MASTER

The frozen horizon length in production planning

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The Frozen Horizon Length in Production Planning

By

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Abstract

One of the main decision variables in using a rolling schedule in production planning and scheduling is the frozen horizon length. Freezing a part of the planning horizon is a traditional approach in reducing the nervousness of a production schedule. This thesis discusses the effect of the frozen horizon length on inventory cost. A manufacturing location of the Kraft Heinz Company, a large food and beverage company, has been chosen as a case study. Previous research on the frozen horizon in rolling schedules has focused on the effect of the interval length on the traditional trade-off between schedule stability, overall cost and customer service level. A literature review has identified gaps in the knowledge on certain real-life manufacturing systems and the integration of several involved costs in setting the frozen horizon. This report presents a model, for similar systems as the manufacturing sites of Kraft Heinz, that maps the effect of the frozen horizon length on raw material and finished good safety stocks. Generally, the factories of Kraft Heinz are characterized by a two-echelon production system, producing large volumes of perishable goods and the operations can be classified under the process industry.

The contribution of this thesis is the modelling of the trade-off between raw material safety stock and finished good safety stock based on the frozen horizon length. Both types of inventory are combined in an analytical expression that shows that cost savings can be made by choosing the appropriate frozen horizon length. The thesis presents a decision support system for determining optimal frozen horizon length for a broad application in planning and scheduling in a Make-To-Stock environment in the process industry.

Management Summary

This report presents the author's concluding project for the Master of Science in Operations Management and Logistics at the Eindhoven University of Technology (TU/e). The thesis has been executed as a collaboration between the TU/e and the Kraft Heinz Company on the topic of the frozen horizon length in production planning. Through the rise of supply chain management and the resulting increased integration of planning systems within and across firms, planning/schedule stability has gained increasingly more attention. Introducing a frozen horizon in a planning environment, i.e. fixing a part of the production schedule, can reduce the instability of a schedule. This thesis discusses the frozen horizon length in production planning in the process industry and its effect on safety stocks and associated costs.

Assignment

A literature study on the frozen horizon has shown that gaps exist on the knowledge of the effect of the frozen horizon in certain real-life manufacturing systems (e.g. with limited resources, multiple uncertainty sources and both raw material as well as finished good inventory) and the incorporation of all involved costs in setting the frozen horizon. The goal of this research is to: "Investigate and map the effect of the frozen horizon length on costs for systems that have characteristics similar to the factories of Kraft Heinz". The two echelon make-to-stock environments of the factories are characterized by stochastic demand, commonality in raw materials, perishability of goods, production & storage constraints and uncertainties arising from demand and lead times. The costs that will be incorporated are restricted to inventory costs. The assignment is to:

1. Develop an analytical expression (or mathematical model) that can be used to map the effect of the frozen horizon on costs for systems that are similar to the factories of Kraft Heinz.
2. Test the model within the Kraft Heinz environment and determine & implement a cost optimal frozen horizon.

The case study, a medium-sized Kraft Heinz factory in Spain called Alfaro, has been used to characterize the system in more detail. The following research questions are drafted:

1. What is the current situation at the case study?
2. What is the effect of the frozen horizon length on the execution of the rolling schedule and the ordering policy?
3. What is the effect of the frozen horizon length on cost considering the system characteristics?
4. What is the optimal setting for the frozen horizon length in terms of costs for the case study?
5. What is the main cost driver in setting the frozen horizon?

General Model

The frozen horizon has an impact on the uncertainty during the lead time for raw materials taken into account in the model. For adjusting the uncertainty during lead time we use the following definition:

$$Time_r = (LT_r + R_r - FH)^+$$

The frozen horizon also has an impact on the lead time of finished goods:

$$Time_f = (FH + LT_f + R_f)$$

With; LT_r = Total Lead Time raw materials, i.e. the time from ordering at an external supplier until the materials are readily available for production in the factory, FH=Frozen Horizon, LT_f = Total Lead Time finished goods, i.e. the time from starting production until the finished goods are readily available at the warehouse. The subscripts r and f refer to raw materials and finished goods respectively.

The following objective function needs to be minimized to find a cost optimal frozen horizon length within this framework:

$$TC_{SS} = \sum \left(C_{SS_{RM}} + C_{SS_{FG}}\right)$$
$$= \sum \left[\begin{array}{c} h_r * \sum_{r=1}^{m} \left\{ P_r * \left[k_\beta * \sqrt{\sigma_e^2 * (LT_r + R_r - FH)^+} \right]_r \right\} + \\ h_f * \sum_{f=1}^{x} \left\{ P_f * \left[k_\beta * \sqrt{\sigma_e^2 * (FH + LT_f + R_f) + \mu_d^2 * \sigma_L^2} \right]_f \right\} \end{array} \right]$$

In which
TC_{ss}= Total Cost for safety stocks, $C_{SS_{RM}}$= Cost associated with the safety stocks for Raw Materials (RM), $C_{SS_{FG}}$= Costs associated with the safety stocks for Finished Goods (FG), k_β= safety factor, m = number of raw materials, r = raw material (1,..,m), x = number of finished goods, f = finished good (1,...,x). The following parameters are specific to a certain raw material or finished good; h = holding cost, P = Unit cost, Z = safety factory, σ_e^2= standard deviation of the standard error, μ_d^2 = mean demand squared, σ_{LT}^2 = variance of the lead time, R = review period.

