specific methodologies that will be used for answering each of the research questions to realize the deliverables.

The data necessary for this research will be generated using the intranet of HNS and Pluto. Pluto is an information software enabling to manage data. For this research, access has been obtained for the files of the Supply Chain Development (SCD) department, the Tactical Supply Chain Planning (TSCP) department, and the Operations Scheduling (OS) department. Financial data will be obtained using a contact person in the finance department. Other data that will be needed in order to conduct this research, will be obtained by contacting the company supervisor.

4.1 Methodology for literature review

The goal of the first deliverable is to achieve elements from the literature that affect the production allocation both for existing and new products. Desk research will be performed that consists of a systematic literature review (SLR). For the SLR, the methodology of Vanwersch et al., (2011) will be used to ensure a selection of papers that provide a complete overview of the relevant literature with both high quality and relevance. The methodology of Vanwersch et al. (2011) consists of primary- and secondary search strategies that will be used to establish that important studies (relevant in the field of the research) will be identified. The primary search strategy is an electronic database search for identifying an initial set of studies. This strategy consists of the selection of electronic databases, the selection of data sources, and search terms electronic databases. The secondary search strategy will be conducted to identify additional studies by both backward and forward tracing techniques.

The elements from the literature will be taken into account for the conceptual framework. Furthermore, these elements will be also used for the NPI allocation process.

4.2 Methodology for overview of current situation

The current situation consists of two processes within HNS: the packaging process and the production allocation process. The methodology for the overview of these two processes will be described in this section.

The purpose of this packaging process overview is to understand the important elements that affect the time the production line is able to produce products. Therefore, the production lines within the scope of this research, so the bottle oneway production lines, will be observed and a conceptual overview will be made of a random week with random products. Besides the observation of the packaging process, this process will be discussed with the team leaders of the bottle oneway production lines. This overview is shown to team leaders of the production lines to ensure all elements that may influence the production are taken into consideration. Lastly, one day will be used to work on the production line together with the operators of the production line. This will be done to get a better feeling of the packaging process and the phases within it.

Thereby, an overview of the allocation process of HNS needs to be created to gain more insight into the elements that affect the allocation of products. There is no document that describes this allocation process, so this overview will be created during a focus group. The focus group will consist of the three resource planners of HNS. The resource planners are responsible for the allocation of the products to different production lines. In this focus group, the process and decisions of each planner will be discussed and evaluated to see if this is the same for the three planners or to find out if they are using different methods. At the same time, factors which the planners consider crucial for allocating the products will be discussed in order to understand which factors need to be taken into account while making the HPA model. Furthermore, in this focus group, the factors that the resource planners are not considering at the moment will be discussed to see if there are missing factors that are important for the HPA model.

According to Gorman & Clayton (2005), the disadvantage of a focus group is that a few vocal participants may dominate other members in the course of group discussion. Because of the nature of group conversation, some participants may conform to the responses of other participants, even though they may not agree. Therefore, before the start of the focus group a semi-structured interview will take place with all participants separately to inform them about the subject and to gain more information about their personal way of working.

4.3 Methodology for HPA model

This section describes the methodology for research questions three and four to realize the third deliverable, which is the HPA model. This deliverable will be guided by the 'Systems View of Problem Solving' of Mitroff et al. (1974), which is shown in figure 2.

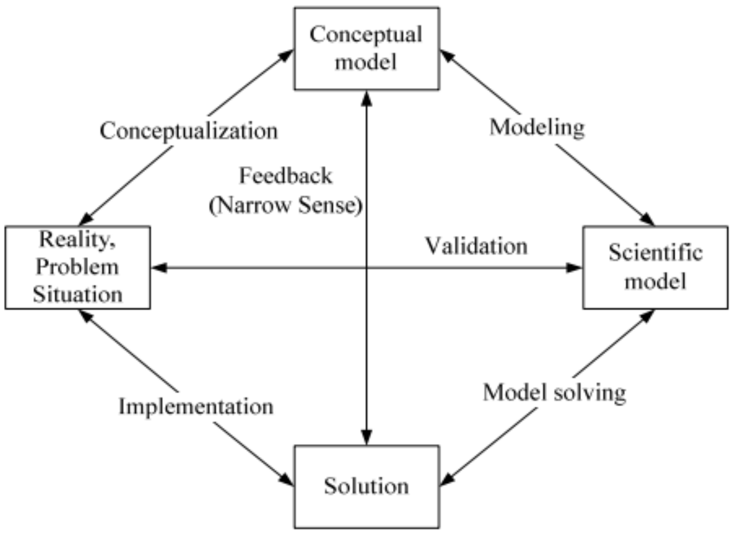

Figure 2. Research model by Mitroff et al. (1974).

The first phase of Mitroff et al. (1974) is the conceptualization phase, which is an abstraction from reality that is made explicitly. The purpose of this phase is to get familiar with the company and its problem. This will be done by the explanation of the current situation using semi-structured interviews and focus groups.

Then the second phase of Mitroff et al. (1974) is the modelling phase, which is building a quantitative model by combining the current situation and the theoretical concepts. This will be used for answering the third research question, considering the model requirements. The information from the literature review will be compared with the information from the current situation to determine the elements that affect the allocation of products to production lines at HNS. The starting points for the HPA model will be based on these model requirements, which answer the third research question.

The third phase is the model solving phase for which a decision support tool will be designed and implemented in AIMMS. The model solving phase, therefore, answers the fourth research question and will show a mathematical representation of the HPA model that will be built in order to improve the product-production line allocation. Using the starting points for the HPA model of research question three, the model will be developed on paper. The model will have time buckets of 1 minute and a planning horizon of one week.

To determine which mathematical model will be developed to solve the problem, research has been executed to understand the different optimization models.

A Linear Program (LP) involves minimizing or maximizing a linear function subject (minimizing or maximizing time or costs) to linear constraints on the decision variables. An Integer Program (IP) can be both a linear and non-linear problem, including the fact that some or all variables have to be integers. If all variables are restricted to be integers, it is called a pure IP. If some, but not all of the variables are restricted to be integers, it is said to be a Mixed Integer Linear Program (MILP). Since not all variables will be restricted to be integers, a MILP model will be developed for this research.

After the model is developed on paper, it will first be discussed with the team manager resource planning to be sure no important factors will be forgotten. Then it will be evaluated by one of the supervisors of TU/e of this project with expertise in the field of mathematical models and production planning.

Subsequently, AIMMS will be used as modelling tool for the mathematical planning model. AIMMS is an optimization software and is used for the modelling part of this research in order to optimize the product-production line allocation. AIMMS has been chosen, because this is a modelling tool that has already been used at HNS and they want to use this in the future as well. Furthermore, Budé (2008) investigated a similar problem at the ice cream department of Unilever and for that project, a mathematical planning model has been developed in AIMMS. To solve the model, AIMMS uses the CPLEX branch-and-bound algorithm for solving Mixed Integer Linear Programming (MILP) problems (AIMMS, z.d.). Branch-and-bound algorithms are heuristics to find integer solutions.

The last phase of the 'Systems View of Problem Solving' of Mitroff et al. (1974) is the implementation phase, but only recommendations will be given about the implementation of the HPA model.

4.4 Methodology for validation and verification

After the model has been finished, it will be first tested by a sample. A random week will be chosen for the first run. The input data will be compared with the data in the Excel files that have been used by the TSCP department to check if the right data has been loaded into the model. Also, the time that has been given for a certain production will be checked by a sample test. Then an extreme value check will be performed in order to see whether or not the HPA model provides plausible outputs to extreme and unlikely combinations of levels of parameters.

Furthermore, the model will be validated in order to resolve whether or not the model is correct. This will be done by discussing it with the resource planners and the operators. First, the model will run for a specific week. Then the hours needed for the production of this week using the HPA model will be compared with the hours needed for the production plan using the method of the planning departments of HNS. The differences will be discussed in order to see why the resource planners normally allocate the products different than the HPA model does.

4.5 Methodology for NPI allocation process

In this section, the methodology that will be used for answering the research questions of deliverable four will be described.

No process has been documented for the allocation of an NPI at HNS. Therefore, in order to answer the fifth research question, a focus group will take place in order to create the current NPI allocation process. This focus group consists of employees of the three planning departments: strategic planning, tactical planning, and operations scheduling (OS). In this research, strategic planning is called Supply Chain Development (SCD) and tactical planning is called Tactical Supply Chain Planning (TSCP).

Using the information of the focus group the process of NPI allocation will be created. After this, a second focus group will take place to review the created process. The factors that HNS is taking into account at the moment will systematically be compared with the elements found in literature. Each element that is currently not part of the NPI allocation process will carefully be discussed in the third focus group whether or not to introduce these elements. Based on the three focus groups, a new NPI allocation process will be developed.

For the description of both the current process and the developed NPI allocation process, the Business Process Optimization (BPO) Approach of Heineken will be used. This approach will be used since the process of the NPI allocation is not documented at HNS. BPO uses tools (SIPOC and Makigami) to understand the current process and the relevant value-added and non-value-added activities. The developed NPI allocation process will answer the sixth research question, which shows how the NPI allocation process will look.

4.6 Methodology for answering the main question

For the seventh research question every week of the last year, 2019, will be run in the model to see which products will be allocated to which production line. This can then be compared with the current way of working to see how much time and money the HPA model could have been saved in 2019.

5. Literature review

In order to gain insight into the theoretical background of production allocation, a literature review has been executed. The aim of this literature review was to find elements that affect the production allocation which can be used further in this research. When these elements are found, the first research question, which reads, '*What elements affect the production allocation according to the literature?*' can be answered.

Since the scope of the NPI part of this research is on new products that can be allocated to one or more existing production lines, the literature about the elements that affect the production allocation according to the literature are the same for both existing and new products. Therefore, no distinction is made between these two parts of the research.

5.1 Search protocol

The search protocol serves as a roadmap to answer the first research question. The methodology of VanWersch et al. (2011) has been followed to ensure a selection of papers that provide a near to complete overview of the literature with both high quality and relevance. This methodology consists of a primary and secondary search, which will be described in sections 5.1.1 and 5.1.2. Furthermore, the positioning of the literature review will be described in section 5.1.3.

5.1.1 Primary search

The primary search starts with a selection of electronic databases used for the literature review to cover the different research domains about the optimization of production allocation. The different databases and their corresponding study field are shown in table 1.

Electronic database	Study fields
Google Scholar	All fields
Scopus	All fields
IEEE Xplore Digital Library	Computer science
ABI Complete	Business and management
ScienceDirect	Engineering

Table 1. Overview of the selection of electronic databases.

For the selection of data sources, the primary search has been targeted at peer-reviewed journal articles and conference papers to identify high-quality studies. A peer-reviewed research has been evaluated by external experts with experience in the subject matter. Also, only English studies have been considered within the selection of data sources. Since actors of articles use different terminologies and the electronic databases use different Boolean expressions, it is impossible to search with the same term combinations. Therefore, search terms have been combined with closely related items for the search. Table 2 shows an overview of the keywords that have been used in the literature search with the 'search term group', which are the combined search terms.

Search term	Search term group
Production allocation	(production planning) OR (production scheduling) OR (production allocation)
Machine planning	(machine planning) OR (machine scheduling)
Production planning with sequence dependent changeovers	(production planning with sequence dependent changeovers) OR (production scheduling with sequence dependent changeovers) OR

	(machine planning with sequence dependent changeovers) OR (machine scheduling with sequence dependent changeovers)
New product introductions	(new product introduction) OR (new product development)
New product planning	(new product planning) OR (new product scheduling) OR (NPD planning) or (new product allocation)
Resource allocation	(resource allocation) OR (product allocation) OR (production line allocation)
MILP	(multi integer linear programming)
Multi-item production allocation	(multi-item) OR (multi-product)
Single-level production allocation	(single-level) OR (single-stage)
Unrelated parallel machine with sequence dependent changeovers	unrelated parallel machine with sequence dependent changeovers
Multiple parallel, non-identical production lines	multiple parallel, non-identical production lines

Table 2. Overview of the keywords used for the literature review.

An initial set of potentially relevant studies has been identified. The next step in the primary search is the screening of the relevance and quality of these articles using inclusion and exclusion criteria. If the inclusion criteria answered with 'yes' and the exclusion criteria with 'no', then the reference will be included in the literature review. Relevance screening verifies whether or not the study provides value for the literature review. The following inclusion (I) and exclusion (E) criteria have been determined for the relevance screening:

1. Does the article relate to the allocation of products to production lines? (I)
2. Is there a mathematical program modelled in order to solve the problem? (I)
    a. Is this model only applicable for this specific company? (E)
    b. Does problem correspond with the problem of the research, so the optimization of the allocation of products? (I)
    c. Are changeovers not incorporated in the model? (E)
3. Does the study focuses on the process industry? (I)
4. Does the study focus on new products that need significant investments? (E)
5. If the reference written in English? (I)
6. Is the reference a journal article, management or scholarly, or a conference paper? (I)

Quality screening must be done to ensure high quality studies. The following inclusion (I) and exclusion (E) criteria have been determined for the quality screening:

1. Does the article explain the problem explicitly? (I)
2. Does the study include a description of the outputs of the developed model? (I)
3. Does the study include a description of the model and explain its corresponding parameters, variables, and constraints? (I)
4. Are the results of the study verified and tested by a real-world company? (I)
    a. Are there multiple verification and validation methods used? (I)
5. Are the findings focused on technical standards? (E)

5.1.2 Secondary search

After the primary search has been executed, a secondary search has been performed to identify additional relevant studies using backward and forward tracing techniques. For the secondary search references of articles have been used to get more knowledge about the subject. Furthermore, articles have been considered that are recommended by experts. This leads to a final set of references used for this research project.

5.1.3 Positioning

The third search that has been executed for the systematic literature review (SLR) is positioning. For the positioning of the literature review, the article of Randolph (2009) has been used. Randolph (2009) claims that a researcher cannot perform significant research without knowledge of the literature field. The positioning of an SLR helps to create a thorough understanding of the needs in the search process. For the positioning of this research the six characteristics of the Taxonomy of Literature Review of Cooper (1984) have been used: *focus, goal, perspective, coverage, organization,* and *audience.* The *focus* of this SLR is to get a general impression of the problem in the literature field and on providing information about the models that can be used for the problem. The *goal* is to identify issues of previous research and compare this with the problem of this particular research. The *perspective* of the SLR will be neutral to consider different views. Due to time constraints, the *coverage* of the literature review is classified as representative. Since the SLR will be used as a clear structure, the *organization* is methodological. Lastly, the *audience* will be the supervisors form the TU/e, those form the company, and others who are interested in this particular subject.

5.2 Literature review results

By using literature studies, elements have been found that affect the allocation of products to production lines. Table 3 shows an overview of the elements that have been found in literature and by which authors it has been written. Similar elements have been mentioned in multiple articles, but only the first article found that mentioned the element will be linked to this element. After table 3 these elements will be explained.

Element	**Authors**
Processing time	Lee and Pinedo (1997)
Sequence-dependent changeover times	Lee and Pinedo (1997)
Idleness is not allowed	Lee and Pinedo (1997)
Jobs/products are weighted of importance	Lee and Pinedo (1997)
Sequence- and machine-dependent changeover times	Avalos-Rosales et al. (2013)
Machine can handle one product at a time	Avalos-Rosales et al. (2013)
Availability of jobs at time zero	Rabadi, Morgana and Al-Salem (2006)
Machine-dependent production speed	Rabadi, Morgana and Al-Salem (2006)

Number of products	Rabadi, Morgana and Al-Salem (2006)
Number of machines	Rabadi, Morgana and Al-Salem (2006)
Recipe	Kallrath (2002)
Production quantities	Kallrath (2002)
Overtime	Kallrath (2002)
Outsourcing	Kallrath (2002)
Capacity restriction: limited availability of production line	Kallrath (2002)
Continuous or batch production systems	Kallrath (2005)
Single-or Multi-purpose (multi-product) production lines	Kallrath (2005)
Finite intermediate storage	Kallrath (2005)
Deterministic dynamic demand	Meyr (2002)
Capabilities of production lines	Meyr (2002)
Lost sales/penalty costs	Meyr (2002)
Planning horizon	Lukaç (2008)
Satisfy demand per period	Lukaç (2008)
Parallel, identical production lines	Lukaç (2008)
Cyclic production	Budé (2008)
Fixed production sequence	Budé (2008)

Table 3. Elements that affect the production allocation according to literature.

This research can be characterized as a problem in which line allocation decisions have to be made for multiple products at parallel, non-identical production lines with sequence- and machine-dependent changeover times. The sequence-dependent changeovers are a set of operations that should be performed on a production line after processing a product to prepare it for processing the next product. These times depend not only on the product that will be produced but also on the product produced just before (Lee and Pinedo, 1997). Furthermore, the changeover times not only depend on the processor and successor products, but also on the machine the product will be produced on. Neumann et al. (2002) state that many articles that incorporate parallel, non-identical production lines have as objective to minimize the total make span of all production lines together and costs are not incorporated. This can be compared with this research, for which the objective is to minimize the total make span. Meyr (2002) states that parallel non-identical production lines are often not discussed in the literature, which is confirmed in the article by Avalos-Rosales et al. (2013). According to Avalos-Rosales et al. (2013), most articles focus on identical machines, where the production time of a product is the same regardless of the machine where it is processed. In the case of this research, the processing time of each product, in this research called the resource speed, depends on the machine on which it is produced.

Lee and Pinedo (1997) investigated the scheduling of jobs on parallel machines with sequence-dependent setup times. They describe that a job has a processing time and weight. If a job *k* is followed by another job *j* a setup time is incurred, which depends on both job *j* and job *k*. Lee and Pinedo (1997) use the term setup time as the time that is needed to change the machine from producing product A to product B. At HNS this definition has been used for the word 'changeover' and 'setup time' is defined as the time that is needed for the start-up and termination phase of the production line. The definition of setup time in this article is equal to the definition of changeover time at HNS, so from now on the term changeover will be used. In this article, the changeover time does not depend on the production line the two jobs have been processed on. Comparing this to the HNS case, this differs since at HNS the changeover time does not only depend on both products *j* and *k*, but also on the production line on which these products will be produced. Because of the changeover time, an optimal schedule may exist in which a machine remains idle, then an available job waits for processing on another machine on which it may incur a shorter changeover time and be completed earlier. In the article by Lee and Pinedo (1997) they do not allow unforced idleness, so if a machine is free and a job is waiting, then the machine is not allowed to remain idle. Since the goal at HNS is to reduce the total time of all production lines together to produce all orders, the model will automatically choose the best solution, which means that idleness does not necessarily affect the production allocation. Lee and Pinedo (1997) also weighted the jobs, such that one job is more important than another job and therefore receives priority.

Avalos-Rosales et al. (2013) propose an improved formulation for an unrelated parallel machine problem with machine and product sequence-dependent changeover times. This means that the changeover time between product 1 and product 2 can be different on different machines, but also that the sequence of the products can cause different changeover times. Furthermore, they describe that in the articles where the production time that depends on a machine is discussed, most of them do not assume that there are sequence-dependent changeover times. This means that the changeover times not only depend on the product that will be produced, but also on the job produced just before. The sequence dependence constraints from the article by Avalos-Rosales et al. (2013) are used as starting points for the HPA model.

Avalos-Rosales et al. (2013) conclude that a problem with parallel, non-identical production lines, and sequence-dependent changeovers is also a NP-hard problem. An NP-hard problem is defined by Almada-Lobo et al. (2007) as 'a problem that cannot be solved in polynomial time, in which polynomial-time algorithms are known to be 'fast''.

Figure 3 is the graphical representation of a solution given by Avalos-Rosales et al. (2013). In this figure, *j* and *k* both represent products and the time between them is the changeover time. The grey blocks are the production times for a certain product. *Cmax* is the objective to minimize the make span, which means the maximum span in the solution of the problem.