The function accounts for uncertainties in demand and replenishment lead times. Several assumptions have been made, amongst others that the forecast errors is normally distributed, that there are no capacity constraints (in production or inventory), no perishability of goods, raw material lead times are deterministic, the safety stocks are determined from a single echelon perspective and all unmet demand is backordered.

Model Scenarios

Currently no specific models are used for setting the safety stocks of raw materials and finished goods within the Kraft Heinz. The case study, Alfaro, produces different kind of sauces, mainly tomato based. The site in Spain supplies up to 6 warehouses and currently employs a frozen horizon of 21 days. Figure 1 shows the results of the objective function for the case study. The graph, with the raw material and finished good safety stock on the y-axis and the frozen horizon length on the x-axis, shows a minimum total cost for a

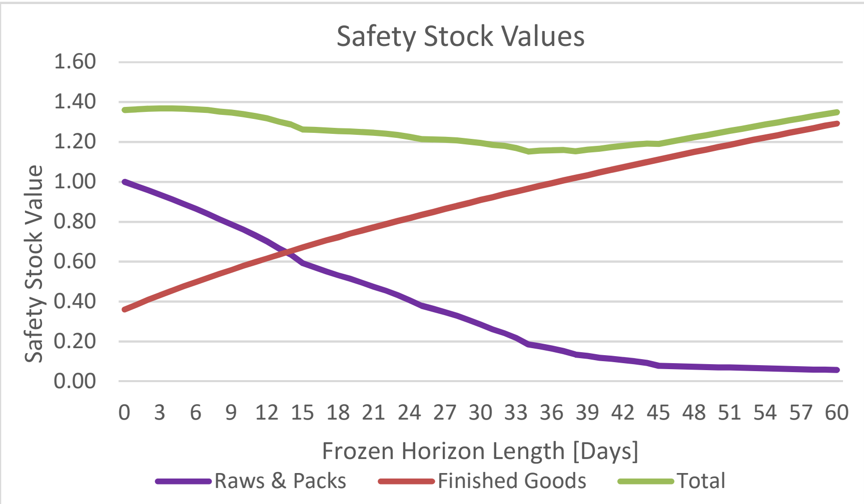

Figure 1: Main results Alfaro. Raw Material and Finished Good safety stock level as a function of the Frozen Horizon Length

frozen horizon of 34 days. Several sensitivity scenarios have been generated that test the sensitivity of the model to the customer service level, the number of replenishments, the forecast error, the variance of the finished goods replenishment lead time and the inventory carrying cost percentage.

Recommendations

The results show that total costs related to safety stocks can be reduced by increasing the frozen horizon length. However, increasing the frozen horizon decreases the flexibility of the production schedule. Given that the S&OP department is looking for more flexibility but the manufacturing sites are aiming at more stability for their production plan, there will remain a discussion between the parties that want the opposite with the frozen horizon length.

It has been recommended to make the data required for the presented model more easily accessible. The focus should be on raw materials and finished goods forecast accuracy. Efforts have been started to clarify some data inputs, like raw material forecast accuracy. In addition, the data integrity (regarding demand, MOQ's, lead times etc.) is important in finding the correct safety stock values. Finally, in the effort to reduce the inventory value within the organization, it is valuable to focus on other parameters affecting the total inventory, like lead times and forecast accuracy.

Contribution & Learnings

Amongst others, this thesis has focused on including both raw material as well as finished goods safety stocks. This thesis contributes to the literature on the frozen horizon by clarifying the effect of frozen horizon length on involved costs and presenting an analytical expression of its effect on safety stocks.

This clarification has led to learnings for the management of the Kraft Heinz company. However, the effect of the frozen horizon on the raw material safety stock levels in the real-life environment is questionable, because of operating flexibility, vendor managed inventory and the required service level for raw materials. The use of operating flexibility has driven the actual raw material safety stock levels down, but is complex to explicitly model. In general, the identification of the systems within Kraft Heinz and the scientific approach of setting safety stock levels has clarified the interpretation and effect of certain parameters (besides the frozen horizon) on safety stock. The management has gained insights on setting safety stock levels.

Discussion

On multiple areas of this research assumptions have been made, or certain factors have not been included, that limit the applicability of the model and the learnings as presented in this thesis. Amongst other the inclusion of several types of uncertainties, production cycles, replenishment rules and a slush time period could prove to be beneficial for other real-life environments. Finally, research on the type of uncertainty (timing or quantity) for raw materials could clarify the usage of safety lead time versus safety stock.

Preface

This master's thesis report is the result of the graduation assignment conducted at the Kraft Heinz company. It has been completed as the final requirements for the degree of Master of Science in Operations Management and Logistics at the Eindhoven University of Technology. This section is dedicated to everyone involved in and affected by the process of completing this project.

First of all, I would like to thank both Mr. Van Ooijen and Mr. Van Donselaar for their time and commitment over an extended period of time in guiding me in completing the thesis. Secondly, I'm grateful for the opportunity I got from Kraft Heinz (most notably Nienke, Sander and Susanne) to perform my thesis at the S&OP department in Zeist. A special thanks goes out to Adriano Martins who was there to support me during my project and was available for all my questions regarding the assignment, the people involved and any data gathering. Also, thanks to everyone within S&OP and Alfaro that helped me with my thesis. Lastly, I would like to thank the people around me, friends and family, that have supported me throughout the completion of not only my thesis, but my entire master's degree.

Kasper Crolla, February 2017

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1. Introduction

This report presents the author's concluding project for the Master of Science in Operations Management and Logistics at the Eindhoven University of Technology (TU/e). It is both a research and a design assignment in which theories and skills learned during the program are applied to a problem. The thesis has been executed as a collaboration between the TU/e and the Kraft Heinz Company, a large food and beverage company, on the topic of the frozen horizon in production planning. The aim of this project is twofold: first, to contribute to the scientific knowledge on the frozen horizon in production planning, and, second, to reduce cost at the Kraft Heinz Company within the scope of this research.

Through the rise of supply chain management and the resulting increased integration of planning systems within and across firms, planning or schedule stability has gained increasingly more attention. Uncertainties from demand, supply and the internal process can lead to plan changes and replanning activities and thus unstable schedules. The term nervousness is used to address problems for planning arising from instable schedules. Introducing a frozen horizon in a planning environment, i.e. fixing a part of the production schedule, can reduce the instability of a schedule. This thesis discusses this planning parameter.

The Master's thesis has been performed at the Sales and Operations Planning (S&OP) department within the European Supply Chain Hub of the Kraft Heinz Company, in Zeist the Netherlands. To introduce the context of this thesis, first, the Kraft Heinz Company, their problem statement and the S&OP department will be introduced in §1.1. This is followed by the report outline in §1.2.

1.1. The Kraft Heinz Company

On the 2nd of July 2015 the Kraft Heinz Company announced the successful completion of the merger between Kraft Foods Group and H.J. Heinz Holding Corporation (The Kraft Heinz Company, 2015). The merger between Kraft Foods and Heinz has created the 5th largest food and beverage company in the world. The portfolio includes more than 200 brands, ranging from the famous Heinz Tomato Ketchup and Philadelphia to local Dutch products like Karvam Cévitam and Honig. The Kraft Heinz Company, in short Kraft Heinz, is divided into five main regions, HEU (Heinz Europe), HNA (Heinz North America), APAC (Asia Pacific), LATAM (Latin America) and RIMEA (Russia, India, Middle East, Africa).

Kraft Heinz uses a management model called Management by Objectives, which is a system that aims to improve the performance of an organizations by defining quantitative and qualitative objectives. Participation and commitments is ensured as the objectives are agreed upon by employees and management and aligned across the organization. The objectives for the head of the S&OP department for 2016 consist of six Key Performance Indicators (KPI's) that fall under two main goals: 'Deliver Kraft Heinz Financial Results' and 'Improve Service Level and Innovation'. The target to reduce the European inventory position/value has resulted in multiple projects aimed at reducing the inventory levels and the interest for this project.

1.1.1. Company Problem Statement

The sentiment exists within Kraft Heinz that the inventory levels can be improved by adjusting the frozen horizon lengths. Currently, beyond empirical evidence, little thought has been put into setting the length of the frozen horizon. Kraft Heinz' motivation is to reduce the involved costs while keeping the same customer service level. The suggested goal of the project is to study this planning parameter and propose a method for optimizing the frozen horizon length that can be applied at the factories of Kraft Heinz. This goal can be translated into a deliverable; a model that can specify either a companywide frozen horizon length, a factory wide frozen horizon length or a production line specific frozen horizon length. The problem or opportunity statement is to analyse and map the impact of adjusting the frozen horizon at the manufacturing sites of Kraft Heinz with the goal of finding an optimal frozen horizon length in terms of cost.

A literature review on the frozen horizon has shown that certain gaps exist on this topic. Chapter 2 presents a summary of the main literature on the frozen horizon. The thesis topic's position in relation to the Master program of the TU/e is discussed in Appendix A. That part also highlights the aim of scientific research and the importance of the rigorousness and relevance of a research. Throughout the thesis this has been kept in mind to achieve a balanced report.

1.1.2. Sales & Operations Planning

The thesis has been performed at the European Supply Chain Hub of the Kraft Heinz Company in Zeist, the Netherlands. Within the Supply Chain Hub, the Sales & Operations Planning, Procurement and Supply Chain Excellence departments are centralized. According to Thomé, Scavarda, Fernandez, & Scavarda (2012) Sales and Operations Planning is "a process to develop tactical plans that provide management the ability to strategically direct its businesses to achieve competitive advantage on a continuous basis". It integrates all the plans of the business (sales, marketing, development, manufacturing, finance) into one set of plans (Thomé et al., 2012). Jacobs (2011) refers to Sales and Operations Planning (S&OP) as the set of activities used for overall direction setting (Jacobs, 2011). S&OP balances the production resources with the sales and marketing plans of a firm to ensure sufficient availability according to the customer service targets.