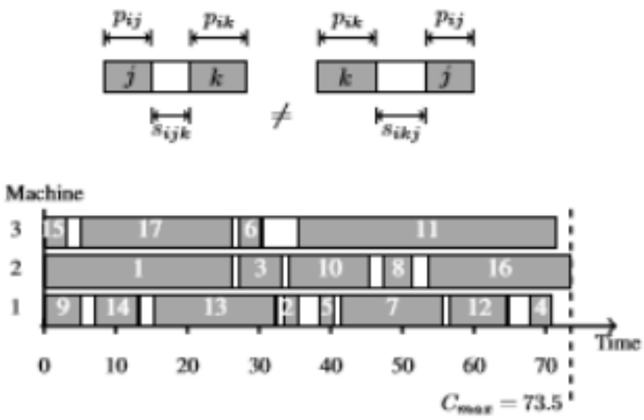

Figure 3. Graphical representation of a solution given by Avalos-Rosales et al. (2013)

Rabadi, Morgana, and Al-Salem (2006) discuss the number of products and machines that impact the allocation of products to production lines. If the number of these parameters increases, the complexity of the problem will increase. The processing times of a job depends on the machine to which they are assigned. This element can be used for the HPA model since at HNS the resource speed of a product depends on the machine it will be produced on. Besides, all jobs are available at time zero which is not discussed in the previously mentioned articles. For this research, it has been determined that all products are available to be produced at time zero, because restrictions of for example material have already been eliminated from the input data.

The article by Kallrath (2002) discusses important constraints such as production quantities, production rates, and recipes. This is interesting since HNS has to deal with bottle sizes, bottle types, beer types and secondary pack types, which can be compared with the recipes Kallrath (2002) is mentioning. Furthermore, the following constraints are also important constraints for achieving the goal of this research:

1. The production quantities must be equal to the demand. Because there may be not enough space on the production lines, a dummy production line is added in the HPA model.
2. The production rates (resource speed) depends on the product to be produced and depend on the production line the product will be produced on. The production time that is needed to produce a certain amount of a product depend on the resource speed.
3. The production lines at HNS have limited availability, which cannot be exceeded.

Kallrath (2005) distinguishes continuous and batch production systems. Continuous production systems are plants that produce a limited number of products in relatively high volumes while batch production systems are small quantities of a large number of products in which a batch is the smallest quantity to be produced. HNS has a continuous production system with minimal production quantities. These minimal production quantities will be explained in chapter 7.6. Besides this, Kallrath (2005) described structural elements of planning and scheduling:

- Single –or Multi-purpose (multi-product) production lines;

- Sequence-dependent changeover times and cleaning costs;

- Finite intermediate storage.

Kallrath (2002) also discusses the difference between planning- and scheduling problems in which the focus on time is more detailed in scheduling problems. Furthermore, the article by Kallrath (2002) states that nearly all data in supply chain management planning may vary over time and allow to evaluate scenarios that involve time-dependent aspects such as demand patterns, new product introductions, and shutdown of production facilities for maintenance.

Meyr (2002) addresses the simultaneous lot sizing and scheduling of several products on non-identical parallel machines. In this paper, the deterministic dynamic demand is to be met without back-logging. As well as for the HNS case, this paper takes into account that the production lines have partially the same capabilities, and thus one product can often be produced on multiple production lines. Furthermore, sequence-dependent changeover times have been considered between two items of different products and the limited capacity of each production line has to be respected. The inventory of a product at the beginning of the planning horizon has been taken into consideration (Meyr, 2002). At HNS the inventory of a product has also been considered at the beginning of the planning horizon, but since this has been incorporated in the production plan – the input data for the model – this does not need to be taken into account when modelling the decision support tool. The capacity of each production line that is finally available is known only when the production run and the sequence of the products have been determined. Meyr (2002) also considers penalty costs when the production quantities do not meet the demand, which means there is lost sales.

Lukaç et al. (2008) investigated a production planning problem with sequence-dependent changeovers and two machines. The considered company has to satisfy the demand of certain products for each period of the planning horizon. The considered company has two production lines that can both produce the final product, which means that they have multiple production lines with the same capabilities, which is called parallel, identical production lines. HNS has multiple production lines that have both the same and different capabilities, which is called parallel, non-identical production lines. Each machine is only able to process one product at a time.

Budé (2008) states that a fixed production cycle- and sequence may play a role in the production allocation. Cyclic production occurs when the time between the production of a certain product is constant. A fixed sequence means that the order in which the products are produced is fixed. Budé (2008) also states that when this is the best option, the mathematical model should incorporate this. As HNS does have a cyclic production for certain products, this has to be incorporated in the model and will be discussed in chapter 7.10. HNS does not have a fixed production sequence, which means that the model has to determine what the sequence of the products on the production lines will be and can be different each week.

5.3 Summary of the literature review

The goal of this chapter was to investigate the elements in literature that affect production allocation, which has been shown in table 3. Multiple articles have been assessed to ensure no important element was left out. These elements will be compared with the current situation of HNS to determine which of the elements need to be taken into account for the development of the HPA model.

6. Current situation

This chapter will encompass a description of the current situation of HNS, which will answer the second research question *'What are the important elements that affect the allocation of products to production lines?'.* In order to answer this research question, two sub questions have been created. The first sub question reads *'What does the current packaging process look like?'* which will be answered by explaining the packaging process in a random week at a random production line. The second sub question is formulated as *'What does the current production allocation process look like?'* which will be described with the current allocation process of HNS. Through these two sub questions, the specific elements that affect the production allocation at HNS will become clear.

6.1 Current packaging process

In order to gain insight into the functioning of the production lines of HNS, it is important to know that the company has 26 production lines divided over three locations: Zoeterwoude, 's-Hertogenbosch, and Wijlre. Each of these production lines can only produce one of the following pack types: 'bottle oneway', 'bottle returnable', 'can', 'air keg', 'draught keg,' and 'keg', which are shown in Appendix C. Out of these 26 production lines, 12 are within the scope of this research; those that produce bottle oneway products. These bottle oneway production lines have been observed in order to create an overview of the current production process. After this overview has been made, it has been checked by the team leaders of the production line in order to make sure they agreed with the overview.

Before the current packaging process has been mapped, the first element that affects the allocation at HNS can already be described. This element is that the 12 production lines at HNS have different *capabilities*. This element needs to be considered when developing the HPA model, since not every product can technically be produced on every production line. The capabilities of the production lines differ in a number of ways. First of all, they differ in 'primary pack type' which entails both the bottle type, for instance, K2, which is the typical green Heineken bottle, and the bottle size, say 330 milliliters (ml). Secondly, the capabilities of production lines differ in what is referred to as 'secondary pack type', meaning the type of package of the bottle, an example of this would be a crate in which 24 bottles fit. And lastly, they differ in terms of 'pallet load', with which the type of the pallet is meant. These different capabilities are of crucial influence whether or not a line can be used for the allocation of a certain product.

Figure 4 shows how the production of one random week at a random production line might look, which answers the first sub question. The figure has been discussed with the operators of different production lines. All elements that may affect the production have been included in this figure and will be explained in more detail in the text below. The identified elements are put in italic to highlight these elements.

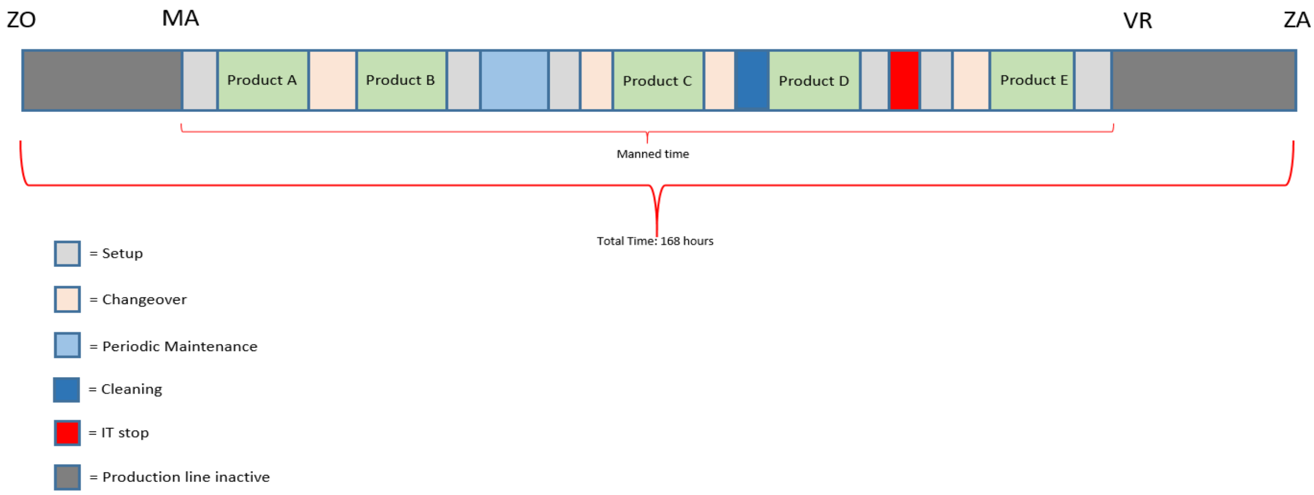

Figure 4. A random production week at a random production line derived.

Noting that the packaging process has now been illustrated, the elements that affect the production allocation in this packaging process can be discussed. In this example, the production line is not fully-continuous, meaning it does not operate 24 hours a day, 7 days a week. The time that the line is available for production is also referred to as the manned time or gross hours. This is the time that there are employees working on the production line. Within these *gross hours, the setup times,* and *planned downtimes* need to be taken into account, since those are times in which the production line cannot produce a product. The gross hours minus the setup times and planned downtimes is called the *capacity.* Within the capacity of a production line, the products can be allocated taking into account the changeovers that are needed between products. Setup time is defined as the time that is needed for the production line to start and terminate the production at this line. The setup time is elaborated in further detail in chapter 7.2. Furthermore, the *changeover time* can be described as the time that is needed to change the production line from producing product A to producing product B. At HNS the changeover time from product A to product B may differ from the changeover time from product B to product C etc. etc., which is called sequence-dependent changeover time. In addition to sequence-dependent changeover time, HNS also distinguishes machine-dependent changeover time. This is used referring to when the time for a changeover between product A and product B is different between production lines. Lastly, planned downtime is described as the time that is taken into account for the production line to stop. This can be divided into two distinct categories, internal and external. The internal planned downtime is the time that HNS needs for periodic maintenance, cleaning, training, regular meetings, and test runs. For periodic maintenance, the production line needs to shut down and setup time is needed. After the periodic maintenance, the production line will start up, again and again, a setup time is needed. The external planned downtime is the time that a third party needs for maintenance and is, for example, an IT stop. As similar to periodic maintenance, setup time has to be taken into account for the external downtime. The last element that influences the allocation of a product to a production line is the time that is needed for an order to be produced at a certain production line, which is called the *resource speed*. The resource speed at HNS depends on both the product and the production line on which the product will be produced. Elements influencing the production allocation that have been emerged from the packaging process will be summarized in table 4 in chapter 6.3. Now that it is clear how production lines at HNS work and the elements that affect the production allocation have been defined, the current production allocation process can be looked at.

6.2 Current production allocation process

In this section, the second sub question which reads '*What does the current allocation process of HNS look like?*' will be answered. The elements that derive from this process will partly answer research question two. Before the current production allocation process of HNS will be discussed, the definition of production allocation has to be known. Karimi et al. (2013) describe production allocation as the activity that considers the best use of production resources in order to satisfy production goals over a certain period, which is referred to as the planning horizon.

As a basis for the HPA model, it is important to understand the production allocation process to recognize the scope of the project and figure out which elements influence the production allocation. Because there is no existing document that describes the current production allocation process, an interview has been taken place with the resource planners separately and a focus group with them. The focus group has been used to compare the methods for planning the production plan used by the individual resource planners. Additional information on the interview and the focus group can be found in Appendix H.2 and respectively Appendix I.1. From comparing these interviews and the focus group, it can be concluded that the planners are using the same techniques and methods for their planning.

The resource planners of HNS use two methods combined to determine the allocation of products to production lines. The allocation of products is based on priorities when a product can be produced by multiple production lines. An example of the priorities at HNS is given in figure 5. This figure shows that the Stock Keeping Unit (SKU) '100002' can be produced by both HBLYN11 ('s-Hertogenbosch line 11) and ZWLYN06 (Zoeterwoude line 6). The figure needs to be read that the lower the priority, the better. This means that for this specific SKU, production line ZWLYN06 with priority 100 is best. The best priority is based on the production line with the highest outflow rate. The outflow rate, which is called the resource speed in this research, is in boxes or crates per hour (HNS VW_Productieplan, 2019). These priorities are not reexamined with a systematic analysis by TSCP, instead, the priorities are adjusted from time to time by one of the employees whenever they know the priorities have changed.

BOM_MATERIAL	RESOURCE_CODE	PRIORITY	OUTFLOW_RATE
100002	HBLYN11	1000	2500
100002	ZWLYN06	100	3750

Figure 5. Example of priorities of SKU 100002.

Every product will be allocated to the production line with the best priority. Then, based on this allocation the capacities per production line will be allocated using the Operational Performance Indicator (OPI). The OPI expresses the performance of a production line in percentages. When it turns out that the products cannot be produced on the priority line due to the capacity of the lines, then products will be reallocated until the production of the products fit within the capacity of the lines. The OPI is affected by *efficiency, planned downtime, changeover time, gross hours of a production line,* and *resource speed*. The OPI is calculated per production line and shows the average of this particular line, which can be considered a disadvantage as it is not quite accurate. For instance, when the OPI reads 60%, it means that for one product the OPI can be 80% while for another product on the same production line, it can be 40%. From this, it is concluded that the elements affecting the OPI are also the elements that affect the production allocation of HNS and will be taken into account for the development of the HPA model.

Sometimes, it occurs that resource planners encounter a lack of capacity for the product portfolio to be produced. In this case, they can request overtime hours for the production lines. When they do so, the team leaders of the production lines look on which production lines and at which moments extra shifts can be arranged. If a production line is fully-continuous, it is impossible to have overtime on this production line. As the request of TSCP has to be at least two weeks in advance, the total hours that a production line will produce in the next week is already fixed. Besides using overtime hours, HNS has the possibility to outsource a product, which is referred to as co-packing. This method is used when a product cannot be produced at the production lines of HNS due to technical reasons, for instance, that the lines do not have the capabilities to produce this specific product. In this case, HNS produces a semi-finished product and their partner will finish it. For example, HNS produces 24 cans of 150 ml loose in a box, whereas the final product should be these cans in a 6x4 wrap. Here, the co-pack partner will make sure that the right package type will be used, meaning that the 24 cans will be divided into 6x4 and will be wrapped. The co-packing products are thus beyond the scope of the HNS production lines as they are not able to produce them and thus need to be outsourced.

The goal of this paragraph and both the interviews and focus group was twofold. The first goal was to recognize the scope of this research in the production allocation process. Therefore, the entire production allocation process has been created and is shown in figure 6. In this figure, the scope of the research has been marked green. Illustrating what the current production allocation process looks like, answers the second sub question. In this figure, a legend has been added to show which department is executing the particular steps in the process. In appendix K, figure 6 has been explained in more detail. The second goal was to figure out which elements influence the production allocation. For this, too, it was important to understand the production allocation process shown in figure 6. The elements influencing the production allocation that have been derived from the current production allocation process have been summarized in table 4 in chapter 6.3.

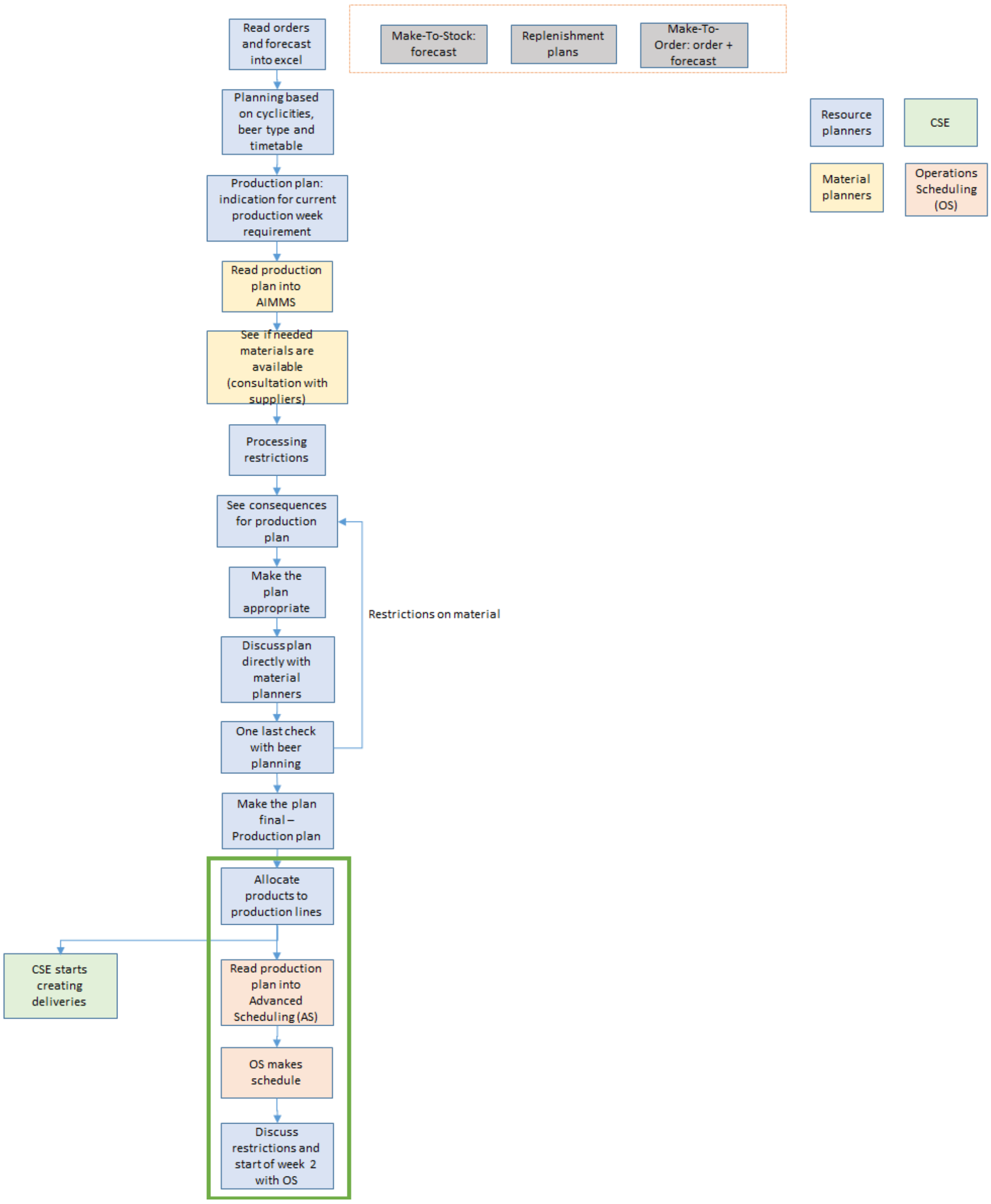

Figure 6. Current production allocation process derived from both the semi-structured interviews and the focus group with the resource planners.

6.3 Summary of the current situation

Elements that affect the allocation of products to production lines at HNS need to be considered for the development of the HPA model in order to improve the allocation. From the current packaging and production allocation process, elements have been identified that affect this production allocation at HNS. These elements have been summarized in table 4 and need to be considered to answer research question two, which will be the focal point in the next paragraph.

Elements	
Capabilities of the production line	Pack type
	Primary pack type
	Secondary pack type

Capacity	Gross hours
	Setup time
	Planned downtimes
	Overtime
Changeover times	Sequence-dependent changeover times
	Machine-dependent changeover times
Line specific products	
Resource speed	Net resource speed
Efficiency	
Material restrictions	
Beer availability	
Storage	
Inventory	
Minimal production quantity	
Outsourcing (penalty costs)	
Planning horizon	
Cyclic production	

Table 4. Summary of elements that affect production allocation.

6.4 Elements that affect the production allocation

From the literature review described in chapter 5, elements have been identified which influence the production allocation. In the first column of table 5, these elements have been summarized, and the second column represents the authors of the articles from which the elements have been identified. Based on the elements identified in the current processes of HNS, it has been indicated whether the elements identified from literature are applicable to HNS. The applicable elements have been determined to be the important elements that affect the production allocation. With these important elements, the second research question '*What are the important elements that affect the allocation of products to production lines?'* is answered.