For Kraft Heinz Europe, the supply planning for nine manufacturing locations and several copackers (i.e. external factories) is done by S&OP in Zeist. Together with the schedulers and the material planners at the sites, the supply planners are responsible for capacity planning, inventory optimization, production planning and material planning. The supply planning activities are centralized to leverage the knowledge sharing on managing the supply of all finished goods across Europe. An overview of the factories can be found in Appendix E.

1.2. Report Outline

The outline of this report is as follows, Chapter 2 summarizes the literature review and Chapter 3 presents the thesis assignment, the scope and the research questions. Chapter 4 elaborates on the case study and gives detailed system characteristics. The general model is discussed in Chapter 5 and the results of the model at a case study are discussed in Chapter 6. Finally, Chapter 7 concludes the report with a discussion, management learnings, the limitations of this research and future research opportunities.

2. Literature Review

The goal of scientific research is to bridge a gap in the existing knowledge. In the 'Literature Study of the Frozen Horizon Part I' by Crolla (2015) gaps have been identified in the frozen horizon literature. Paragraph 2.1 summarizes the literature review by discussing the research on manufacturing planning and the frozen horizon. This study has been extended as it became apparent during further analysis of the problem case that more knowledge was required on certain topics. Paragraph 2.2 summarizes the most relevant parts of Literature Review Part II. The full report can be found in Crolla (2016). Finally, the motivation and goal for the thesis from a literature perspective are presented in §2.3.

2.1. Literature Study Part I

Manufacturing planning and control processes deal with organizing and optimizing manufacturing operations. Information about capacity restrictions, inventories and demand are used to develop detailed production schedules and determine order quantities. This process of planning and scheduling is concerned with managing materials and optimally scheduling resources to meet demand. It plays an important role in the performance of an organization.

The literature review by Crolla (2015) offers an overview of the significant literature on manufacturing planning and control and in particular the so-called frozen horizon used in production planning. The frozen horizon is a main parameter in the rolling horizon concept. The practice of a rolling horizon is to routinely update or revise the (production) schedules, by rolling forward the planning horizon[1] and taking into consideration more reliable and recent data (Chung & Krajewski, 1987). The frozen horizon is a part of the planning horizon that is fixed to reduce the instability of production schedule. Although a frozen horizon eliminates changes in the frozen periods, it also limits the system's possibility to respond to demand changes (P. C. Lin & Uzsoy, 2016). When the demand is revised upwards, freezing may result in reduced service levels because of unmet demand. Vice versa, when demand is revised downwards, freezing may result in excess inventories (P. C. Lin & Uzsoy, 2016).

Schedule stability is an important enabler for efficient supply chain operations and therefore an essential aspect of production planning. Several sources of uncertainty, originating from e.g. forecast errors, can lead to many plan revisions and thus instable schedules. The term nervousness is used to refer to problems resulting from this instability of planned orders. Nervousness can lead to a reduction in customer service and productivity as well as an increase in the bullwhip effect[2] and global costs because of e.g. overtime, extra inventory and the need for emergency orders (RH Hayes & Clark, 1985; Sridharan, Berry, & Udayabhanu, 1987; Steele, 1975; Van Donselaar, 2000). As Campbell (1971) adequately summarized "scheduling is no problem, it's the rescheduling that kills me".

Nervousness can be managed on several levels, ranging from lot-sizing rules and implementing safety stock to damping procedures that reduce certain uncertainties. Freezing a certain part of the planning

[1] The planning horizon is the amount of time an organization will look into the future when preparing a production plan (Chapman, 2006).

[2] First described by Forrester (1961) the Bullwhip Effect refers to the phenomenon that order variability increases as orders move upstream along the supply chain (Lee, Padmanabhan, & Whang, 2004).

horizon is frequently used in practice to mitigate nervousness. During the frozen horizon, no changes in the planning are allowed, but the free interval can be subject to rescheduling. After waiting the duration of the replanning interval, the system updates the information and initiates the next planning cycle.

A fundamental trade-off exists between schedule stability, costs and customer service level when setting the frozen horizon length. The literature review showed several gaps in the frozen horizon literature. First, it has been shown that results cannot be easily generalized to systems with different characteristics. Therefore, it has been concluded that research is lacking on certain specific deterministic and stochastic demand environments. Mainly on systems that portray real-life situations more accurate, with joint replenishment cost structures instead of rather simple single item cost structures and systems with multiple planning layers (i.e. systems that aim for integrated supply chains, by integrating purchasing and scheduling policies among all supply chain members). In more detail, literature gaps exist on:

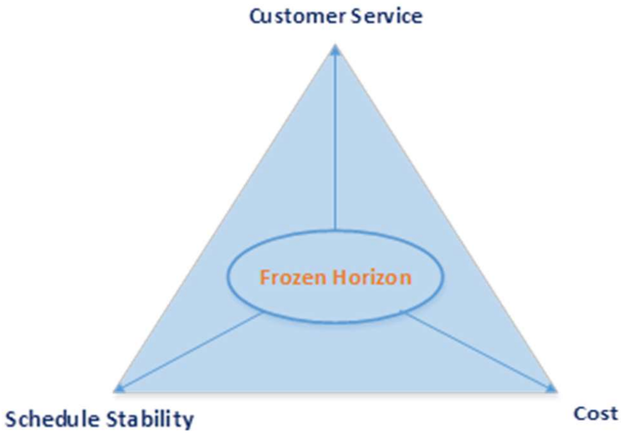

Figure 2: The trade-off between customer service, stability and cost

(i) Knowledge on the combined influence of the replanning interval, planning horizon, system nervousness/stability, forecast error and safety stocks on costs and their interaction with setting the frozen horizon. Subsequently, the incorporation of all relevant cost parameters into a single cost function to find a cost optimal frozen horizon.

(ii) The human influence in setting rolling horizon parameters including the frozen horizon length.

(iii) Environments that more closely resemble real-life situations with
- limited resources
- uncertainties besides demand uncertainty
- both production and replenishment lead times
- both raw material[3] inventory as well as finished good[4] inventory
- heterogeneous demand, which combines stochastic and deterministic demand

A gap exists on complex systems under stochastic demand with capacity restrictions. From earlier research, it became clear that not all conclusions from research on systems with deterministic demand can be generalized to stochastic environments. In addition, in the reviewed literature only the costs related to setups and holding inventory are considered. Only finished goods inventory has been included in previous research, but raw material or component inventory has been left out. Lastly, most literature focusses on simulation models instead of analytical expressions of costs.

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[3] Raw materials are materials purchased from external suppliers and waiting for first processing (Minner, 2000). Raw materials are used in the production of goods. For more information see Crolla (2016).

[4] Finished goods are end items that have completed the production process and that can be sold to a customer.

2.2. Literature Study Part II

Throughout the exploration and execution of the assignment, it became apparent that additional knowledge was required for the thesis. An extended literature study was performed, taking into account more detailed information about the assignment and encountered systems. It discusses among others Sales & Operations Planning, the rolling horizon concept within Kraft Heinz, uncertainty and instability of production schedules, inventory types and cost, safety stock models and multi echelon systems. This gained knowledge has been used throughout the thesis to achieve a well-grounded research. The section below only highlights uncertainty and schedule instability in more detail as it is a useful extended explanation at the start of this thesis.

Uncertainty and Schedule Instability

The frozen horizon is aimed at reducing instability of a production schedule caused by uncertainties. In general, uncertainty refers to "the probability that the realisation will deviate from the expectation/estimate" (Van Donselaar, 1989). It is measured by the probability that there is a difference as well as the extent to which the realisation deviates from the expectation (Van Donselaar, 1989). Uncertainty leads to an instable schedule, which in its turn leads to planning problems, or nervousness. Besides the earlier mentioned disadvantages of nervousness, it is concluded that instability in production schedules is undesirable for several reasons: it generates short and medium term adjustment effort (Inderfurth, 1994), it leads to a lack of coordination in supply chains (Tunc, Kilic, Tarim, & Eksioglu, 2013), it can lead to less effective operations and support activities (such as material procurement, staffing and setup planning) (P. C. Lin & Uzsoy, 2016), and it causes a general loss in schedule confidence (De Kok & Inderfurth, 1997).

Reducing uncertainty is therefore in the interest of an organization. In reducing uncertainty from demand, it is beneficial to be able to categorize demand, to identify its distribution and to have high quality forecasts. From a production planning perspective, several methods exist to reduce uncertainty. Besides introducing a frozen horizon, two other main methods are; using inventory buffering techniques and choosing stable lot sizes. A lot or batch is a certain quantity of items bought or produced together. Several methods exist to choose a certain lot size. In terms of inventory buffering techniques, applying safety stock and safety lead time are the most common in Material Requirements Planning (MRP) systems. It became clear that it is not conclusive which methods should be used under what conditions, but safety stock is often preferred for quantity uncertainty while safety lead time is preferred for timing uncertainty (Heisig, 2002; Jacobs, 2011).

Several authors have tried to capture the cost of nervousness by introducing a change cost function (examples are discussed in the literature study part II). However, it is concluded that the cost of nervousness is difficult to measure and it is reasonable to treat planning stability as an independent attribute of an inventory system (De Kok & Inderfurth, 1997; Kilic & Tarim, 2011).

2.3. Literature Motivation and Goal

From a literature perspective, the motivation for research on the frozen horizon length has been to study its effect on the fundamental trade-off between cost, stability and customer service level. This rather rigorous approach, can be balanced with a relevance effort by presenting a support system to aid organizations in choosing the right parameters. Companies might have their own considerations on choosing between stability, cost and service level. With extensive knowledge on the effect of the frozen horizon, firms will be able to make a well-informed decision on its parameter setting. The gap concerning the incorporation of all relevant costs into a total cost function is an interesting starting point for this research as it can lead to a cost optimal frozen horizon length.