Element	**Authors**	**HNS**
Processing time	Lee and Pinedo (1997)	Yes
Sequence-dependent changeover times	Lee and Pinedo (1997)	Yes
Idleness is not allowed	Lee and Pinedo (1997)	Idleness is not allowed
Jobs/products are weighted of importance	Lee and Pinedo (1997)	No

Sequence- and machine-dependent changeover times	Avalos-Rosales et al. (2013)	Yes
Machine can handle one product at a time	Avalos-Rosales et al. (2013)	Yes
Availability of jobs at time zero	Rabadi, Morgana and Al-Salem (2006)	Yes
Machine-dependent production speed	Rabadi, Morgana and Al-Salem (2006)	Yes
Number of products	Rabadi, Morgana and Al-Salem (2006)	Yes
Number of machines	Rabadi, Morgana and Al-Salem (2006)	Yes
Recipe	Kallrath (2002)	Yes; beer type, bottle type etc.
Production quantities	Kallrath (2002)	Yes
Overtime	Kallrath (2002)	Yes
Outsourcing	Kallrath (2002)	Yes
Capacity restriction: limited availability of production line	Kallrath (2002)	Yes
Continuous or batch production systems	Kallrath (2005)	Continuous production systems
Single-or Multi-purpose (multi-product) production lines	Kallrath (2005)	Multi-product production lines
Finite intermediate storage	Kallrath (2005)	No
Deterministic dynamic demand	Meyr (2002)	Yes
Capabilities of production lines	Meyr (2002)	Yes
Lost sales/penalty costs	Meyr (2002)	Yes
Planning horizon	Lukaç (2008)	Yes
Satisfy demand per period	Lukaç (2008)	Yes
Parallel, identical production lines	Lukaç (2008)	Only parallel non-identical production lines
Cyclic production	Budé (2008)	Yes
Fixed production sequence	Budé (2008)	No

Table 5. Elements that affect the production allocation derived from the literature.

In order to determine the starting points for the HPA model, the elements from table 5 will be discussed whether or not they need to be considered in the HPA model.

7. Model requirements

The elements discussed in the previous chapter will be looked upon in this chapter to find out whether or not these have to be introduced in the HPA model. The elements for which it is determined that they will be introduced in the model will be considered as the starting point for the HPA model. This, in turn, will form the answer to the third research question, which reads, '*What elements should be taken into account as starting points?*'.

7.1Capabilities of the production line

The first element that is looked upon with the question of whether it should be incorporated into the model is the capabilities of the production lines. This element needs to be incorporated in the model as not every product can technically be produced on each production line due to the capabilities of a production line. Each production line has different capabilities in terms of bottle type, bottle size, and secondary pack types. For example, production line one is able to produce Heineken 330 12-pack in a crate, while production line two is able to produce Heineken 650 24-pack in a box. This is not interchangeable.

Table 6 shows the number of product differentiations in terms of bottle sizes, bottles types, and secondary pack types that a production line is able to produce (HNS packaging overview [overview], 2018)[3].

Production line	Number of bottle sizes	Number of bottle types	Number of secondary pack types
HBLYN8A	5	5	6
HBLYN8B	6	10	5
HBLYN16A	2	1	6
HBLYN16B	4	6	5
ZWLYN03	3	3	2
ZWLYN07	3	3	3
ZWLYN21	4	4	3
ZWLYN22	4	3	3
ZWLYN51	1	1	3
ZWLYN52	1	1	3
ZWLYN81	2	2	3
ZWLYN82	2	2	1

Table 6. Differences between the twelve bottle oneway production lines.

[3] Reference derived from the intranet (non-public access) of HNS.

7.2 Capacity

In order to understand how many hours can be used for production on each production line every week, the factors that affect the hours of available capacity are explained in detail. The information about the capacity has been retrieved from the discussion with the team leaders of the production line and the observation of the current packaging process. The capacity may vary between production lines and weeks. Furthermore, it consists of different components that will be explained below.

Every production line has a number of gross hours, which is called the effective working time (EWT), this is the same for every week and depends on the production line (OPI handleiding v1.0, HNS)[4]. The production lines that are not fully-continuous, so the ones which do operate 168 hours a week need time for starting up and terminating the production line, which is called the setup times. In the start-up phase of a production line, the operators will ensure that the line is ready to produce the first product. The filler will be filled with the right beer and the bottles will be depalletized and made ready for production. The termination phase includes the time that the last bottle is filled up to and including the moment that this last bottle exits the production line. The setup times differ between production lines but for a production line this is the same for all weeks at a particular line. An overview of the setup time is visualized in Appendix E. Since the capacity depends on planned downtimes, it may vary per week. These planned downtimes consist of maintenance by the production teams cleaning, training, meetings and test runs. Therefore, the capacity in hours available for production and changeovers is called the actual production time (APT) (HNS OPI handleiding v1.0, 2019)[5]. The overtime hours that have been approved by the team leaders of the production lines will be added up to the actual production time, which is the capacity that will be used as input for the HPA model. The overtime will be further explained in chapter 7.7. Concluded, the capacity will be one of the input parameters of the decision support tool and consists of multiple elements that will all be taken into account to determine the total capacity that can be used for the production of a production line.

7.3 Changeover times

The third element which is up for discussion in order to determine whether it should be incorporated into the model is changeover times. At HNS, two types of changeover times have to be considered of which the first one is sequence-dependent changeover times. This means that first producing product A and then product B has, for example, a changeover time of 120 minutes, while first producing product A and then product C may have a changeover time of 180 minutes. So, the sequence in which the products are produced, affect the time of the changeover. The second type of changeover is the machine-dependent changeover time. For example, if production line 1 produces first product A and then product B a changeover time of 120 minutes needs to be considered while the changeover with the same sequence on production line 2 requires 60 minutes.

Analyzing the changeover matrices showed that the changeover times at HNS can vary between 20 and 360 minutes (HNS VW_MD_CHANGEOVER_MATRIX_VALUES, 2019)[6]. Furthermore, this analysis

[4] Reference derived from the intranet (non-public access) of HNS.

[5] Reference derived from the intranet (non-public access) of HNS.

[6] Reference derived from the intranet (non-public access) of HNS.

showed that the changeover matrices differ between the three breweries of HNS. At all breweries, a changeover time is required when the next production is a change in beer type, bottle type, bottle size, secondary pack type, pallet load, and label. Based on the information of this paragraph it can be concluded that it is required to incorporate changeovers which are sequence- and machine-dependent (HNS VW_CHANGEOVER_DEF, 2019)[7].

7.4 Resource speed

The resource speed is the fourth element that is looked upon to determine whether it should be incorporated into the model. The resource speed is defined as the production speed of the number of boxes that can be produced per hour by a specific production line. The resource speed differs per production line and on top of that, it is different per product. This can best be illustrated by an example. The resource speed of product A on production line 3 is 1000 boxes per hour, while the resource speed of product B on the same production line is 800. Besides the resource speed depends on the product to be produced, it also depends on the production line as the resource speed of product A on production line 3 is 1000 boxes per hour while the speed of the same product on production line 7 is 800 (HNS VW_AS_BILL_OF_RESOURCE, 2019)[8].

The resource speed is influenced by the efficiency of a product on a production line, which depends on the product. The resource speed times the efficiency is called the net resource speed. In order to get a better understanding of the efficiency and the net resource speed an example is given. If product A has an efficiency of 80% on production line 3 with a resource speed of 1000 boxes per hour, this means that the net resource speed of product A on production line 3 is 800 boxes per hour. The input data that has been used for the HPA model is the net resource speed that has already been taken into account (HNS VW_AS_MAT_PSTEP_RESOURCE, 2019)[9]. Since the net resource speed influences the number of products that can be produced per hour, this element has to be incorporated in the model

7.5 Material-, beer availability-, storage-, and inventory restrictions

The next element which is up for discussion is the restriction on material, beer availability, storage capacity, and inventory. When making the production plan in which the quantities per product are determined, TSCP takes into account if the material and beer are available and whether there is enough storage capacity available. Furthermore, they check whether the maximum inventories per product are not exceeded and whether the minimum inventories of these products are met. As the production plan will be used as input for the HPA model, these restrictions do not have to be incorporated in the model.

7.6 Minimal production quantity

The sixth element that affects the allocation at HNS and therefore needs to be discussed in this chapter is the minimal production quantity. This is the quantity that HNS quantity of one product in hectoliters (hl) that HNS wants to be produced at minimum. When TSCP receives the orders from the customers, they take these minimal production quantities into account when deciding the quantity

[7] Reference derived from the intranet (non-public access) of HNS.

[8] Reference derived from the intranet (non-public access) of HNS.

[9] Reference derived from the intranet (non-public access) of HNS.

per product to be produced in the production plan. Because these minimal production quantities are taken into account in the production plan, which is the input for the model, this element does not have to be incorporated in the model.

7.7 Overtime

The seventh element that is looked upon is the overtime, which is the time that the production lines produce beyond the regular hours of a production line. It is possible to have overtime hours at the production lines that are not working for 168 hours a week, which became clear during both the semi-structured interviews and the focus group with the resource planners, see Appendix H.2 and Appendix I.1. The labor costs for overtime are two times higher than the costs for regular production hours. If the resource planners of the TSCP department see shortages on the production line, they are able to request overtime hours. At the production lines, the team leaders look together with the operators of the production lines on which lines and at which moments extra shifts can be arranged. This means that every week the number of overtime hours is different. The number of overtime hours needs to be requested at least two weeks in advance. Because the HPA model will be used only one week in advance, the number of overtime hours have already been determined. Therefore, the overtime (in hours) that has been made available per production line per week will be part of the total capacity (in hours) of that production line in the specific week.

7.8 Outsourcing

HNS has made it possible to outsource part of its packaging process, which they refer to as co-pack. Co-pack will only be used for required capabilities of a product that the production lines of HNS are not capable of. The costs for outsourcing are 15 euros per hl higher than the regular production at an HNS brewery, according to the co-pack manager.

As mentioned in the current production allocation process, HNS has products that their own production lines are not able to produce due to technical reasons. For these products, HNS makes use of outsourcing partners who will finish their products. The semi-finished products that go to the outsourcing partners are part of the production plan. The finished products will not be part of the production plan, and therefore, outsourcing will not be incorporated into the model.

7.9 Planning horizon

As the planning horizon is of importance for the allocation of products, this element will be discussed how it will be incorporated in the HPA model. The output of the model should define the quantity per product to be produced at which moment of time at which production line, and therefore, the planning horizon of the model is one week.

7.10 Cyclic production

Cyclic production has been determined to be an element that affects the allocation and is defined as the time between the production of a certain product is constant. To gain a better understanding of the cyclic production at HNS, an example is given. The beer type ‘Sol’ is only produced once in two weeks, which means that the products within this beer type have a cyclic production every two weeks (HNS VW_PRODUCTIEPLAN, 2019)[10]. As the cyclic production is already taken into account in

[10] Reference derived from the intranet (non-public access) of HNS.

the production planning that will be used as input, this element does not have to be incorporated in the model.

7.11 Demand volumes

The last element that affects the allocation of products is the demand volumes. The production plan will incorporate the demand volumes per product that need to be produced in the next week, which means that these demands must always be fulfilled.

7.12 Summary model requirements

In this chapter, the elements that affect the allocation of products to production lines at HNS have been discussed. This section will first summarize the elements determined to be required in the Heineken Production Allocation (HPA) model. Then, the elements determined not to be required in the HPA model will be enumerated.

The requirements that will be the starting points for the Heineken Production Allocation (HPA) model are:

- Different production lines have different capabilities;
- Capacity can be different per period and per production line;
- Changeover times between products depend on the sequence and on the production line, so machine- and sequence-dependent changeover times;
- Products that are line specific can only be produced at one specific production line;
- Different production lines have different resource speeds that depend on the product to be produced;
- The net resource speed depends on the efficiency of a product on a production line and the resource speed of that product on that production line;
- The planning horizon will be one week;
- Per period there are overtime hours available, which are already taken into account by the capacity of the production lines;
- A dummy line is created for products that cannot be produced within the capacity of the regular production lines. The capacity of the dummy line is set to be infinite;
- The production plan is the demand input for the model;
- Production timings and the allocation to lines will be decided by the model;
- The production quantity of a product is equal to the demand volume of a product;

Elements that are not required in the HPA model:

- Outsourcing will not be included in the model, because there are specific products that go directly to the outsourcing partners of HNS;
- The final production plan, which is used as input of the model, already takes into account the minimal production quantity, inventory, cyclic production and the restrictions for available material, beer, and storage capacity.

8. Heineken Production Allocation (HPA) model

This chapter describes the Heineken Production Allocation (HPA) model to solve the following problem:

1. Resource speed depends on both the product and the production line;
2. Limited capacity available that depends on the week and on the production line;
3. Sequence-dependent and machine-dependent changeovers.

The representation of the HPA model answers the fourth research question, which is formulated as '*What does the HPA model look like for existing products?*'

The basis of the HPA model comes from the mathematical model represented in the article by Avalos-Rosales et al. (2013). Extensions on this model have been made to meet the requirements to solve the problem of HNS.

A dummy production line will be introduced to the HPA model for the products that do not fit within the given capacity of the production lines. This means that all demand that cannot be fulfilled by the regular production lines will be allocated to the dummy line. The hours available on the dummy line are set very high, e.g. 10.000 hours.

8.1 Assumptions for the HPA model

For the HPA model the following assumptions have been made:

A1. The assumption has been made that the quantities which are determined in the production plan have to be produced in a specific week. This assumption is considered valid because it is derived from the current situation.

A2. The resource speed per production line has been assumed to be constant per product for the planning horizon of one week. This assumption has been discussed with HNS and because the current methods are using the same assumption, this is determined to be a valid one.

A3. There is no restriction on material, beer availability, and inventory. The beer, materials, and inventory for the products that have to be produced in a certain week are available at the beginning of that week, so time zero of that week. In theory, this is a valid assumption as the quantities of the products in the production plan are based on these restrictions. However, practice shows that the suppliers of the materials do not always deliver to the agreed date. If a supplier delivers later than planned and later than the product was allocated by the model, the production allocation has to be adapted.

A4. It has been assumed that the storage space is no restriction based on the fact that this has not been a bottleneck in the past. Furthermore, if there is no storage space then this is already taken into account in the production plan.

A5. Since the overtime needs to be requested two weeks in advance and the planning horizon of the HPA model is only one week, it has been assumed that the overtime requested by the TSCP department is needed for the production. In this case, the overtime hours are part of the total capacity, but the extra costs of overtime will not be considered by the HPA model. This assumption can be made because these hours would also have been used in the current situation.

A6. An extremely low resource speed, 800 colli per hour, has been assumed for the dummy production line. As this low resource speed ensures that it is unattractive for the model to choose the dummy line instead of a regular production line, this is a realistic assumption.

A7. It has been assumed that there are no lost sales. Products that cannot be produced at the production lines due to the limited available capacity will be produced one week later. As there are agreements with certain customers about this delay, this assumption is valid.

8.2 Representation of the original HPA model

Sets

K : Number of production lines plus a dummy line, index *k=1,2,…,12, DummyLine*

P : Absolute number of products (in colli) to be produced in a certain week, index *p,p1,p2*

P0 : Absolute number of products (in colli) to be produced in a certain week plus a dummy product 0, index *p,p1,p2,0*

Parameters

C_k : Available time for production and changeovers at production line *k* during a certain week (in hours).

$COT_{k,p1,p2}$: The changeover time (in hours) from product 1 to product 2 on production line *k.* For the dummy product *0* the changeover time is zero, $COT_{k,0,p2} = 0$ and $COT_{k,p1,0} = 0$.

M : Is the largest Q_p that exists in the week to be allocated.

$P_{k,p}$: The processing time (in hours) needed for one colli of product *p* on production line *k* after the line has been setup for this, which is calculated by the following formula: $\frac{1}{RS_{k,p}}$.

$RS_{k,p}$: Resource speed of product *p* at production line *k*.

Q_p : Quantity of product *p* (in colli) to be produced during a certain week.

Variables

$ComplO_{k,p}$ *:* Moment in time (in minutes) when the production of product *p* has been ended on production line *k*.

MS_k *:* Make span of production line *k:* the total time that production line *k* needs for production and changeovers in a week.

TMS *:* Total make span of all production lines together: $\sum_{k=1}^{K} MS_k$

$Y_{k,p} \in \{0,1\} \qquad \forall k \in K, \forall p \in P$

: 1 is product *p* can technically be produced on production line *k*, 0 otherwise.

$Z_{k,p} \in \{0,1\} \qquad \forall k \in K, \forall p \in P$

: 0 if there is nothing of product *p* produced on production line *k* during a week, so when $Q_{k,p} = 0$, if there is one or more colli of product *p* produced on production line *k*, so when $Q_{k,p} \geq 1$, then $Z_{k,p} = 1$.

Decision variables

$Q_{k,p}$ $\qquad \forall p \in P, \forall k \in K$

: number of units (in colli) of product *p* that will be produced in one week on production line *k*.

$X_{k,p1,p2} \in \{0,1\}$ $\qquad \forall p1 \in P0, \forall\, p2 \in P, p2 \neq p1, \forall k \in K$

: 1 if product *p1* is scheduled before product *p2* to production line *k,* 0 if product *p1* is not scheduled before product *p2* to production line *k*. The variable $X_{k,0,p2}$ is used to specify which product will be processed first on production line *k*. The variable $X_{k,p1,0}$ is used to specify which product will be processed last at production line *k.*

Min! ***TMS*** **(1)**

s.t.

$$\sum_{k=1}^{K} \sum_{p2 \in P0, p2 \neq p1} X_{k,p1,p2} = \sum_{k=1}^{K} Z_{k,p1} \qquad \forall p1 \in P \qquad (2)$$

$$\sum_{p2 \in P} X_{k,0,p2} \leq 1 \qquad \forall k \in K \qquad (3)$$

$$X_{k,p1,p2} \leq Y_{k,p1} \qquad \forall k \in K, \forall p1 \in P, \forall\, p2 \in P, p2 \neq p1 \qquad (4)$$

$$X_{k,p1,p2} \leq Y_{k,p2} \qquad \forall k \in K, \forall p1 \in P, \forall p2 \in P, p2 \neq p1 \qquad (5)$$

$$\sum_{p2 \in P0, p2 \neq p1} X_{k,p1,p2} = \sum_{p3 \in P0, p3 \neq p1} X_{k,p3,p1} \qquad \forall p1 \in P, \forall k \in K \qquad (6)$$

$$ComplO_{k,p2} + M * \left(1 - X_{k,p1,p2}\right) \geq ComplO_{k,p1} + (P_{k,p2} * Q_{k,p2}) + COT_{k,p1,p2}$$

$$\forall p1 \in P0, \forall p2 \in P, p2 \neq p1, \forall k \in K \qquad (7)$$

$$ComplO_{k,0} = 0 \qquad (8)$$

$$\sum_{k=1}^{K} Q_{k,p} = Q_p \qquad \forall p \in P,\ \forall k \in K \qquad (9)$$

$$Q_{k,p} \geq 1 - Q_p(1 - Z_{k,p}) \qquad \forall p \in P,\ \forall k \in K \qquad (10)$$

$$Q_{k,p} \leq Q_p * Z_{k,p} \qquad \forall p \in P,\ \forall k \in K \qquad (11)$$

$$\sum_{p1 \in P0} \sum_{p2 \in P, p2 \neq p1} ((P_{k,p2} * Q_{k,p2}) + (COT_{k,p1,p2} * X_{k,p1,p2})) = MS_k \qquad \forall k \in K \qquad (12)$$

$$MS_k \leq C_k \qquad \forall k \in K \qquad (13)$$

The objective function (1) minimizes the total make span of all production lines *k*, which is the sum of all production lines *k*.

Constraints (2) ensure that every product is produced.

Constraints (3) ensure that at most one product is scheduled as the first job on each machine.

Constraints (4) and (5) denote that a product can technically be produced on a production line *k*.

Constraints (6) ensure that if a product is scheduled to a production line, then a processor and a successor must exist in the same machine.

Constraints (7) provide a right processing order, avoiding loops. Basically they establish that, if $X_{k,p1,p2}$=1, then the completion time of product 2 *p2* must be greater than the completion time of product 1 *p1.* If $X_{k,p1,p2}$ = 0, the constraints become redundant.

Constraints (8) set the completion time of the dummy product to 0, which guarantees in conjunction with constraint (7) that the completion time of all jobs is positive.

Constraints (9) ensure that the total number of units of product *p* is produced.

Constraint (10) and (11) ensures that if there is one or more units of product *p* scheduled to production line *k,* the binary variable $Z_{k,p}$ is 1 and if there is nothing of product *p* scheduled to production line *k*, the binary variable $Z_{k,p}$ is 0.

Constraints (12) compute the time that the last product is finished on a production line *k*.

Constraints (13) ensure that the total time on a production line *k* does not exceed the capacity of that production line *k.*

8.3 Complexity of the model

The problem mentioned before is a complex one. After 24 hours of solving the problem, the model gave the result that there was no feasible solution found. Therefore, it can be concluded that this problem is too complex to be solved. Besides this, 24 hours is already too much time for HNS to run the model for one specific week. The reason for this is that the planning department receives the production plan each Monday before 5 a.m. The production plan contains the quantities per product that have to be produced in the next week. Because the resource planners have to allocate the products to the production lines before Tuesday 5 a.m., this means that they have a maximum of 24 hours to allocate the products to the production lines. If a crash of the model occurs or the model cannot find a feasible solution within 24 hours, they do not have a final production plan before Tuesday 5 a.m. Within the model represented before, there exists an enormous number of possibilities to allocate the products to production lines. This is because there are two decision variables that both impact the number of possibilities: 1) the number of colli per product per production line and 2) the sequence of the products that depend on the changeover times between the products and lines. The number of possibilities of the first one is 12 (production lines) times Q_p, which is the number of colli per products. Q_p can have a large range that goes for example from 1 colli to 400.000 colli. The number of possibilities of the second decision variable is 12 (production lines) times the number of products *p1* times the number of products *p2.* Since there are 125 SKUs in a regular week, this number of possibilities will be 12 * 125 * 125 = 187.500. In order to reduce the complexity of the problem to be examined, i.e. to reduce the number of possibilities, the number of products *p* has been reduced from SKU level to product group level. An SKU is based on beer type, bottle type, bottle size, secondary pack type, pallet type, and label. The complexity of the problem has been reduced in terms of the number of SKUs, which entailed that products with the same beer type, bottle type, bottle size, secondary pack type, and pallet type have been categorized in the same group. A further reduction of the number of product groups is not possible since these product properties affect both the resource speed as the changeover times significantly. The label does not affect the production rate of a product nor the changeover times. There are 75 product groups in a regular week, so the number of possibilities of the second decision variable – the sequence of the products that depend on the changeover times between products and lines – is reduced from 187.500 to 67.500. This reduction is done so that the model could remain intact, but after this simplification, the model could still not solve the problem within 24 hours. As a result of this, the model gave the result that there was no feasible solution found. Therefore, it can be concluded that the problem is still too complex due to the first decision variable, which is the number of colli per product per production line. This means that the complexity of the model has to be reduced further. In order to do so, the model has been changed in such way that the number of decision variables is reduced. In the model showed before, there were two decision variables of which one can be removed in the simplified HPA model. To simplify the HPA model the decision variable that determines the number of colli per product per production line will be removed as decision variable. This means that once the processing of a product has started on a production line it cannot be interrupted and the entire quantity of this product needs to be produced on this production line. This simplification reduces the number of possibilities because the model has no longer the ability to determine the quantity – number of colli - per product per production line. This simplification is shown in section 8.4.

8.4 Simplified HPA model

The model given in section 8.2 is able to determine the quantity per product per production line, but it is not able to solve such a complex problem of HNS within 24 hours. This section shows the simplified HPA model, in which the model has no longer the ability to determine the quantity per product per production line. Now it is assumed that when a product is allocated to a production line, the total quantity of this particular product must be produced on that production line. Because one product has to be produced on only one production line it may occur that the total quantity of a product is too large for one production line to be produced as a result of the lack of capacity of that production line. In order to deal with these products, a dummy production line has been introduced to the simplified HPA model. If a product cannot fit on one of the production lines due to the lack of capacity, this product can be allocated to this dummy line by the HPA model, so that the model is able to find a feasible solution. This section will first represent the simplified HPA model and will then explain how to deal with an allocation of a product to the dummy line.

8.4.1 Representation of the simplified HPA model

<u>Sets</u>

K	: Number of production lines plus a dummy line, index *k=1,2,…,12, DummyLine*
P	: Absolute number of products (in colli) to be produced in a certain week, index *p,p1,p2*

P0 : Absolute number of products (in colli) to be produced in a certain week plus a dummy product 0, index *p,p1,p2,0*

Parameters

C_k : Available time for production and changeovers at production line *k* during a certain week (in hours).

$COT_{k,p1,p2}$: The changeover time (in hours) from product 1 to product 2 on production line *k.* For the dummy product *0* the changeover time is zero, $COT_{k,0,p2} = 0$ and $COT_{k,p1,0} = 0$.

M : Is the largest Q_p that exists in the week to be allocated.

$P_{k,p}$: The processing time (in hours) for the production of product *p* at production line *k* after the line has been setup for this, which is calculated by the following formula: $\frac{Q_p}{RS_{k,p}}$.

Q_p : Quantity of product *p* (in colli) to be produced during a certain week.
$RS_{k,p}$: Resource speed of product *p* at production line *k*.

Variables

$ComplO_{k,p}$ *:* Moment in time when *p2* has been produced. This is the calculated amount of time required for product *p* to be completed. The completion time of product *p2* is the processing time of product *p1* plus the changeover time between products *p1* and *p2* plus the processing time of product *p2.*

MS_k *:* Make span of production line *k:* the total time that production line *k* needs for production and changeovers in a week.

TMS *:* Total make span of all production lines together: $\sum_k MS_k$

$Y_{k,p} \in \{0,1\}$ $\forall k \in K, \forall p \in P0$

: 1 is product *p* can technically be produced on production line *k*, 0 otherwise.

Decision variable

$X_{k,p1,p2} \in \{0,1\}$ $\forall p1 \in P0, \forall\, p2 \in P, p2 \neq p1, \forall k \in K$

: 1 if product *p1* is scheduled before product *p2* to production line *k,* 0 otherwise. The variable $X_{k,0,p2}$ is used to specify which product will be processed at first on production line *k*. The variable $X_{k,p1,0}$ is used to specify which product will be processed last at production line *k.*

Min! ***TMS*** **(1)**

s.t.

$$\sum_{k=1}^{K} \sum_{p2 \in P, p2 \neq p1} X_{k,p1,p2} = 1 \qquad \forall p1 \in P \qquad (2)$$

$$\sum_{p2 \in P} X_{k,0,p2} \leq 1 \qquad \forall k \in K \qquad (3)$$

$$X_{k,p1,p2} \leq Y_{k.p1} \qquad \forall k \in K, \forall p1 \in P, \forall\, p2 \in P, p2 \neq p1 \qquad (4)$$

$$X_{k,p1,p2} \leq Y_{k,p2} \qquad \forall k \in K, \forall p1 \in P, \forall p2 \in P, p2 \neq p1 \qquad (5)$$

$$\sum_{p2 \in P0, p2 \neq p1} X_{k,p1,p2} = \sum_{p3 \in 0, p3 \neq p1} X_{k,p3,p1} \qquad \forall p1 \in P, \forall k \in K \qquad (6)$$

$$ComplO_{k,p2} + M * \left(1 - X_{k,p1,p2}\right) \geq ComplO_{k,p1} + P_{k,p2} + COT_{k,p1,p2}$$

$$\forall p1 \in P0, \forall p2 \in P, p2 \neq p1, \forall k \in K \qquad (7)$$

$$ComplO_{k,0} = 0 \qquad (8)$$

$$\sum_{p1 \in P0, p2 \neq p1} \sum_{p2 \in P} \left(P_{k,p2} + COT_{k,p1,p2}\right) * X_{k,p1,p2} = MS_k \qquad \forall k \in K \qquad (9)$$

$$MS_k \leq C_k \qquad \forall k \in K \qquad (10)$$

The objective function (1) minimizes the total make span of all production lines *k*, which is the sum of all production lines *k*.

Constraints (2) ensure that every product is produced.

Constraints (3) ensure that at most one product is scheduled as the first job on each machine.

Constraints (4) and (5) denote that a product can technically be produced on a production line *k*.

Constraints (6) ensure that if a product is scheduled to a production line, then a processor and a successor must exist in the same machine.

Constraints (7) provide a right processing order, avoiding loops. Basically they establish that, if $X_{k,p1,p2}$=1, then the completion time of product 2 *p2* must be greater than the completion time of product 1 *p1.* If $X_{k,p1,p2} = 0$, the constraints become redundant.

Constraints (8) set the completion time of the dummy product to 0, which guarantees in conjunction with constraint (7) that the completion time of all jobs is positive.

Constraints (9) compute the time that the last product is finished on a production line *k*.

Constraints (10) ensure that the total time on a production line *k* does not exceed the capacity of that production line *k.*

It has been determined that for planning purposes a run time of 12 hours is reasonable because the model can run during the night. If a crash occurs, the resource planners have time to run the model again before they have to send the production plan that results from the HPA model to the next department.

It is recommended to use this HPA model based on SKUs and not on product groups. The reason for this is that the simplified HPA model requires that when a product starts on a production line, the production line must first produce the entire product before moving on to the next product. When running the model with product groups, the quantities of the products are greater than or equal to the quantities of the SKUs. Because for product groups the SKUs that only differ in labels will be merged to the same product group. Practice shows that as a result of the increased quantity per product, the HPA model is not able to find a feasible solution. The error in finding a solution occurs due to the quantity of the product groups, which is too large for one production line to produce. The different SKUs within this product group would, therefore, normally be allocated to multiple production lines. In addition to the reasons presented, there is also a more practical reason why SKUs have been recommended instead of product groups. This reason lies in the fact that using product groups requires manual work, which is time-consuming. The data that will namely be used for the HPA model will be gathered from Pluto, the database of HNS, but when working with product groups this is not possible. As the product groups are gathered manually and thus does not exist within HNS yet. Due to the fact that at HNS no product groups exist that are based on beer type, bottle type, bottle size, and secondary pack type, product groups have to be created manually in excel. That is why a link has to be created manually between the product group and the resource speed and changeover times. Since the HPA model is able to find a feasible solution within 12 hours for the SKUs, this way of working is preferred.

As the quantity of an SKU still can exceed the capacity of a production line, a dummy line 'DummyLine' has been introduced to the HPA model with infinite available capacity, e.g. 10.000 hours. How HNS can deal with the products allocated to 'DummyLine' will be explained in the next section.

8.4.2 How to deal with allocation to dummy line

The way HNS has to deal with products allocated on the dummy production line will be explained using an example. Figure 7 shows the allocation of the products in week 10 of 2019 for which the dummy line 'DummyLine' has been used. The product that has been allocated to DummyLine is the SKU-code 123268 and has a quantity of 68.324 colli. This product can technically be produced on production lines HBLYN16A, HBLYN16B, and ZWLYN52.

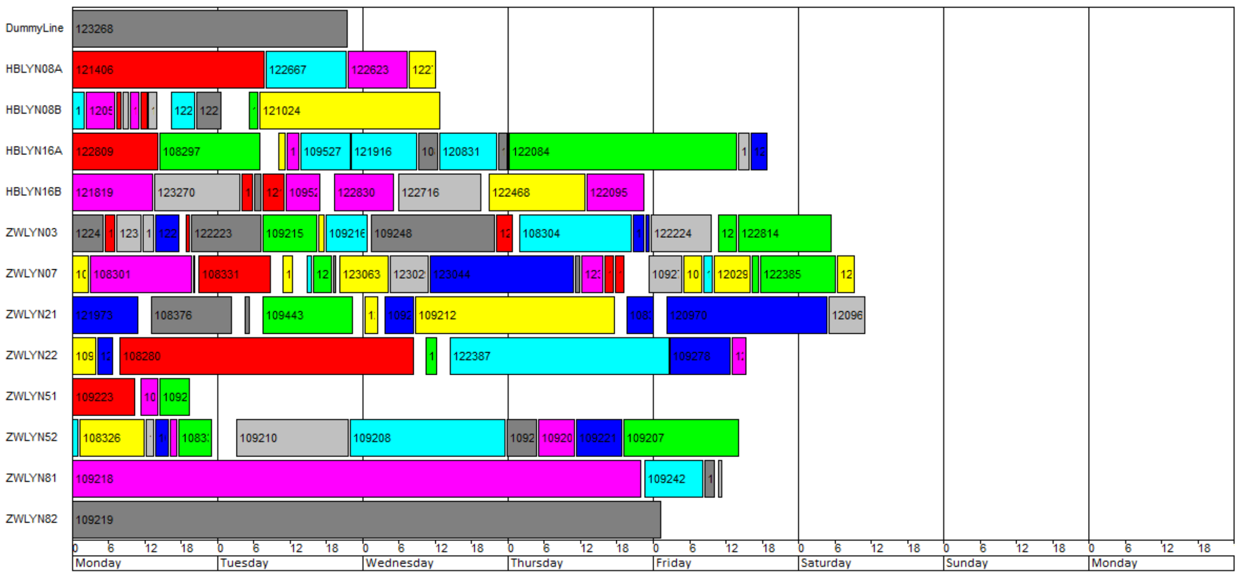

Figure 7. Representation of the allocation by the HPA model for week 10 2019 with dummy line.

If there are one or more products allocated to the dummy line, the following procedure is recommended to be handled by HNS.

First investigate if this product is line specific, which means that it only can be produced on one production line. The changeover time that is needed on this production line to produce this product has to be subtracted from the remaining capacity to see what part of the product can be produced on this production line. The rest of the products that cannot be produced within the capacity of this production line need to be produced in the next week.

If the product allocated to the dummy line is not line specific, then look to the quantity of the product. The simplified HPA model is not able to divide a product over multiple production lines, even though this might be the case in reality. Therefore, look to the remaining capacities of the production lines to which this product can be allocated. The product might be divided over multiple production lines, e.g. SKU 123268 can be produced on three production lines with different resource speeds, which have been shown in table 7.

Production line	Resource speed (colli/hour)	Hours production for 68.324 colli
ZWLYN52	2166.45	31.5
HBLYN16A	1400	48.80
HBLYN16B	1312.5	52.1

Table 7. Resource speed of the production lines of product 121916.

Since ZWLYN52 is the line that is able to produce most colli per hour of this product, it is most attractive to fill this production line as much as possible with this product. The capacity of ZWLYN52 in week 10 is 111 hours of which 110.3 hours have already been used. Because there is less than one hour left, it makes no sense to allocate a part of the product 123268 to production line ZWLYN52 due to changeover times. The production line that is second best is HBLYN16A with a capacity of 148 hours of which 114.9 hours have already been used. A minimum changeover of 90 minutes is required on this production line before this product can be produced on this production line, this means that there are 31.6 hours left for production. In 31.6 hours HBLYN16A is able to produce 44.240 colli of product 123268. The last production line is HBLYN16B which has a capacity of 121 hours available for week 10 of which 94 hours have been used. It can be concluded that there are enough hours available for the production of the remaining 24.084 colli of this SKU.

If this SKU cannot be allocated to the production lines within the available capacity, this means that too much quantity has been demanded. The resource planner can then see how much quantity of the product can be allocated to the production lines this week and the rest of the quantities need to be produced one week later.

8.5 Summary of HPA model

The goal of the HPA model was to optimize the allocation of products to production lines. This HPA model has been developed for HNS in such way that it is generally applicable for all OPCOs of Heineken all around the world. Due to the complexity of the problem of HNS, the original HPA model was not able to solve this problem within a reasonable time of 12 hours. To achieve a solution that is valuable for HNS, the original HPA model needed to be simplified. In order to do so, a simplification has been found in striking the right balance between the theoretical optimum and the practical applicability. The solution of this simplified model might be suboptimal from a theoretical perspective, but should improve the allocation of products to production lines and therefore, will benefit HNS with significant cost savings. The input and output parameters of both the original and simplified HPA model are shown in table 7. The input data used for the simplified HPA model are shown in table 8. The data that has been used comes from the HNS database and has been used for the base situation.

8.5.1 Input and output parameters of the HPA model

Input parameters original HPA model	**Input parameters simplified HPA model**	**Output parameters original HPA model**	**Output parameters simplified HPA model**
Processing time	*Processing time*	*Total production time:* • *Production time* • *Changeover time*	*Total production time:* • *Production time* • *Changeover time*
Capacity available per line (in hours)	*Capacity available per line (in hours)*	*Capacity used per production line (in hours)*	*Capacity used per production line (in hours)*
Changeover time from product 1 to product 2 on a production line	*Changeover time from product 1 to product 2 on a production line*	*Production line to which the product will be allocated to*	*Production line to which the product will be allocated to*
Number of production lines	*Number of production lines*	*Quantity per product that will be produced per production line*	
Number of products	*Number of products*		
Quantity per product	*Demand volume per product*		
Resource speed (production speed) of a product on a production line	*Resource speed (production speed) of a product on a production line*		
Line capability for a certain product	*Line capability for a certain product*		

Table 8. Input and output parameters of the HPA model.

8.5.2 Input data used for HPA model

This section shows the data that has been used as input for the HPA model, which is shown in table 9. For the changeover parameter ($COT_{k,p1,p2}$) multiple input datasets have been used. At HNS the changeovers are not documented from product 1 to product 2 on a certain production line but per product characteristic. The characteristics on which the changeovers are based are beer type, bottle type, bottle size, secondary pack type, and pallet type. Furthermore, a label change takes 20 minutes. But if there is a bottle type change of 120 minutes, a beer type change of 90 minutes and a label change of 20 minutes, the maximum of these changes will be considered to be the changeover time, so 120 minutes. Therefore, the product has been connected to a beer type, bottle type, bottle size, secondary pack type, pallet type and label type in AIMMS.

Input parameter	Input data
$RS_{k,p}$	VW_AS_MAT_PSTEP_RESOURCE
Q_p	VW_PRODUCTIONPLAN
C_k	VW_REPORT_MD_RESOURCE_WEEK
$COT_{k,p1,p2}$ Beer type Bottle type and bottle size Secondary pack type	VW_MD_CHANGEOVER_MATRIX_VALUES (for Zoeterwoude production lines) VW_MD_MAT_SPECIAL (for 's-Hertogenbosch production lines) VW_AS_MATERIAL TB_MD_MATERIAL VW_AS_MAT_PSTEP_MAIN
$Y_{k,p}$	VW_BILL_OF_RESOURCE

Table 9. Input data given per input parameter.

9. Verification and validation

This chapter describes whether or not the model has been built right (verification) and whether or not the right model has been built (validation). Sargent (2013) relates verification and validation in the model development process, which will be used as a guideline for the verification and validation of the model in this research. The model development process described by Sargent (2013) is shown in figure 8.

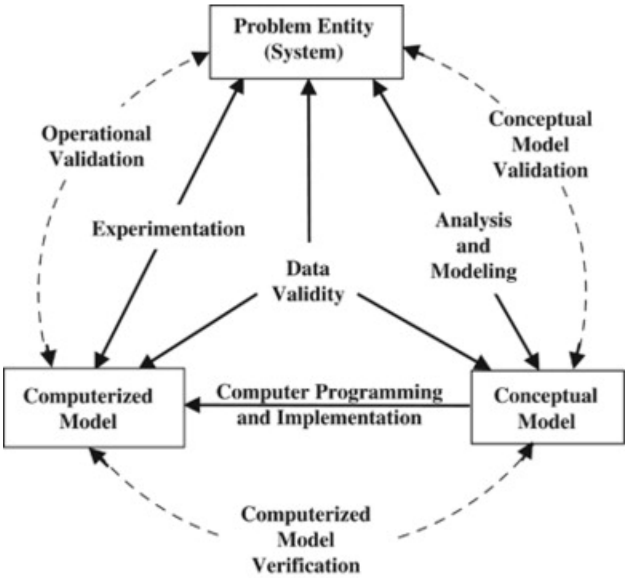

Figure 8. Model development process described by Sargent (2013)

9.1 Data validation

Data validity is ensuring that the data that has been used for building the model is adequate and correct. A list has been kept which shows the files that have been used and can be found in Appendix F. This data has been checked with the IT department of HNS.