By incorporating the aspects of the fundamental trade-off in a single model, an appropriate length for the frozen horizon can be found for manufacturing companies using a rolling schedule. This research can expand the knowledge on the effect of the frozen horizon on costs for systems that have similar characteristics as the manufacturing locations of Kraft Heinz. The goal of this research from the point of view of the literature will be to close a gap in the literature on the frozen horizon by presenting a total cost function that can be optimized by setting the frozen horizon length.

3. The Assignment

This Master's thesis has been performed at the Sales and Operations Planning department of the Kraft Heinz Company, in Zeist the Netherlands. The thesis discusses the selection of the frozen horizon length in the production scheduling environment of a food and beverage company. To clarify the setup of the rest of the report, the first paragraph of this chapter discusses the research approach.

3.1. Research Approach

The literature on the frozen horizon has been reviewed and the problem as presented by Kraft Heinz has been introduced. Next, the problem is assessed on a higher level by discussing the rolling horizon schedule within Kraft Heinz, the stakeholder analysis and the broad system characteristics (§3.2). After scoping the research in §3.3, a thesis assignment is presented in §3.4. The assignment relates to both gaps in the literature on the frozen horizon as well as the problem statement. Research questions that aid in guiding the assignment are presented in §3.5. The report continues in Chapter 4 by discussing the selected case study in more detail. In Chapter 5 the general model is presented and in Chapter 6 this model is applied to the case study. Eventually in Chapter 0 the conclusions of this thesis are discussed. The rigorous learnings (aimed at filling gaps in the literature) and relevant recommendations for the Kraft Heinz company (aimed at answering their problem statement) are presented. The full approach of this research is displayed in Figure 3.

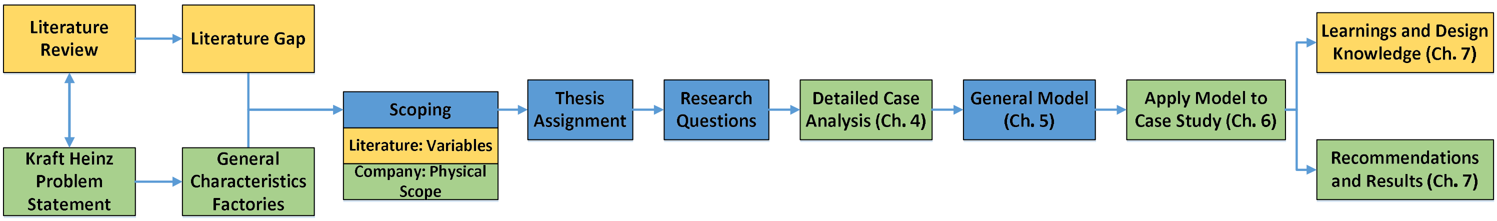

Figure 3: Thesis approach; from literature review and Kraft Heinz problem until learnings and recommendations. Green boxes are company related, yellow boxes are literature related and the blue boxes are more general thesis parts.

3.2. Problem Assessment

In the literature on the frozen horizon it is stated that results from research on this topic cannot be generalized to all systems (Crolla, 2015). The knowledge and applicability of a model only applies to certain systems. Therefore, an assessment of the general system characteristics of the European manufacturing sites of Kraft Heinz has been made. The assessment is done through empirical investigation as introduced in §3.2.1. The rolling schedule within Kraft Heinz is shortly introduced in §3.2.2, followed by stakeholder insights in §3.2.3, the reason for the frozen horizon within Kraft Heinz in §3.3.4 and finally the general system characteristics in §3.2.4.

3.2.1. Empirical Research

To fully assess and describe the problem case, empirical investigation can be used. Empirical research/investigation is a way of gaining knowledge by means of direct and indirect observations and experiences. The empirical cycle by De Groot (1969) can be used to approach this research.

As displayed in Figure 4, five steps are identified in his cycle:

1. Observation: Collecting and organizing empirical facts.
2. Induction: Formulating hypothesis.
3. Deduction: Deducting consequences of hypothesis as testable predictions.
4. Testing: Testing the hypothesis with new empirical material.
5. Evaluation: Evaluating the outcome of testing.

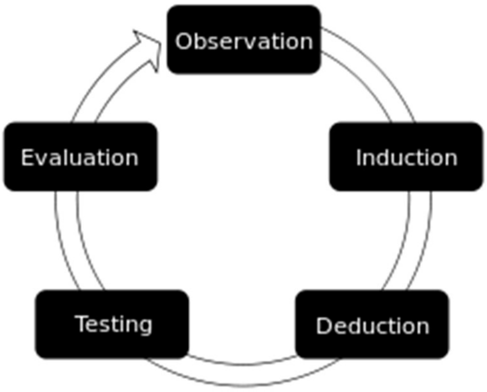

Figure 4: The empirical cycle by De Groot (1969)

The collection of empirical facts has been done through observations and interviews.