9.2 Conceptual model validation

The validation of the conceptual model, the mathematical model represented in chapter 8, can be defined as the correctness of the theories and assumptions of the conceptual model. Furthermore, it determines the model's representation of the problem entity, structure and logic of the model, and whether the mathematical and causal relationships are reasonable for the purpose of the model. In addition to this, the assumptions that have been considered for the model have to be validated in terms of correctness. For this validation, the face validity method has been used. Irobi et al. (2001) describe face validity as asking people, that are familiar with the system if the logic used in the conceptual model is correct and whether or not the input-output relationship is reasonable. Since the model is a simplification of the real problem, there may be neglected aspects that influence the practical optimality of the solution (Sergant, 2013). The conceptual model has been discussed and evaluated in detail with the resource planners and the resource planning manager of HNS. This face validity has been done after the assumptions have been made and before the HPA model is modelled in AIMMS. A second face validity has been done with the same people after the HPA model has been modelled in AIMMS to see if the products allocated by the HPA model makes sense. The resource planners and the manager agreed with the assumptions and setup of the model and they considered the input-output relationship to be reasonable. Furthermore, they agreed that the allocation of the HPA model make sense.

The method that has been used to validate whether the right model has been built is the extreme condition test.

9.2.1 Extreme condition test

The extreme condition test is a technique to test if the model structure and outputs are plausible for any extreme combinations of levels of factors in the systems. The test provides insight into the behavior of the model. In this section, multiple extreme conditions will be checked and discussed.

9.2.1.1 Zero demand check

When the demand for all products is set zero, it is expected that the model allocates no products. After executing this zero demand check in AIMMS, the conclusion could be drawn that no products are allocated and the production time remains zero.

9.2.1.2 Extreme demand values

For the extreme demand value check, the demand values will be ten times the normal demand values in a random week. Since the model cannot have lost sales, it is expected that the model allocates these products to the dummy production line as the capacity of the dummy line is set infinite. The model solved the problem by allocating the products to the regular production lines until the capacities of these lines have been reached, the rest of the products have been allocated to the dummy line.

9.2.1.3 Extreme changeover times

For the extreme changeover times check, the changeover times will be ten times higher than the normal changeover times. With these extreme changeover times, it is expected that the total production time will increase as well and cannot be produced within the capacity of the regular production lines. For example, the changeover time between two products is normally 2 hours, but with the extreme changeover time test this changeover is 20 hours. If a production line has to produce 10 products with a changeover time of 20 hours each instead of 2 hours each, then the total changeover time of this production line in a certain week is 200 hours instead of 20 hours. The test resulted in an allocation where products have first been allocated to the regular production lines until the available capacity of these lines has been reached. The rest of the products have been allocated to the dummy line.

On the other hand, if extremely low changeover times are used, e.g. ten times lower than the normal changeover times, the total production time will decrease. This is confirmed by running the model with changeover times of 0.2 hours instead of 2 hours.

9.2.1.4 Extreme available capacity

As the HPA model has been restricted as a result of the limited available capacity of the regular production lines, an extremely available capacity will influence the production plan. For this test, the available capacity is set extremely high, e.g. 10.000 hours per production line. This has been done for one week to see the influence of the capacity restriction of this week. First of all, the model was able to find a solution with an optimality gap lower than 1% within 100 seconds, which is much faster than the calculating time needed with limited available capacity: 2.74% optimality gap in 40.000 seconds.

Table 10 shows the hours per production line that has been used for production. The first column denotes the production line. The second column denotes the hours used for production per production line when there is limited available capacity, so the real available capacity. The third column denotes the hours used for production per production line when there is an extreme capacity available. This table shows that the total production time with the limited capacity available is 1225 hours per week for all production lines together and 1085 hours when there is an extreme capacity available. As can be seen in table 10, both production lines HBLYN16A and ZWLYN07 use more time than there exist in one week. This has been expected since the resource speed of the production line HBLYN16A and ZWLYN07 have the highest resource speed in combination with the lowest changeover times for most products. ZWLYN 81, ZWLYN82, and HBLYN16B have (almost) not been used when there is an extreme capacity available on the other production lines. This makes sense because these production lines are the slowest production lines for all products. Furthermore, this makes sense since most of the products that can be produced on these production lines can also be produced on HBLYN16A or ZWLYN07. So, when there is enough capacity available, HBLYN16A and ZWLYN07 are then the preferred lines. Products that cannot technically be produced on one of these production lines, will be produced on the production line that can technically produce these products.

Production line	**Number of hours used with capacity restriction**	**Number of hours used with extreme capacity availability**
HBLYN08A	109.75	89.88
HBLYN08B	114.87	69.87
HBLYN16A	127.82	219.32
HBLYN16B	120.57	5.7
ZWLYN03	115.88	115.88
ZWLYN07	130.85	447.25
ZWLYN21	93.98	34.8
ZWLYN22	126.98	46.38
ZWLYN51	100.38	12.55
ZWLYN52	98.38	42.78
ZWLYN81	85.3	0.38
ZWLYN82	0	0
Total time	1225	1085

Table 10. Production time per production line for limited and extreme capacity availability.

9.2.1.5 Extreme resource speeds

The last extreme condition test that has been executed is the extreme resource speed check. An extremely low resource speed leads to long production runs, which means that the demand cannot be produced within the available capacity and the products are expected to be allocated to the dummy line. If the resource speeds are set zero, the model output is expected to give an allocation with zero products, because production can only take place when there is a resource speed. If the resource speeds are set, for example, 20 colli per hour instead of 2000, the production time will increase extremely. This means that the products cannot be produced within the available capacity of the regular production lines. To test this, the resource speeds have been divided by 100. This resulted in the expected solution that the products have been allocated to the regular production lines until the capacity has been reached. The rest of the products has been allocated to the overtime line.

The higher the resource speeds in the HPA model the shorter the production runs. The model has been tested with normal resource speeds and ten times the normal resource speed. It is expected that the production time per product and the total production time of all products together will decrease immensely. To test this, the resource speeds have been multiplied by 100, so from 2000 to 200.000 colli per hour. This leads to an extremely decreased total production time of 18.5 hours instead of 1225 hours.

9.3 Computerized model verification

Sargent (2013) illustrates that computerized model verification ensures that the computer programming and implementation of the conceptual model are correct. The verification of the HPA model has first been done by the checks in AIMMS. Several consistency checks are already built in AIMMS. AIMMS checks the consistency of the units and formulas that have been used during the programming phase. AIMMS uses the unit specified in the function to check the unit consistency. If a unit has been programmed incorrectly, then AIMMS will give a warning report. Furthermore, AIMMS will verify the number of arguments in the formulas and whether or not the arguments and results are consistent with the specified domains and ranges. Moreover, AIMMS helps to check the consistency of all the constraints in the model. The AIMMS verification has been taken place after the introduction of each new parameter, variable, or constraint. In addition, if there is an overlap in the input data, AIMMS will give a warning report, e.g. product 29 has a net resource speed of 2500 colli per hour and 2000 colli per hour on production line 7.

Furthermore, after each run, the total time for 2 random production lines has been calculated by hand: the production run per product plus the changeover time from that product to the next. In all cases, the total time of the production line was equal to the time provided by the HPA model.

9.4 Operational validity

“Operational validation is determining whether the simulation model’s output behavior has the accuracy required for the model’s intended purpose over the domain of the model’s intended applicability. This is where much of the validation testing and evaluation take place.” (Sargent, 2013). According to Sargent (2013), there are multiple validation techniques that can be used for operational validity.

For the HPA model, the scheduling tool that is used by HNS has been used for the operational validity. The OS department of HNS uses the Advanced Scheduling (AS) tool for determining the sequence of the products at particular production lines. The input data needed for using AS are the production quantities per product, the production week, and the production line to which the products are allocated. Then, AS puts the products in the best sequence based on changeovers. To check whether the allocation of the HPA model is correct, the output data of the HPA model has been used as input for AS and AS has been run. This has been done to check whether the same production time is needed per product and per production line and if the capacity per production line has not been exceeded. After running five weeks and checking all production lines for these five weeks it could be concluded that the HPA model functions as expected.

9.5 Summary verification and validation

The results of all extreme condition tests were in line with the expectations of the behavior of the HPA model. Furthermore, if the number of possibilities for the model to allocate the products decreases due to significant differences in input parameters, the run time of the model will decrease as well. The computerized model verification confirmed that the model has been implemented correctly in AIMMS and the operational validity concluded that the HPA model functions as wanted.

10. Insights for HNS

The insights which have been generated for HNS through this research will be described in this chapter. The purpose of the HPA model was to be applicable to all OPCOs of Heineken, but only the data of HNS has been used for the development and testing of the model. The first section of this chapter shows how the HPA model has been allocating products to the production lines of HNS in one week of 2019 compared to how this has been done by the planning departments of HNS. Furthermore, this chapter shows the time and cost savings that could have been obtained in 2019 when using the HPA model instead of the "common sense" based method. Due to fire and flooding, there were five weeks where there was no production at one of the breweries of HNS, so these weeks have been excluded. The total production time of the allocations is compared with the total production time used by the planning departments of HNS for the same weeks to show whether or not the model could save time and costs.

10.1 Allocation of the HPA model vs current method

In order to show the differences in allocation between the HPA model and the "common sense" based method of HNS, one random week has been picked to highlight these differences in this chapter. The last column of Appendix J shows that there are a few weeks with big differences, of around 100 hours, in allocation time between the HPA model solution and the solution of the current method. Week 32 has been chosen randomly out of the weeks with this big difference. In addition to the comparison of both allocation methods, the seventh and last research question, which reads, '*Which product has to be produced on which production line to fulfill the demand in lowest possible time at lowest possible costs?'* will be answered.

This research question can directly be answered with the production line that has to produce a certain product to fulfill the demand in the lowest possible time at the lowest possible costs varies between weeks. This can be explained through the fact that the quantities of a product vary between weeks and every week there is a different product portfolio that has to be produced. Therefore, production week 32 will be discussed elaborately in terms of which product has to be produced on which production line compared with the allocation done by the current method.

What is important is to know that in week 32, the total capacity in hours that can be used for production and changeovers per production line is shown in figure 9. The downtimes and the unmanned time have been subtracted from the 168 hours, i.e. HBLYN08A has 51 hours of downtime or unmanned time, which means that there are 117 hours available for production. But as can be seen in figure 10 HBLYN08A is not used for 117 hours by the HPA model for production, only 54 hours have been used at this production line. This can be declared by the fact that HBLYN08A has a relatively low resource speed compared to the other production lines. So, if there are products that can be produced on other production lines than HBLYN08A, the model will first try to allocate them on these other lines.

ResourceCode	
DummyLine	100000
HBLYN08A	117
HBLYN08B	117
HBLYN16A	122
HBLYN16B	122
ZWLYN03	119
ZWLYN07	133
ZWLYN21	152
ZWLYN22	148
ZWLYN51	104
ZWLYN52	109
ZWLYN81	110
ZWLYN82	101

Figure 9. Representation of the capacity in hours available in week 32 in 2019.

The HPA model allocated week 32 such that there are 1134 hours needed for the production of the entire demand for that week, which is called the 'Best Solution' in AIMMS. The 'Best Solution' is the objective value of the best integer feasible solution that the solver was able to find. Besides the 'Best Solution', AIMMS also provides the 'Best LP Bound' which is the best possible objective value the solver could theoretically obtain. In week 32 this has been given to be 1097 hours. For the 'Best LP bound', the constraints have been relaxed, which means that the integrality constraint of each variable is removed. So, instead of only containing integers the solution may also contain fractions of the integers. The gap between the 'Best Solution' and the 'Best LP Bound' is the optimality gap, which is 3.25% after running the model for 12 hours. The optimality gap is defined by Marquant et al. (2015) as the difference in percentages between the best solution and the best Linear Programming (LP) relaxation of the problem. The planning departments of HNS allocated the same quantities of the same products of week 32, but such that there are 1232 hours needed for the production of the entire demand. As a result of the comparison of the two methods, a conclusion can be drawn that the HPA model needs 98 hours of production time less than the current allocation method of HNS.

It is interesting to compare the production allocation of the HPA model with the allocation using the current method of HNS for the same week, which are shown in respectively figure 10 and 11. The number combinations in the colored blocks in these figures represent SKU-codes used by HNS. An SKU-code is a specific product based on beer type, bottle type, bottle size, secondary pack type, pallet load, and label. Furthermore, the white blocks between two colored blocks represent the changeover time between these products.

In order to highlight the differences in allocation between the HPA model and the current allocation method of HNS, these products have been outlined with the color that is associated with the production line. The color of the products that have been outlined corresponds to the production line to which the products have been allocated by the current allocation method of HNS. To better understand this, an example will be given. There are two products that have been allocated by the HPA model to production line HBLYN08A, while they have been allocated by the planning departments to HBLYN16B. As a result, these products have been outlined in red, see figure 10, which corresponds to HBLYN16B, as can be seen in figure 11.

First of all, due to the small production time of multiple products, the SKU-codes are not represented well in figures 10 and 11. Therefore, an appendix has been created, Appendix G, showing per production line which SKU-code has been allocated to this line by both the HPA model and the current allocation method of HNS.

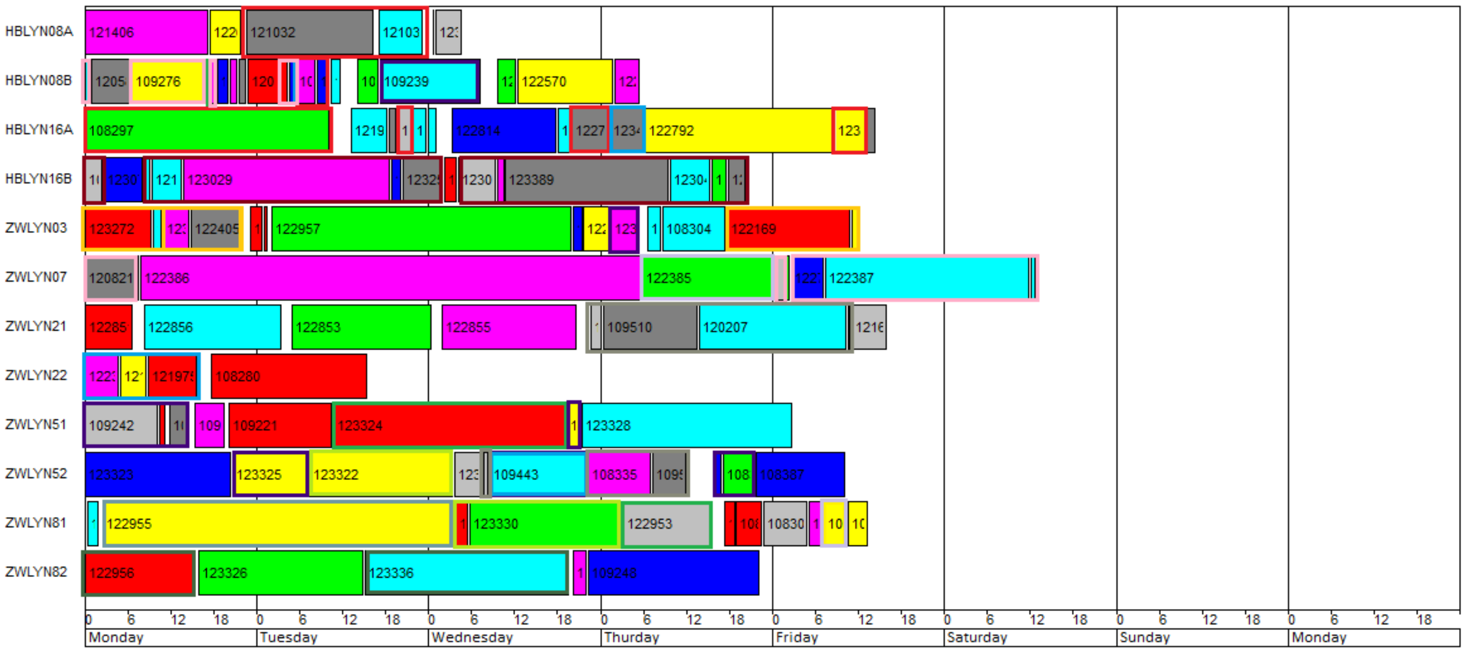

Figure 10. Representation of allocation done by HPA model for week 32 of 2019.

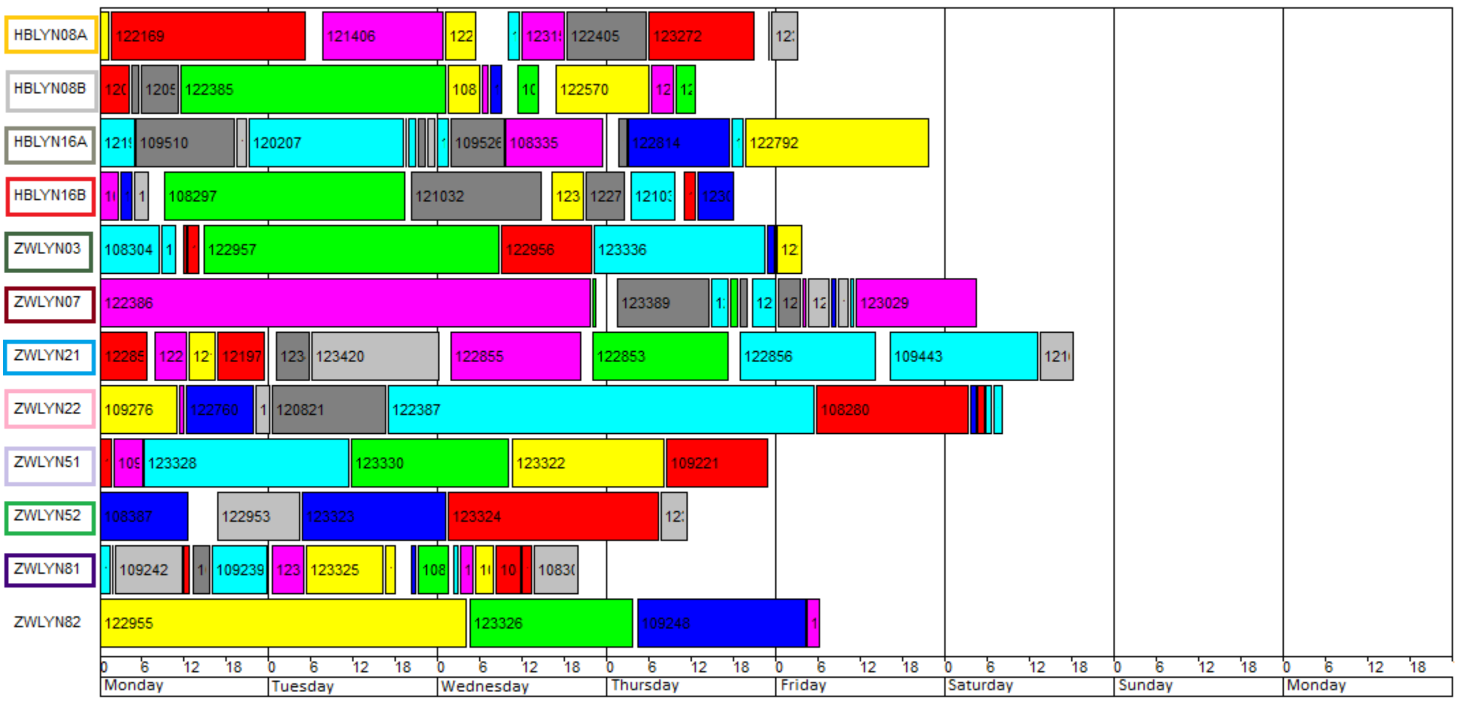

Figure 11. Representation of allocation done using the current allocation method of HNS for week 32 of 2019.

One of the first things that can be noticed when comparing figures 10 and 11 is that the planning departments of HNS use more than five days of production at ZWLYN22, while the HPA model uses only one day of production at the same production line. One of the products allocated to ZWLYN22 using the current allocation method is the product with SKU-code 122387, which has been allocated by the HPA model to ZWLYN07. This product is exactly the same as the product with SKU-codes 122385 and 122386, they only differ in label. These products can be produced with a resource speed of 1537 colli per hour on production line ZWLYN22, 1400 colli per hour on production line HBLYN08B and 3220 colli per hour on ZWLYN07. The HPA model allocated all three products to production line ZWLYN07, which takes 7028 minutes, so 117.13 hours. Using the current method of HNS, product 122387 has been allocated to production line ZWLYN22, 122385 to HBLYN08B and 122386 to ZWLYN07. This production of the current method takes in total 10089 minutes, which is 168.15

hours. The difference in the allocation of these three products between the HPA model and the allocation of the current allocation method is 51.02 hours. This major hourly difference is a clear indication of how the HPA model can be used as an optimization tool for the allocation of products to production lines.

When highlighting the differences in allocation for the HPA model and the current method, it is key to acknowledge that 69 out of 124 of the allocated products were allocated differently by the two methods. In the case of week 32, the 69 different allocated products lead to a difference of 98 hours on the production lines. Two of these 69 products were already mentioned that cost 51 hours. The other 67 differently allocated products lead to a difference of 47 hours, which is a substantial difference considering the total production hours of 1232 that HNS used this week.

A major finding that became clear after conducting this analysis was that 14 out of 16 products allocated to production line ZWLYN07 by the current method were allocated to HBLYN16B by the HPA model. As a result of this, more space will be free at production line ZWLYN07 for the allocation of 650 cl bottles – with the SKU-codes mentioned before '122385', '122386', and '122387' - that have a resource speed of 3219 colli per hour, which is the fastest resource speed of all production lines at HNS.

A comprehensive analysis showed that the planning departments of HNS allocated 330 cl and 355 cl bottles with the regular Heineken beer to the following three production lines ZWLYN52, ZWLYN81, and ZWLYN51. However, the HPA model showed that ZWLYN52 could best be used for 330 cl and ZWLYN51 for 355 cl. ZWLYN81 can then be used for both 330 cl and 355 cl that do not fit within the capacity of the other two production lines. Showing these differences to the resource planning manager he agreed that in this way the changeovers could be reduced. Furthermore, he agreed that ZWLYN52 is the best production line for 330 cl while ZWLYN51 is the best for 355 cl.

The analysis of week 32 in 2019 showed that the HPA model allocated 69 out of 124 products different than the current allocation method of HNS did. These differences in allocation led to an improved allocation of 98 hours. In order to be able to draw conclusions on the real improvement of the HPA model compared to the current allocation method, 46 more weeks of 2019 have been compared. The results of this comparison will be discussed in the next section.

10.2 Time savings over 2019

In order to investigate whether or not the production time and costs could have been reduced, the HPA model has been compared with the current allocation method of HNS. The data of 2019 has been used since this is the most recent year and nothing out of the ordinary happened in this year - no new lines were introduced and no new planners were appointed to the bottle oneway pack type, making the data reliable for comparison. The 47 compared weeks have been summarized in Appendix J. Using the information of this comparison, the conclusion could be drawn that 2635 hours could have been saved in 2019 when HNS used the HPA model for the allocation instead of the current method.

10.3 Summary about insights of HNS

This chapter discussed the insights that have been gained from this research for HNS. Using the data of HNS and the information that has been given in this research, the first main question ***'Does a mathematical planning model result in a better allocation of products to production lines in order to save time and costs?'*** can be answered. The HPA model improves the allocation of products to production lines which saved 2635 hours of the production time seen throughout 2019. 2635 hours over 2019 is a saving of 4.4%, which could lead to a saving of €800.000 according to the finance department of HNS.

11. Implementation of HPA model

The main recommendation is to replace the current “common sense” based method by the HPA model for the allocation of products. Therefore, this chapter will discuss the steps that are needed for the implementation of the HPA model at HNS.

First of all, the manager Supply Chain Planning (SCP) has to approve the HPA model to replace the current allocation method. At HNS there is no standard decision process for this, so the SCP manager has to make this decision himself.

To ensure the resource planners are able to work with the HPA model and understand the model well, a work instruction has been made in which the model has been explained in detail. Besides the work instruction, an intensive training has been given to the HNS supervisor of this project and the project leader of Planning Excellence (PLEX) about how to use the model and how the model functions based on the work instruction. PLEX is a project of HNS to improve the planning. Together with the SCP manager, it has been determined that the project leader of PLEX will be the owner of the HPA model within HNS. When the SCP manager approves the HPA model to replace the current production allocation method, an intensive training ought to be given to the resource planners of HNS. This training includes running the HPA model for the quantities of next week together with the resource planners. If the SC department of HNS is going to use a new tool, there will always be a transition period. It is recommended to use both the current and the new tool during this transition period. This means that after the training the HPA model will be used as a planning tool in addition to the current production allocation method for five weeks. After this period, the resource planner manager, in consultation with the resource planners, determines whether the HPA model will be used as the planning tool in the future. During the first months of using the model the resource planning manager and the resource planners should exchange thoughts about the tool. During this evaluation phase, the resource planners can give their opinion on the model and how the model functioned in the past three months.

12. NPI allocation process

This chapter focuses on the allocation process of new product introductions (NPI) and will answer the second main question ***'What steps should be considered to determine the allocation of an NPI to a production line?'***. This question will be handled using the BPO approach of HNS, which consists of 5 steps displayed in figure 12.

Figure 11. Business Process Optimization (BPO) approach of HNS (PLAN-NA-PRO-BPO Approach-July2014, HNS)[11].

The *Process selection* step consists of defining the scope and objective of the project to understand the process to be analyzed. The scope of this part of the project includes new products that can be assigned to one or more production lines. The *Current state* step will identify the current NPI allocation process which will be handled in the next section. From the *Current state* step the opportunity to improve will be defined using literature studies and the knowledge of the employees of HNS. Based on the insights of the *Identify opportunity* step, the *Future state* will be developed. Using this BPO approach, the steps that should be considered to improve the allocation of an NPI to a production line can be determined.

12.1 Current NPI allocation process

In order to understand the process of new products to be introduced at HNS, an introduction to this will be given. The process of an NPI starts with the Market Business Partners (MBP) who receive an application form from their market. These application forms are wishes of and/or needs for new products introductions (NPI). These forms will be added to the NPI community SharePoint by MBP as a new NPI. Those NPIs are discussed every Monday by MBP and the head NPI project manager, who will then decide whether or not this new product will be introduced at HNS.

To answer the main question, two research questions have been formulated of which the first one is *'What are the elements that are taken into account at the moment for the allocation of an NPI?'.* This is the fifth research question of this project. To determine what the elements are at the moment for allocating an NPI, the current NPI allocation process needs to be clear. For the development of the current NPI allocation process a focus group has been taken place with the three planning departments of HNS: SCD, TSCP, and OS. The focus group started with a discussion tackling a question regarding the current NPI allocation process. An interesting finding that can be deducted from the first discussion was that employees from different planning levels were not informed about what the job and its responsibilities of other planning level employees within the NPI allocation process entailed. The NPI process is made up of several stages, but due to the length and scope of this research, the focus will be limited to specific steps. These steps include the ones tackled by the department of planning since the research is narrowed down to supply chain planning.

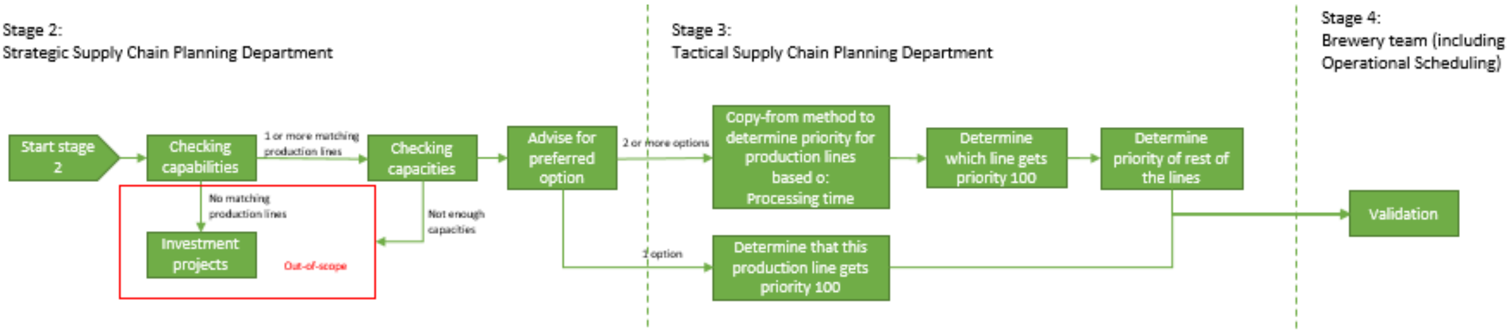

Figure 12. Process of stage 2, 3, and 4 of the NPI process, which is created in a focus group with the three planning departments.

Now this process will be described in more detail. Stage 2 of the NPI process starts with the SCD checking the existing capabilities of the production lines and whether they match with the capabilities of the NPI. The capabilities will be checked on beer type, bottle type, bottle size, secondary pack type, and pallet load. An important remark to be made is that beer type is never the bottleneck, because a new beer type can be introduced to an existing production line at all times. For the introduction of a beer type, no additional costs have to be taken into account. At the moment, when there is a production line that matches all capabilities, this production line will be chosen directly. After the capabilities have been checked, the capacities of these production lines will be checked on both line specific volume and total pack type check. Line specific volume is the percentage of volume (hl beer) that can only be produced on a specific production line. HNS has a rule that the line specific volume may not exceed 70%. In case the line specific volume exceeds the 70%, the NPI cannot be allocated to this production line or that the entire product portfolio of the lines has to be adapted. This percentage has been set due to the fact that production lines need a certain flexibility of producing other products. For the total pack type check SCD determines whether the capacity of all production lines of the NPI pack type together are able to produce the volume of the NPI based on the current volumes. Subsequently, the NPI supply chain specialist of SCD will give an advice for the preferred production lines. In case just one option has been given, TSCP directly concludes that the NPI will be allocated to this production line. The preferred production line then gets a priority of 100, which is the best priority and, therefore, the product will always be allocated to this production line until the priorities will be reallocated. In case SCD gives two or more preferred options, then TSCP uses the copy-from method to determine the priority of the production lines. The copy-from method means that they look for products that have similar capabilities as the NPI to determine the resource speed of the product on the different production lines. They compare, for example, a product that only differs in secondary pack type or beer type to determine the resource speed. Based on this resource speed, the priorities will be determined. The TSCP department determines that one line gets priority 100 and then they determine the priority of the other production lines for the NPI. After the priorities have been set, the allocation of the NPI to a production line has been determined. In stage 4 the validation process takes place, which entails that the NPI will be tested on the production line with priority 100. After three test runs have been done, the NPI will not be considered as an NPI anymore but as an existing product. Based on this information it can be concluded that four distinct elements are taken into account at the moment when allocating an NPI to a production line are. The first element is existing capabilities of the production lines, the second is the line specific volume of the production lines, the third is the capacity of all production lines of the pack type of the NPI, and the last element is the priorities of the product group.

Due to the fact that the process was not documented yet prior to the research, an overview of the process had to be created in order to get a clear depiction of it and visualize the elements that ought to be improved. In order to improve it, the missing elements were zoomed in on by systematically comparing each element with the existing literature on the matter, taking the elements into account which HNS finds especially important.

12.2 Elements of NPI allocation

To answer the main question, also the second research question, which is the sixth research question of this project, needs to be answered which reads *'What does the developed NPI allocation process look like?'.* Before this question can be answered, the most important elements for the NPI allocation process have to be determined which will be done in this section. Therefore, a second focus group took place with the same participants of the first one to discuss the element that should be taken into account. Furthermore, the elements identified from literature have been reviewed in this focus group. Details about this second focus group can be found in Appendix I.2.2. A third focus group followed in order to be able to answer the second research question. In this focus group the elements, that are not part of the NPI allocation process at the moment, have been discussed whether or not to introduce them to the NPI allocation process. More details about the last focus group can be found in Appendix I.2.3

In order to improve the process, every element affecting the allocation that has been identified from literature has been discussed systematically during the focus group, whether or not it is part of the current NPI allocation process. Furthermore, four elements have been mentioned by the participants that they consider to be important to include in the NPI allocation process, which are currently not used by HNS. These elements can be found in table 11 in the column 'Other important HNS elements' and will be discussed in more detail after the table. Furthermore, table 11 shows the elements identified from literature in the column 'Element' and the column 'HNS already' describes whether or not HNS is currently using this element for allocating an NPI to a production line and in which stage it is used. The column 'authors' portrays the author of the article in which the specific element has been discussed.

Element	**Authors**	**HNS already**	**Other important HNS elements**
Processing time	Lee and Pinedo (1997)	Processing time – stage 3 (copy-from method)	
Sequence-dependent changeover times	Lee and Pinedo (1997)		Changeover
Idleness is not allowed	Lee and Pinedo (1997)	Idleness is not allowed: if a machine is ready, it has to start with the next product in line without remaining idle.	
Jobs/products are weighted of importance	Lee and Pinedo (1997)	No	

Sequence- and machine-dependent changeover times	Avalos-Rosales et al. (2013)		Changeover
Machine can handle one product at a time	Avalos-Rosales et al. (2013)	Machine can handle one product at a time – stage 2	
Availability of jobs at time zero	Rabadi, Morgana and Al-Salem (2006)	Jobs are available at time zero – stage 2, 3 and 4	
Machine-dependent production speed	Rabadi, Morgana and Al-Salem (2006)	Machine-dependent production speed – stage 3	
Number of products	Rabadi, Morgana and Al-Salem (2006)	No	
Number of machines	Rabadi, Morgana and Al-Salem (2006)	No	
Recipe	Kallrath (2002)	Beer type, bottle type, bottle size, secondary pack type – stage 2 and 3	
Production quantities	Kallrath (2002)	Production quantities – stage 2	
Overtime	Kallrath (2002)	Yes, the production lines that are not fully-continuous can be scaled up (increase the time that the production line is available for production) – stage 1 (checking capabilities)	
Capacity restriction: limited availability of production line	Kallrath (2002)	Capacity restriction (capacity of all production lines of pack type) – stage 2	
Continuous or batch production systems	Kallrath (2005)	Continuous production systems – stage 2	
Single-or Multi-purpose (multi-product) production lines	Kallrath (2005)	Multi-product production lines – stage 2	

Finite intermediate storage	Kallrath (2005)	No	
Deterministic dynamic demand	Meyr (2002)	Deterministic dynamic demand	
Capabilities of production lines	Meyr (2002)	Capabilities of production lines – stage 2	
Lost sales/penalty costs	Meyr (2002)	No	
Planning horizon	Lukaç (2008)	Copy-from method – stage 3 (how often will this product be produced in a certain time period?)	
Satisfy demand per period	Lukaç (2008)	Satisfy demand per period – stage 2	
Parallel, identical production lines	Lukaç (2008)	Only parallel, non-identical production lines – stage 2	
Cyclic production	Budé (2008)	Copy-from method – stage 3 (how often will this product be produced compared to the products that are similar?)	
Fixed production sequence	Budé (2008)	No	
			Actual production plan
			Reduce complexity of NPI
			Forecast

Table 11. Elements that are taken into account by the literature for allocating a product to a production line.

After the elements have been discussed in the second focus group, the third and last focus group with the three planning levels took place. In this focus group, each element which is currently not part of the NPI allocation process will be discussed below and points have been made as to whether or not those have to be introduced.

Changeover

The changeovers at HNS differ between the sequence of the product and depend per production line, but are currently not taken into account for deciding which production line has to produce an NPI. As the changeover time does impact the total production time significantly, it has been decided in the third focus group that this should be taken into account when allocating an NPI. In chapter 12.3 the developed NPI allocation process will be represented and the changeovers will thus be part of that process.

Products are weighted of importance

At the moment the products are not weighted of importance, which means there is no prioritization among products. If there is not enough capacity to produce the entire demand for the next week, the resource planners either determine which products will not be produced or they have to decrease the quantity of products. During the focus groups, it became clear that some products are more important than others, namely those which always have to be on the shelves of the shops. Therefore, HNS should make a list of products that always have to be produced when they are demanded to avoid shortages of these products. Furthermore, when an NPI is allocated to a production line, the NPI should be weighted according to their importance and thus a prioritization of the NPI has to be introduced to the NPI allocation process.

Number of products and number of machines

The number of products and the number of machines influence the complexity of the problem. The number of products is taken into account for the NPI allocation process as HNS wants to produce the entire demand at a particular production line. Furthermore, the number of production lines does not affect the allocation of an NPI as the number of production lines is fixed.

Finite intermediate storage

Finite intermediate storage means that the storage capacity available for an intermediate is limited. At HNS, when a product does not leave the production facility as a final product, it directly goes to the outsourcing partner who will then finalize the product. This is because HNS has an agreement with its outsourcing partners that they can be flexible in delivering the semi-finished products. As a result of this, the finite intermediate storage element does not have to be taken into account for HNS nor for the NPI process. As a result of this information the finite intermediate storage is concluded not to be a constraint for HNS.

Lost sales

When there is a capacity shortage on the production lines, HNS is not able to produce the entire demand of a specific week which results in lost sales. When the production of HNS cannot meet the demand, they inform certain customers that they are not able to produce the products in the next week and that the production will be delayed with one week. The products that cannot be produced in that specific week will be produced in the week after. The possible delay of one week is described in the contracts that HNS has with some of their customers. Besides this, the element lost sales does not further impact the allocation of an NPI to a production line and will therefore not be considered in the developed NPI allocation process.

Fixed production sequence

At the moment HNS is not using a fixed production sequence, which means that the production sequence may vary every week. Since this is one of the flexibilities that HNS handles for its production plan, this will not be introduced in the NPI allocation process.

Actual production plan

The participants of the focus group agreed that the actual production plan should be taken into account when allocating an NPI to a production line. The actual production plan shows an overview which products have actually been produced on a certain production line in the past. Practice shows that even when a product can technically be produced on a certain production line, it may not be the preferred line to produce the NPI due to, for example, changeovers. Therefore, the actual production plan will be introduced to the NPI allocation process.

Reduce complexity of NPI

At the moment, the customers of HNS can request an NPI and compile it themselves on NPI level, which means that they can choose the beer type, bottle type, bottle size, secondary pack type, and pallet. Practice shows that some customers are indifferent to, for example, the type of pallets, which results in a randomly choice of a pallet. But for HNS the pallet type can make a difference in the complexity of an NPI to produce. In order to handle the complexity of the NPI, two ways to deal with this were mentioned in the focus group. The first suggested solution is when there is a complex NPI requested by the customer this has to fed back to the customers in order to see if the complexity of the NPI can be reduced. An NPI is considered to be complex when it is difficult to produce, for example, a pallet type that can only be produced on one production line. Furthermore, an NPI is considered to be complex when the product can only be produced on a production line with a high line specific volume (>70%). The participants of the focus group think that in this way there is an opportunity that the customers change, for example, the pallet to make the NPI less complex. The second suggested solution is to reduce the NPI option that the customers have from NPI level (beer type, bottle type, bottle size, secondary pack type and pallet) to portfolio level (beer type, bottle type and bottle size). If this suggestion will be executed, then the first suggestion is not needed anymore. Based on the discussion in the focus group, it is recommended to reduce the NPI option to portfolio level instead of NPI level. This will not be introduced into the NPI allocation process, but will be a recommendation towards HNS.

Forecast

At the moment HNS does not use the forecast of an NPI to determine to which line the NPI will be allocated. In the focus group one participant suggested to introduce the forecast of an NPI to be part of the NPI allocation process as the volume of the NPI might be of importance for the allocation. But the other participants did not agree as practice shows that the forecast of an NPI is not accurate enough to base the allocation on. This has further been discussed in the focus group and all participants finally agreed not to incorporate this in the NPI allocation process.

After all elements have been discussed in the third focus group, the new NPI allocation process could be developed, which answers the sixth research question. This developed NPI allocation process will be discussed in the next section.

12.3 Representation of the developed NPI allocation process

This section represents the developed NPI allocation process, which answers the sixth research question: ‘*What does the developed NPI allocation process look like?’.* Based on the third focus group, the important elements for the decision of the right allocation of an NPI have been identified. These elements have been introduced to the NPI allocation process. After the developed NPI allocation process was created, this was fed back to the participants of the focus group to check this for one last time.