3.2.2. Rolling Horizon Schedule within Kraft Heinz

The production planning process within Kraft Heinz uses a rolling horizon schedule. A rolling horizon framework is a practice of production planning that routinely updates the schedule and takes into account more reliable and recent data. The **Frozen Horizon** is one of the decision variables in a rolling schedule and determines the period during which no changes can be made to the production plan. This freezing of a schedule is done to reduce the instability of a production plan. A general introduction on rolling horizon schedules can be found in Crolla (2015, 2016) and the horizons used in Kraft Heinz are discussed in Appendix C. Within Kraft Heinz, the Frozen Horizon (FH), or as it is called by S&OP the *Manufacturing Frozen Duration* (MFD), differs per manufacturing site and sometimes even within a site per product category. In general, three main groups can be identified for the internal factories:

1. A Manufacturing Frozen Duration of 7 days
2. A Manufacturing Frozen Duration of 21 days (Most factories)
3. A Manufacturing Frozen Duration of 28 days

The period of the schedule defined by the MFD is supposed to be firm/frozen and the Planning Software[5] cannot change anything within this interval. However, the plan within the Manufacturing Frozen Duration can be split up in the real frozen part (generally the first 2 weeks) and the slushy part (the last week). Within this last part, the responsibility of the schedule lies with the manufacturing location (i.e. the production scheduler), but changes can be manually requested by the supply planners. The number of changes to the schedule within the MFD differs across the locations, but rescheduling is mainly aimed at changing quantities and less on the timing of certain productions.

3.2.3. Stakeholder Analysis

To ensure a successful implementation of the research, it is important to determine and consider the stakeholders for this research. *Stakeholders are the individuals or groups of people who are affected by the outcome of a project.* First, the supply planners in Zeist are stakeholder as they are affected when the frozen horizon length is changed. Second, the material planners and schedulers at the site are stakeholders. Although supply planners and schedulers are the main stakeholders, others can be

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[5] Within S&OP a planning tool is used that incorporates all demand and inventory information and builds a preliminary production plan. The software will simply be referred to as the 'Planning Software'.

affected as well. The frozen horizon might influence various operations throughout the supply chain involving higher level managers, purchasing and logistics.

To get more insights on the stakeholder’s views on the frozen horizon, interviews have been conducted. The interview questions can be found in Appendix D and extended insights can be found in Appendix F. It is concluded that supply planners prefer a shorter horizon to improve their planning flexibility, whereas manufacturing locations prefer a longer horizon to be able to control their raw material procurement and inventory.

3.2.4. General System Characterisation

The complexity, classification and modelling of certain problems depend on the characteristics considered in the model that represents the problem. Besides the interviews, data have been extracted from the Enterprise Resource Planning (ERP)[6] system and the Planning Software used by Kraft Heinz Based on this information general system characteristics have been identified for the factories of Kraft Heinz. More information on the factories, among others the product categories produced in each factory, can be found in Appendix E.

It is concluded that Kraft Heinz factories are **production** systems operating with **rolling schedules** and their main targets involve reducing cost and **inventory levels**. The characterisation has been done from three system perspectives: a rolling horizon perspective, a manufacturing perspective and an inventory problem perspective. These perspectives are useful in clearly describing a system and characterizing the problem, and are based on research by Karimi, Ghomi, & Wilson (2003), MacCarthy & Fernandes (2000), Sahin, Narayanan, & Robinson (2013), Silver (1981) and Snyder (2008). A more extensive discussion of these classifications can be found in Appendix G, Appendix H and Appendix I. A summary of the characterisations is given in Table 1.

Table 1: Three perspectives on system characterisation

Rolling Horizon Perspective	Manufacturing System	Inventory System
Stochastic demand	Make-to-Stock	Finite planning horizon of 2 years
Resource constraints	High production rates	Serial two-echelon system
Linear & Joint cost structure	Process Industry	Perishable inventory
Multiple manufacturing steps	Repetitive production process, largely automated and a fixed product layout	Inventory & Production capacity constraints
Multiple items	Simple multi-level product structure & Standard products	Unmet demand is backordered
Single planning layer (i.e. no full supply chain integration with suppliers to align schedules)	Response time to customer = distribution time of finished goods	Uncertainty (quantity, timing and quality) in supply, internal processes and demand

[6] Within Kraft Heinz an ERP software package is used that will simply be referred to as ‘ERP’.

3.3. Research Scope

The scope depends on the most prevalent characteristics of the factories that are related to the frozen horizon. Below, first variables of the research are discussed in relation to the literature review (§3.3.1), then the scope is drilled down further by focussing on the physical scoping (including the choice for a pilot factory/case study) (§3.3.2). This is followed by scoping in terms of cost (§3.3.3). Finally, the reasons for a frozen horizon with Kraft Heinz are discussed. (§3.3.4)

3.3.1. Variables

The variables *Replanning Interval* and *Planning Horizon* are usually considered as independent variables in the frozen horizon literature, but these variables will act as fixed parameters. The replanning interval is equal to 1 week as the plan is rolled ahead for a full week and the planning horizon is 2 years. This thesis will focus one independent variable: the *Frozen Horizon* (Length). The effect of the independent variables on the performance measures *Service Level*, *Schedule Stability* and *Cost* is commonly studied in the frozen horizon literature. The frozen horizon affects the stability of a production schedule and therefore the nervousness of a system. To find a cost optimal solution to the frozen horizon planning problem, it is important to determine what cost factors should be included and how to capture these costs. Therefore, it is interesting to determine how to capture the cost associated with the initial trade-off between Customer Service , Schedule Stability and Cost as depicted in Figure 2.