Three elements have been introduced to the NPI allocation process in order to improve this process. The first introduced element is the changeover time, which has been introduced within a step of the process that already existed, called the ‘copy-from method to determine priority for production lines’. Before, this step was only based on the resource speed, but as of now it should also include the changeover times of this product on the production lines. The second added element is that products have to be weighted of importance, which has been introduced in the second stage of the NPI allocation process. This means that the Supply Chain Development (SCD) department has to take this step into account in the future. They have to base the importance of producing the NPI on the entire product portfolio. If the NPI increases in volume (hl) then it is recommended that SCD reconsiders the weight of importance of this product. The last introduced element is to compare the allocation with the actual production plan, which has been introduced in stage 3 of the NPI allocation process. The allocation should be reconsidered when there are significant differences.

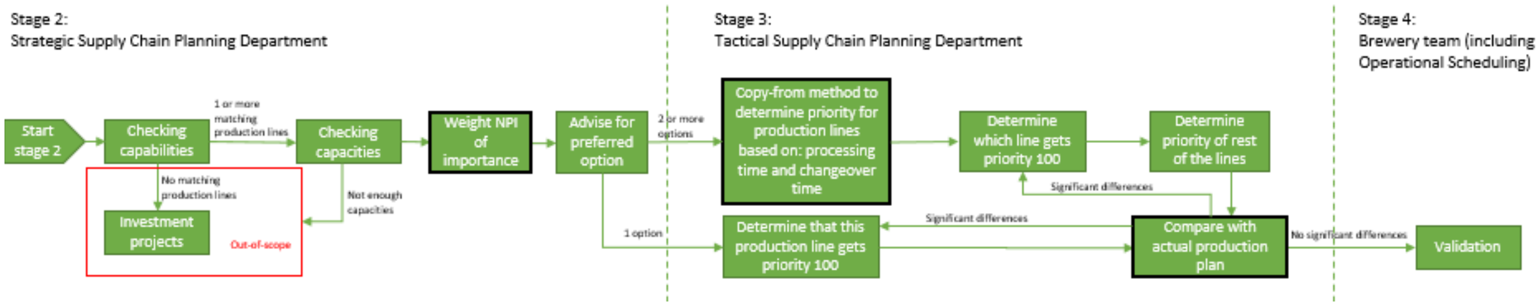

Figure 13. Developed NPI allocation process.

Besides the recommendations to implement the three elements mentioned before in the NPI allocation process, there is one more recommendation to make. This is to reduce the complexity of an NPI level (beer type, bottle type, bottle size, secondary pack type and pallet) to portfolio level (beer type, bottle type and bottle size). As a result of this, the NPIs requested by the customers will be limited in terms of complexity.

In order to test whether the developed NPI allocation process is an improvement or not, it is recommended to use this process for the allocation of the NPI that has been described in the introduction, *Amstel Bright 355 CL*. This way, it can be concluded whether the allocation of the developed NPI allocation process is better than the allocation process HNS has been using until now. However, the reaction of HNS showed that they are enthusiastic about the developed process. Moreover, HNS will try to adapt the application forms of an NPI so that a customer has no longer the ability to choose for complex NPIs.

12.4 Summary of NPI allocation process

This chapter was focused on answering the second main question of this research, which reads, ***'What steps should be considered to determine the allocation of an NPI to a production line?'***. In order to answer this question, first the current NPI allocation process needed to be documented, which has been done in the first focus group. In the second focus group, the elements found in literature have been reviewed systematically whether or not they are currently taken into account at HNS. The elements that are currently not part of the NPI allocation process have been discussed in the third focus group whether or not this element has to be introduced in the NPI allocation process. Based on the literature and the focus groups, three elements are highly recommended to include in the NPI allocation process to improve this process. The first element that needs to be added is to weight the importance of the NPI, the second element is changeovers, and the last added element is to compare the allocated NPI to actual production plans.

13. Conclusions and recommendations

This chapter first describes the conclusions that can be derived from this research. Furthermore, it contains the recommendations that can be made after conducting this research.

13.1 Conclusions of the research

The main aim of this research was twofold and consisted of two main questions. First of all, this report studies the optimization of allocating products to production lines. The main question that comes with this is ***'Does a mathematical planning model result in a better allocation of products to production lines in order to save time and costs?'.*** Based on this research it can be concluded that HNS can improve the allocation of products to production lines with 4.4% in time based on 2019. This amounts to 2635 hours production time less than the current production allocation method. Saving this amount of production time results in a cost saving in the packaging process of around €800.000 in 2019 according to the finance department of HNS. In order to optimize the allocation of products to production lines a decision support tool has been developed in AIMMS, which is called the Heineken Production Allocation (HPA) model. It was decided that a reasonable run time for the model was 12 hours, because the model can run during the night. The original HPA model was not able to solve the problem within 12 hours due to the complexity of the problem and, therefore, a simplified HPA model has been developed. Because this simplified model is restricted to produce the entire quantity of a product on one production line, it can be concluded that the solution given by this model might be suboptimal. But the outcomes of running the HPA model 45 weeks of 2019 showed that the simplified HPA model improved the allocation of products to production lines at HNS.

The second topic of this report studies is the allocation of new products to existing production lines. The main question related to this topic reads ***'What steps should be considered to determine the allocation of NPI to a production line?'***. Based on literature studies, reviews of the current NPI allocation process, and focus groups, it can be concluded that the NPI allocation process can be improved by introducing three elements to the current NPI allocation process. Before this conclusion can be confirmed, the developed NPI allocation process needs to be tested. The first element that needs to be added is to weight the importance of the NPI in the second stage of the NPI process, the second is to include changeovers in the third stage of the NPI process, and the last added element is to compare the allocated NPI to actual production plans in the third stage of the NPI process. This actual production plan shows an overview of which products have actually been produced on a certain production line in the past.

13.2 Recommendations

This section first describes the recommendations based on the first topic, which is the allocation of existing products to existing production lines. Thereafter, the recommendations based on the second topic, the allocation process of new products to existing production lines, will be discussed.

13.2.1 Recommendations to improve allocation of existing products

The main recommendation to HNS is to replace the current "common-sense" based production allocation method by the scientific HPA model proposed in this research in order improve the allocation of existing products. The steps that should be followed for the implementation of the HPA model at HNS have been explained in chapter 11.

Before the implementation of the HPA model, it is recommended to first start with showing the HPA model to an AIMMS expert, as it takes time to get to know all the features and still not all features of AIMMS are known. The expert should investigate the improvements which can be made in the 'hard programming language' of the model, in the settings of AIMMS, and which license fits the needs of

HNS and the HPA model best. This is important because of a couple of reasons. First of all, this is important to determine whether the run time of the model can be reduced. Secondly, it is key in investigating whether the original HPA model could be solved in order to bring the solution of the HPA model as close as possible to the theoretical optimal solution.

The HPA model has been created on an HP Elitebook laptop with a memory of 16 gigabytes (GB). Furthermore, the laptop that has been used has a 'i5 @ 2.40 GHz' processor of Intel. Intel has four types of processors, i3, i5, i7, i9, of which i9 is best. According to AIMMS, both the processor and memory of the laptop influence the speed of which the AIMMS model is able to find a solution. The specifications of the laptop used have been discussed with an AIMMS expert and he concluded that a laptop with a better processor and more memory could reduce the run time of solving the problem. Therefore, the second recommendation in order to implement the main recommendation is to use a laptop with a faster processor (i9) and with at least 32 GB of memory.

The third recommendation in order to replace the current allocation method by the HPA model is that the input data for the model is available automatically in one data file to make the HPA model more user friendly.

The resource planning manager needs to determine how the HPA model can be integrated in the weekly planning process. The fourth recommendation to HNS is to use the HPA model within the production allocation process after the production plan has been made. This means that three steps in the current production allocation process can be replaced by the HPA model, which are 'allocate products to production lines', 'read production plan into Advanced Scheduling (AS)', and 'OS makes schedule'.

13.2.2 Recommendations to improve NPI allocation process

The main recommendation in order to improve the allocation of NPIs is for HNS to use the developed NPI allocation process instead of the current NPI allocation process.

In order to use this developed NPI allocation process, it is first recommended to use both the current and developed NPI allocation processes for the next NPIs. The solution of these processes can be compared to see if there are differences in allocation between the processes. Based on these differences, it can be determined whether the developed NPI allocation process has improved the allocation compared to the current NPI allocation process.

To improve the allocation of NPIs further, the second NPI allocation recommendation is to introduce an NPI to the HPA model. Before the HPA model can be used for an NPI, the input data for the NPI has to be determined since these are not known beforehand. The input data can be identified by using the copy-from method, which has been explained in the developed NPI allocated process.

The last recommendation related to NPI allocation is to reduce the complexity of an NPI. It is recommended that the customer cannot compile the NPI on NPI level anymore, which is beer type, bottle type, bottle size, secondary pack type, and pallet load. But instead, the customer can only compile the NPI on portfolio level, which is beer type, bottle type, and bottle size.

14. Reflection

This chapter reflects on the performed research. First the contribution of this research to the literature will be discussed. Secondly, the limitations of this research will be described. And lastly, ideas for further research following this current research will be presented.

14.1 Contribution to literature

The upcoming section describes the research's contributions to scientific literature. None of the articles found in literature discusses the problem of parallel, non-identical production lines with sequence- and machine0dependent changeovers. Therefore, the contribution to scientific literature is based on the combination of the elements that have been incorporated in the HPA model to improve the allocation of products to production lines.

Most articles discuss problems in which the production time of a product is the same regardless of the production line on which it is produced. The problem that has been discussed in this research includes products that have different resource speeds on different production lines. This means that the production time of a product differs per production line.

Moreover, only a few articles deal with parallel, non-identical production line problems. This research deals with parallel, non-identical production lines as the production lines have different capabilities. This means that not every product can technically be produced on all production lines. In the articles where this problem is discussed, sequence-dependent changeovers are often considered at a lower level or in a separate sub model. Besides this research focuses on parallel, non-identical production lines, it also considers sequence-dependent changeovers.

On top of sequence-dependent changeovers, this research also takes into account that the changeover time between two products depends on the production line on which the products will be products. This is called machine-dependent changeover times and is barely dealt with in the literature before.

The problems dealt with in literature were less complex than the case of HNS because of the number of production lines and products. These problems are easier to solve than the problem that has been handled in this research with 12 production lines and about 125 products each week on average. Therefore, a conclusion can be drawn that the HPA model is able to solve problems that are by far more complex, which is also a contribution to the literature.

Additionally, an overview of the elements that are important for or affect the allocation of (new) products to production lines is never given in the literature. A near to complete overview is provided in this research.

14.2 Limitations and future research

Throughout the research several limitations can be identified from the research and several directions for further research will follow.

Based on the assumption that the resource speed per production line is constant per product for the planning horizon of one week, the first limitation can be described. As a result of the performance of the production line, the resource speed can be lower or higher than the time used in the model, which can influence the production time. When the production time of a product is significantly higher than expected, this can lead to products not being able to be produced within the capacity of a certain week anymore. When the production time of a product is significantly lower than expected, this results in extra products that can be produced within the available capacity.

It has been assumed that there is no restriction on storage space as this has never been a bottleneck and the storage capacity has been taken into account in the production plan. However, in the rare case that there is no storage space, HNS will have to rent storage by a third party, which will cost five times more than using the storage space at HNS. In order to prevent these high costs, HNS employees try to be creative. A perfect example of this was when the 's-Hertogenbosch brewery used part of their parking lot once as storage space. This can be considered as the second limitation.

Based on the assumption that there is no restriction on material, beer availability, or inventory, the third limitation can be described. When a certain product has been allocated at the beginning of the week, but the material supplier is not able to deliver the materials before this moment in time, this product cannot be produced at the allocated time. As a result of this, the entire allocation needs to be adapted because of the material being delivered too late. This does not count for beer availability and inventory since these factors are in their own management. An interesting topic for future research would be to find out whether it would be possible to establish a link between the material planning system and the HPA model. Through such a link, the HPA model would be able to take material shortages into account while making the production plan, which ultimately leads to the further optimization of the process.

The HPA model has only been tested in the case of HNS. The goal of the research is the for HPA model to be applicable for all OPCOs of Heineken. Based on information of HNS, it has been assumed that there are no restrictions on storage, material, beer, and inventory for the development of the HPA model. If one of these elements is a bottleneck within another OPCO, it will influence the reliability and usability of the allocations resulted from the HPA model. Therefore, the fact that the HPA model has only been tested for HNS can be seen as the fourth limitation. It is interesting to further investigate what the full potential of savings can be for all OPCOs of Heineken whilst using the HPA model for the allocation of products. To use the model for other OPCOs, the elements that seem to be bottlenecks at these OPCOs need to be investigated in more detail. If there are bottlenecks such as storage or material, these have to be incorporated in the model.

The fifth limitation is based on the assumption that the overtime requested by the TSCP department is needed for the production. As TSCP has to request the overtime two weeks in advance, the overtime is already arranged before the HPA model is even used for allocation. In an ideal situation, the overtime can be arranged one week in advance so that the HPA model can determine whether and how much hours of overtime are needed. Future research may therefore further explore this ideal situation because in this way extra costs can be saved.

The sixth limitation that has been encountered during this research is the complexity of the problem of HNS, due to the number of products and the number of production lines. This complexity led to the original HPA model not being able to solve within 12 hours. In order to solve the problem, the model has been simplified with the restriction that one product needs to be fully produced on one production line. It can be interesting to further investigate if the requirement of only producing one product in full on one production line can be dropped.

The seventh limitation is related to the NPI allocation process as the developed process has not been tested on the allocation of a real NPI. Based on literature studies and focus groups, it is expected that the developed process improves the allocation of NPIs, but to be sure, this process has to be tested with real NPIs.

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Appendix A. List of abbreviations and definitions

Appendix A.1 List of abbreviations

APT	Available Production Time
AS	Advanced Scheduling
BCSC	Business Controller Supply Chain
BPO	Business Process Optimization
cl	Centiliters
CSE	Customer Service Export
EWT	Effective Working Time
GB	Gigabytes
hl	Hectoliters
HNS	Heineken Nederland Supply
HPA	Heineken Production Allocation
IP	Integer Programming
LP	Linear Programming
MES	Manufacturing Execution System
MILP	Mixed Integer Linear Program
ml	Milliliters
MTO	Make-To-Order
MTS	Make-To-Stock
NPD	New Product Development
NPI	New product introduction
OPCO	Operating company
OPI	Operational Performance Indicator
OS	Operations Scheduling
PLEX	Planning Excellence
SC	Supply Chain
SCD	Supply Chain Development
SCP	Supply Chain Planning
SLR	Systematic literature review

SKU	Stock Keeping Unit
S&OP	Sales & Operations Planning
TSCP	Tactical Supply Chain Planning
USA	United States of America

Appendix A.2 List of definitions

Available production time	The time that can be used for both production and changeovers.
Changeover time	The time that is needed to change the production line from producing product A in producing product B
Full continuous production line	A production line is able to produce 24 hours day, 7 days a week.
Machine-dependent changeover time	Set of operations that should be performed on a production line after processing a product to prepare it for processing the next product, these times depend not only on the product that will be processed, but also on the product processed just before. The time of this set of operations can be different per production line.
Manned time	Total time minus the unused time, the time that a production line is available for production. The manned time is also called gross hours.
Planned downtime	The time that is taken into account for the production line to stop.
Primary pack type	Shape in which the beer touches the packaging material. For example: a bottle oneway of 330 milliliter Heineken.
Production capability	The ability of a production line to produce a certain product.
Production plan	The final plan that the resource planners of the TSCP department deliver, which determines the allocation of the products to be produced to the production lines. In the production plan, the material-, beer- and inventory restrictions are already taken into account.
Resource speed	The production speed of how many boxes per hour the production line can produce.
Seasonal cycle	The time period which incorporates all demand peaks and in the following periods (of the same length) the same pattern in the demand peaks can be seen

Secondary pack type	Packaging of the primary pack. For example: 18 bottles of 330 milliliter in a crate.
Sequence-dependent changeover	Set of operations that should be performed on a production line after processing a product to prepare it for processing the next product, these times depend not only on the product that will be processed, but also on the product processed just before.
Setup time	The time that is needed for the production line to start and terminate the production at this line.
Tertiary pack type	The different loading forms that HNS has: mechanistic - the products are not on a pallet; palletized - the products are on a pallet; Conventional - the products are on a pallet, but cannot go directly into a container.

Appendix B. Fixed costs of the production process of HNS in 2018

Fixed Expense components	Fixed Expenses/HL	Fixed Exp. HNS	Personnel	Depreciation	R&M	Other Fix.	3rd party services	Energy & Water
Brewing costs	€ 1,22	€ 22 mln	€ 9 mln	€ 7 mln	€ 6 mln	-	-	-
Packaging costs	€ 4,33	€ 78 mln	€ 52 mln	€ 15 mln	€ 11 mln	-	-	-
Primary warehouse costs	€ 1,85	€ 33 mln	€ 12 mln	€ 3 mln	€ 3 mln	€ 3 mln	€ 12 mln	-
Total	€ 7,40	€ 133 mln	€ 73 mln	€ 25 mln	€ 20 mln	€ 3 mln	€ 12 mln	

Table 12. Fixed costs of the internal process of HNS in 2018.

Appendix C. Pack types and production lines of HNS

As mentioned in chapter 6.1, HNS has 26 production lines and six pack types. Table 13 shows which pack type is produced on which production line in which brewery. The six pack types can be described as follows (HNS, 2018)[11]:

1. Bottle oneway: bottles that will be throw in the glass container after use;
2. Bottle returnable: the bottles that can be returned, mainly in the Netherlands and Germany;
3. Cans;
4. Draught keg: a keg of 5 liters;
5. Air keg: inflatable bag of 8 liters (blade) or 20 liters (brew lock) that you can connect to a tap;
6. Keg: 10, 20, 30 and 50 liters.

Brewery	**Production line name**	**Pack type**
Wijlre	BRLYN01	Bottle returnable
	BRLYN02	Keg
's-Hertogenbosch	HBLYN08A	Bottle oneway
	HBLYN08B	Bottle oneway
	HBLYN14	Keg
	HBLYN15A	Bottle returnable
	HBLYN15B	Bottle returnable
	HBLYN16A	Bottle oneway
	HBLYN16B	Bottle oneway
	HBLYN17	Can
	HBLYN24	Can
Zoeterwoude	ZWLYN03	Bottle oneway
	ZWLYN06	Can
	ZWLYN07	Bottle oneway
	ZWLYN09	Keg
	ZWLYN11	Bottle returnable
	ZWLYN12	Bottle returnable

[11] Reference derived from the intranet (nonpublic access) from HNS.

	ZWLYN21	Bottle oneway
	ZWLYN22	Bottle oneway
	ZWLYN41	Draught keg
	ZWLYN42	Draught keg
	ZWLYN43	Air keg
	ZWLYN51	Bottle oneway
	ZWLYN52	Bottle oneway
	ZWLYN81	Bottle oneway
	ZWLYN82	Bottle oneway

Table 13. Production lines with the pack types that fit on these lines in the three breweries of HNS.

Appendix D. External workers

This figure shows per packaging line the actual number of workers in 2018 and the external hours that were needed to fulfill the demand.

Row Labels	FTE Actual	External Hours
PC2150 Zoeterwoude Packaging	3,21	70,7
PC2151 Zoeterwoude lijn 11 Fles retour lijn	45,59	16.615,1
PC2152 Zoeterwoude lijn 12 Fles retour lijn	7,61	556,5
PC2156 Zoeterwoude lijn 52 Fles eenmalig lijn	29,58	17.118,9
PC2157 Zoeterwoude lijn 7 Fles eenmalig lijn	42,11	11.995,4
PC2158 Zoeterwoude lijn 6 Blik lijn	33,90	8.382,9
PC2159 Zoeterwoude lijn 9 Fust lijn	5,00	3.770,2
PC2160 Zoeterwoude lijn 30 Fles eenmalig lijn	29,84	7.715,0
PC2163 Zoeterwoude line 41 - Draughtkeg	26,15	22.536,5
PC2166 Zoeterwoude line 81 - One way bottles	37,52	19.162,1
PC2168 Zoeterwoude Overhead rayon 1	6,47	0,0
PC2169 Zoeterwoude Overhead rayon 2	6,69	0,0
PC2170 Zoeterwoude lijn 2 Fles eenmalig lijn	46,42	17.557,3
PC2171 Zoeterwoude Overhead rayon 3	4,50	0,0
PC2172 Zoeterwoude lijn 51 Fles eenmalig lijn	21,76	2.998,3
PC2173 Zoeterwoude Overhead rayon 4	8,45	687,9
PC2178 Packaging - Overhead rayon 5	25,89	0,0
PC2179 Packaging Airkeg line 43	21,71	12.304,7
PC2250 Den Bosch Packaging	21,45	0,0
PC2251 Den Bosch lijn 16a Fles eenmalig lijn	43,32	8.903,6
PC2253 Den Bosch lijn 8a Fles eenmalig lijn	43,03	17.473,8
PC2256 Den Bosch lijn 15a Fles retour lijn	51,79	16.558,8
PC2258 Den Bosch lijn 11 Blik lijn	11,13	0,0
PC2259 Den Bosch lijn 17 Blik lijn	24,99	13.767,4
PC2260 Den Bosch Lijn 14a Keg	4,62	2.289,3
PC2270 Den Bosch Packaging overhead rayon 3	8,63	1.007,6
PC2271 Den Bosch Packaging overhead rayon 1	6,65	1.600,2
PC2274 Den Bosch Packaging overhead rayon 2	5,51	0,0
PC2275 Den Bosch lijn 24 blik lijn	34,40	5.030,8
PC2350 Brand Packaging	2,12	1.255,2
PC2351 Brand lijn 01 Flessenlijn	16,01	1.427,3
PC2352 Brand lijn 02 Fustenlijn	2,84	801,0
Grand Total	**678,87**	**211.586,3**

Figure 14. External hours in the packaging process of HNS in 2018.

Appendix E. Setup time per production line

Production line	AANLOOP	AFLOOP	TOTAAL		
ZWLYN09			0	ZWLYN	Production line at Zoeterwoude
ZWLYN11	1	8	9		
ZWLYN12	2	8	10		
ZWLYN07	1,5	3	4,5		
ZWLYN51	2	4	6		
ZWLYN52	2	4	6		
ZWLYN81	1,5	3	4,5		
ZWLYN82	1,5	3	4,5		
ZWLYN06	0	0	0		
ZWLYN41	0	0	0		
ZWLYN42	0	0	0		
ZWLYN43	0	0	0		
ZWLYN21	0	0	0		
ZWLYN22	0	0	0		
ZWLYN03	2	2	4		
				HBLYN	Production line at 's-Hertogenbosch
HBLYN17	0	0	0		
HBLYN24	0	0	0		
HBLYN15A	1	4	5		
HBLYN15B	1	4	5		
HBLYN08A	1	4	5		
HBLYN08B	1	4	5		
HBLYN16A	1	4	5		
HBLYN16B	1	4	5		
HBLYN14	0	0	0		
BRLYN01				BRLYN	Production line at Brand brewery Wijlre
BRLYN02					

Figure 15. Setup time per production line (Star_masterdata_downtimes, HNS)[12]

[12] Reference derived from the intranet (nonpublic access) of HNS.

Appendix F. List of used data files

Data file	
VW_PRODUCTIEPLAN	Input data for the quantities per product to be produced
VW_REPORT_MD_RESOURCE_WEEK	Input data in AIMMS for the planned downtimes per week
VW_AS_MATERIAL	Link in AIMMS with an SKU-code and beer type for the production lines in Zoeterwoude
TB_MD_MATERIAL	Link in AIMMS with an SKU-code and product type and with product size for the production lines in Zoeterwoude
VW_AS_MAT_PSTEP_MAIN	Link in AIMMS with an SKU-code and secondary pack type for the production lines in Zoeterwoude
VW_AS_MAT_PSTEP_RESOURCE	Input data for the resource speed per product per production line in colli per hour
VW_MD_CHANGEOVER_MAT_SPECIAL	Link in AIMMS with an SKU-code and a product description of the production lines in 's - Hertogenbosch
VW_MD_CHANGEOVER_MATRIX_VALUES	Link in AIMMS with beer type, bottle type, bottle size and secondary pack type and the changeover times between them.

Table 14. List of data files used in this research.

Appendix G. Product allocated to production line

This appendix shows the which product has been allocated to which production line by the HPA model and by the planning departments of HNS.

Appendix G.1 Products allocated by HPA model for week 32

ResourceCode	Product	
HBLYN08A	121406	☑
HBLYN08A	121027	☑
HBLYN08A	121031	☑
HBLYN08A	121032	☑
HBLYN08A	122283	☑
HBLYN08A	122638	☑
HBLYN08A	123091	☑
HBLYN08B	108301	☑
HBLYN08B	108331	☑
HBLYN08B	108360	☑
HBLYN08B	108367	☑
HBLYN08B	109239	☑
HBLYN08B	109276	☑
HBLYN08B	109285	☑
HBLYN08B	120403	☑
HBLYN08B	120584	☑
HBLYN08B	121968	☑
HBLYN08B	122189	☑
HBLYN08B	108283	☑
HBLYN08B	109533	☑
HBLYN08B	123380	☑
HBLYN08B	123382	☑
HBLYN08B	120121	☑
HBLYN08B	122570	☑
HBLYN08B	122676	☑
HBLYN08B	122679	☑
HBLYN16A	108297	☑
HBLYN16A	108336	☑
HBLYN16A	108457	☑
HBLYN16A	122814	☑
HBLYN16A	122380	☑
HBLYN16A	122754	☑
HBLYN16A	123419	☑
HBLYN16A	121905	☑
HBLYN16A	121993	☑
HBLYN16A	122792	☑
HBLYN16A	122805	☑
HBLYN16A	123171	☑
HBLYN16A	123352	☑

HBLYN16B	109153	☑
	120941	☑
	121612	☑
	123029	☑
	123044	☑
	123075	☑
	123078	☑
	123106	☑
	122652	☑
	123080	☑
	123090	☑
	123162	☑
	123257	☑
	123389	☑
ZWLYN03	108304	☑
	108388	☑
	122366	☑
	122405	☑
	123154	☑
	122169	☑
	122362	☑
	122363	☑
	122364	☑
	122448	☑
	122957	☑
	123272	☑
	123433	☑
	123327	☑
ZWLYN07	108358	☑
	122385	☑
	122386	☑
	122387	☑
	109591	☑
	120574	☑
	120821	☑
	122760	☑

ZWLYN21	108376	☑
	108337	☑
	109510	☑
	120207	☑
	121605	☑
	122851	☑
	122853	☑
	122855	☑
	122856	☑
ZWLYN22	108280	☑
	121973	☑
	121975	☑
	122314	☑
ZWLYN51	109211	☑
	109220	☑
	109221	☑
	109240	☑
	109242	☑
	109243	☑
	123324	☑
	123328	☑
ZWLYN52	108315	☑
	108335	☑
	109443	☑
	109526	☑
	108303	☑
	108353	☑
	108387	☑
	123321	☑
	123323	☑
	123325	☑
	123322	☑

ZWLYN81	108277	☑
	120018	☑
	122683	☑
	108276	☑
	108281	☑
	108302	☑
	108394	☑
	109246	☑
	122953	☑
	122955	☑
	123329	☑
	123330	☑
ZWLYN82	109248	☑
	109249	☑
	122956	☑
	123336	☑
	123326	☑

Figure 16. Products allocated by HPA model per production line in week 32.

Appendix G.2 Products allocated by planning departments of HNS for week 32

ResourceCode	Product	
HBLYN08A	121406	☑
	122405	☑
	123154	☑
	122169	☑
	122448	☑
	123272	☑
	123433	☑
	121027	☑
	122283	☑
	122638	☑
	123091	☑
HBLYN08B	109285	☑
	120403	☑
	120584	☑
	121968	☑
	122189	☑
	122385	☑
	108394	☑
	120121	☑
	122570	☑
	122676	☑
	122679	☑
HBLYN16A	108315	☑
	108335	☑
	108336	☑
	108376	☑
	108457	☑
	109526	☑
	122814	☑
	108337	☑
	109510	☑
	120207	☑
	122380	☑
	121993	☑
	122792	☑
	122805	☑
	123352	☑

HBLYN16B	⊟	108297	☑
		108301	☑
		123078	☑
		109533	☑
		122754	☑
		123080	☑
		121031	☑
		121032	☑
		121905	☑
		123171	☑
ZWLYN03	⊟	122956	☑
		123336	☑
		108304	☑
		108388	☑
		122366	☑
		122362	☑
		122363	☑
		122364	☑
		122957	☑
ZWLYN07	⊟	109153	☑
		120941	☑
		121612	☑
		122386	☑
		123029	☑
		123044	☑
		123075	☑
		123106	☑
		109591	☑
		122652	☑
		123090	☑
		123162	☑
		123257	☑
		123389	☑

ZWLYN21	⊟	109443	☑
		121973	☑
		121975	☑
		121605	☑
		122314	☑
		122851	☑
		122853	☑
		122855	☑
		122856	☑
		123419	☑
ZWLYN22	⊟	108280	☑
		108358	☑
		108360	☑
		108367	☑
		109276	☑
		122387	☑
		120574	☑
		120821	☑
		122760	☑
		123380	☑
		123382	☑
ZWLYN51	⊟	109211	☑
		109221	☑
		123329	☑
		123330	☑
		123322	☑
		123328	☑
ZWLYN52	⊟	108331	☑
		108387	☑
		122953	☑
		123321	☑
		123323	☑
		123324	☑

ZWLYN81	108277	☑
	109220	☑
	109239	☑
	109240	☑
	109242	☑
	120018	☑
	122683	☑
	108276	☑
	108281	☑
	108283	☑
	108302	☑
	108303	☑
	108353	☑
	109243	☑
	109246	☑
	123325	☑
	108386	☑
	123327	☑
ZWLYN82	109248	☑
	109249	☑
	122955	☑
	123326	☑

Figure 17. Products allocated by the planning departments of HNS per production line in week 32.

Appendix H. Details about the interviews

This appendix shows more details about the interviews that have been held during this research.

Appendix H.1 Details about the unstructured interview

The first interview that has been held was for qualitative research and was an unstructured interview. The goal of this interview was to investigate why HNS wanted this research and what could be improved at HNS. The following three people were involved in this unstructured interview:

1. Sales & Operations Planning manager (S&OP): Steven Drenth;
2. Resource planning manager: Ruud van Oost;
3. Business Controller Supply Chain (BCSC): Sander Nijman.

The S&OP and resource planning manager have been initiated this research at HNS, since they encountered this specific problem in their work. The BCSP was present at the interview for the financial background of the problem. The company supervisor of this research, the S&OP manager, started with an introduction about the problems within the Supply Chain Planning (SCP) of HNS. This is explained in the introduction and problem statement of this research. Furthermore, he explained the problems that were encountered within the NPI allocation part of the SCP of HNS. The resource planning manager, Ruud van Oost, provided a short introduction of the current way of working of the resource planners and why this was not optimal. Then the BCSC told that there were 211.586 hours of external workers paid in 2018. So, when the demand could have been produced in a reduced time, those external workers were not necessary in the future. The total duration of this interview was two hours and a half, since the information about the problem needed to be clarified by answering questions of the researcher.

Since this interview was an unstructured interview, no questions have been prepared in advance.

After the problem was formulated based on this unstructured interview, the formulated problem was fed back to the participants of the focus group to determine whether it was understood right.

Appendix H.2 Details about the semi-structured interview

The second interview that has been held was to inform the interviewees about the subject of a focus group, which is explained in appendix I.1. Furthermore, this semi-structured interview was held to gain more information about the current way of working of the interviewees. A semi-structured has been chosen because as it consists of several key questions that help to define the areas to be explored and it allows the interviewer or interviewee to diverge in order to pursue an idea or response in more detail (Merton et al., 1990). During these semi-structured interviews the interviewee is asked to explain the steps to be taken to come to the production plan.
This interview has been taken place with the three resource planners of HNS:

1. Peter Grundmann;
2. Merel van Engelshoven;
3. Paul Wennekes.

The semi-structured interviews with the three resource planners have been held separately from each other. First the interviewer explained the subject of the focus group: the current way of working of the production allocation process. The following questions were prepared before the start of the interview and have been asked to all three resource planners:

1. Can you explain in detail the steps you take for the planning of the products?
2. Is this process the same for every pack type?
3. Is this process the same for each week?
4. Do you think you colleague resource planners have the same way of working as you have?
5. What factors do you think that are important for the allocation of products to production lines?

The first interview has been held with Peter Grundmann and took two hours. The second interview was held with Merel van Engelshoven and took one hour and a half. The third interview was held with Paul Wennekes and took two hours.

The difference in time was because Merel van Engelshoven took the researcher/interviewer through the process stepwise, which made the process easy to understand. The other two resource planners had more difficulty with explaining the process stepwise.

Therefore, the total duration of the three interviews was five hours and a half.

Appendix I. Details about the focus groups

This appendix shows more details about the focus groups that have been held during this research.

Appendix I.1 Details about the current production allocation process focus group

The first focus group consist of three resource planners:

1. Peter Grundmann;
2. Merel van Engelshoven;
3. Paul Wennekes.

This focus group has been held to create an overview of the allocation process within HNS. Before this focus group interviews have been taken place with the resource planners separately about the processes and decisions of each planner. These processes and decisions have been evaluated in the focus group to see whether or not there are differences in the process between the planners. Furthermore, the crucial factors for the allocation of products according to the planners have been discussed. The total time that was used for the focus group was 2 hours. After the current production allocation process was created based on the information of both the semi-structured interviews and the focus group, this process was showed to the same people to check whether it was created right.

Appendix I.2 Details about the NPI allocation process focus group

For the NPI allocation process three focus group have been taken place and will be handled in this research separately.

Appendix I.2.1 NPI allocation process focus group one

The first focus group within the NPI allocation process was to investigate the current NPI allocation process of HNS. This process consists of three stages within the planning departments of HNS. The tasks in the first stage are within the responsibility of SCD, in the second stage of TSCP, and in the last stage of OS and the brewery team. Besides these people, also the NPI project head and a Market Business Partner (MBP) were part of the focus group. A Market Business Partner has the responsibility to have contact with clients for example when they apply for an NPI. Therefore, this focus group consisted of the following departments and persons:

1. Supply Chain Development (SCD): Siebe Brinkhof and Steven Drenth;
2. Tactical Supply Chain Planning (TSCP): Ruud van Oost and Suzam Oomen;
3. Operational Scheduling (OS): Joke Blom;
4. NPI project head: Rob Tummers;
5. Market Business Partner (MBP): Pim van de Laar.

As mentioned in chapter 12, the employees had no idea of the tasks done by other employees in other stages. During the focus group, they were asking questions to each other, which was the reason the focus group took four hours.

Appendix I.2.2 NPI allocation process focus group two

The second focus group about the NPI allocation process has been initiated to review the elements found in literature about the allocation of (new) products. But first the overview of the current NPI allocation process that was created in the first focus group has been reviewed again. Furthermore, the elements that are important for HNS according to the participants of the focus group have been discussed in this second focus group.

The same participants as in the first focus group consisted in this second focus group. The total time that this focus group took was around three hours.

Appendix I.2.3 NPI allocation process focus group three

The third and last focus group discussed the elements whether or not they have to be introduced to the process. With the information of this focus group a developed NPI allocation process has been introduced and recommendations have been made.

As the first and second focus group, also the last focus group consisted of the same participants. The total time of this focus group was around two hours. Similar as for the other focus groups and interviews, the developed NPI allocation process too was reviewed for one last time with the participants of the focus group to assess whether or not everything was understood well.

Appendix J. Results HNS planning vs HPA model

The first column of Appendix J is the week in which the production has to take place. The hours represented in the second column are the hours that are needed for the production in that week when using the allocation of the planning departments of HNS. The hours represented in the third column are the hours that are needed for the production in the same week when the HPA model determines the allocation of the products. In the fourth column, a percentage has been displayed that represents the percentage hours the planning of HNS needed more time for the production than the planning of the HPA model.

Week	Planning HNS (in hours)	Planning with HPA model (in hours)	Difference between planning HNS and planning HPA Model
201901	838	806	32
201902	1129	1114	15
201904	903	887	16
201905	757	752	5
201906	1123	1062	61
201907	1259	1205	54
201908	1341	1295	46
201909	1368	1261	107
201910	1320	1293	27
201911	1308	1246	62
201912	1382	1339	43
201913	1339	1267	72
201914	1404	1383	21
201916	1282	1225	57
201918	1359	1302	57
201919	1411	1318	93
201920	1429	1368	61
201921	1402	1371	31
201923	1391	1308	83
201924	1327	1263	64
201925	1402	1310	92

201926	1428	1383	45
201927	1334	1287	47
201928	1431	1388	43
201929	1363	1359	4
201930	1416	1324	92
201931	1331	1268	63
201932	1232	1134	98
201933	1378	1346	32
201934	1317	1301	16
201935	1347	1296	51
201936	1266	1252	14
201937	1300	1248	52
201938	987	956	31
201940	1171	1118	53
201941	1308	1265	43
201942	1339	1245	94
201943	1333	1258	75
201944	1238	1148	90
201945	1260	1234	26
201946	1268	1225	43
201947	1276	1172	104
201948	1242	1144	98
201949	1132	1046	86
201950	1209	1103	106
201951	1141	1087	54
201952	1188	1112	76

Table 15. Representation of time (in hours) needed for production of the total demand determined by HNS planning department vs. the HPA model in certain week of 2019.

Appendix K. Explanation of the production allocation process of HNS

As can be derived from figure 6, the first step of this process is 'read orders and forecast into excel', which can be considered as the demand. The demand is given in colli, which are either boxes or crates. This consists of three demand types: Make-To-Stock (MTS), Replenishment, and Make-To-Order (MTO). MTS is a forecast for the Dutch market, while Replenishment is the forecast for the most important export markets. Those export markets are the markets that affect the production of HNS: United States of America (USA), Taiwan, and France. MTO are the orders placed by customers and the forecast combined. The forecast of MTO is an indication of the demand for the coming year and the orders are the actual demand. Since the allocation planning is partly based on forecast, the actual demand can be different. Each week new demand data is available and will be used for the next production planning. The second step of the process is the planning based on cyclicities, beer types, and the timetable. For the cyclicities, the resource planners pay attention to products that can be produced more efficiently in fixed cycles, for instance, Amstel Radler 0.0 is only produced in the odd weeks with a fixed cycle of two weeks. The third step is focused on resource planners making the production plan, which is afterwards checked on production capacity and beer availability. The production plan contains information on which products are being produced, how many are being produced, and in which week they are produced.

Then, the material planners are reading the production plan into AIMMS and see if the needed materials are available. If there are material or storage restrictions, these will be applied to the production plan for the coming week. Examples of material restrictions are that the material is not available. When all the restrictions are processed, the resource planners will look at the consequences for the production plan, in other words, they will look at the gaps in the production plan which are there due to the restrictions. These gaps will be filled in order to make an appropriate plan. MTS and replenishment have a minimum and maximum amount, which means that the resource planners are able to allocate these products within a certain range. This range is used when there are gaps in the production plan or when there is too little capacity available for the products to be produced. As products are added to the plan when filling the gaps, it will directly be discussed with the material planners to find out whether the needed material and storage is available or not. If the gaps are filled, the production plan will be checked for one last time with the beer availability. Then the resource planner of the TSCP department will allocate the products to production lines without giving them a certain sequence on these production lines.

After the production plan is set, Customer Service Export (CSE) starts with creating deliveries and Operations Scheduling (OS) starts with reading the production plan into Advanced Scheduling (AS). Following these actions, OS makes the schedule for the coming week which they will discuss with TSCP, as well as the restrictions and the start of week 2.

In order to understand the process of 'creating deliveries' of CSE, an example will be given to visualize this process. If there is an order of 100.000 boxes and one container can hold 2.000 boxes, then CSE will arrange the shipment through, for example, containers on a ship. Each delivery will contain 2.000 boxes, which means that fifty deliveries will be created. Moreover, in order to ship the entire order, CSE will have to arrange that three ships are used.