When a stockouts occurs, the orders for all unmet demand are cancelled. However, the sales are not lost as customers will (normally) place new orders. As has been concluded in the literature review, shortage costs are hard to define or estimate. Therefore, it has been decided not to include *Service Level* as a part of the cost parameter through shortage cost. Kraft Heinz has set a target for the Customer Service Level. Performing under this target is undesirable and overachieving might unnecessarily increase cost related to safety stocks. The cost associated with safety stocks to achieve the target are captured under *Cost.* Furthermore, *Schedule Stability* is not the main concern in the thesis. In the literature review (and highlighted in the cost assessment in Appendix J) it is concluded that the cost of nervousness (i.e. the costs associated with the problems arising from instability) is difficult to measure. Among others, De Kok & Inderfurth (1997) and Kilic & Tarim (2011) state that planning stability or schedule stability should be treated as independent attributes for assessing an inventory control system, as it cannot be replaced by cost or profit values in most practical situations. Reducing the schedule instability is on itself not a goal of this assignment, therefore it will be left out of the scope. This research is aimed at examining the effect of the frozen horizon on costs and therefore the only dependent variable that remains is *Cost*. It can be concluded that the initial trade-off depicted in Figure 2 is not relevant for this research. The focus will be on the effect of the frozen horizon on *Cost* as depicted in Figure 5. The system parameters are displayed in Table 2.

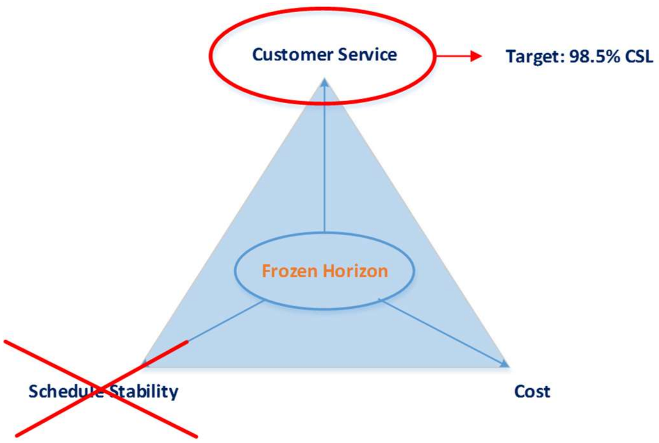

Figure 5: Revised Trade-off affected by the Frozen Horizon

The replenishment policy, i.e. the decisions regarding the replenishment timing and quantity, can also be considered as a parameter in rolling horizon schedules. As discussed in the literature review, the choice of the replenishment rule can affect the stability of a schedule. However, deciding on replenishment/lot-sizing rules is a problem on its own and therefore the current rules within Kraft Heinz will not operate as a variable. For raw materials, several replenishment rules are present within Kraft Heinz. The main rule that is used is the Period Order Quantity policy, under which a quantity equal to the requirements over a predetermined number of periods (minus the projected on-hand inventory of the previous period) is ordered. The actual lot sizes are variable but constraint by Minimum Order Quantities (MOQ) and incremental order quantities. The MOQ and incremental quantities are fixed and based on contracts with suppliers. Minimum Production Quantities (MPQ) are present for finished goods and are based on capacity restrictions and changeover times. MOQ's and MPQ's are widely used in practice to achieve economies of scale in distribution and production and these scale advantages are important in many industries (Zhou, Zhao, & Katehakis, 2007).

Table 2: System parameters split up in dependent and independent variables.

Dependent Variable	Notation	Interpretation
Service Level	g	Customer Service Level is measured by Case Fill rate[7]; Target is set to 98.5%.
Schedule Stability	SI	Stability of the production schedule; No target is set.
Cost	C_t	Sum of all relevant costs; Target is to minimize the cost.
Independent Variable	**Notation**	**Interpretation**
Replanning Interval	RI	The time between replanning the production schedule; Fixed to 1 week.
Planning Horizon	PH	The time covered by the entire production plan; Fixed to 2 years.
Frozen Horizon	FH	Number of weeks of the planning horizon that are frozen/ fixed; Variable.

3.3.2. Physical Scope

The physical scope of this thesis concerns setting the frozen horizon length for the 9 internally planned manufacturing locations. The copackers, i.e. the external factories that are not in possession of Kraft Heinz, fall outside the scope as there is less flexibility in setting the horizon for those factories. To allow for a more detailed system characterisation and facilitate data gathering, one factory (called Alfaro), which represents a somewhat average case in terms of the general characteristics, has been chosen as a case study. In addition, some managerial aspects from the perspective of Kraft Heinz were considered in selecting the case study. For example, some factories had project challenges and were not a preferred choice. The decision variables for choosing the pilot case from the perspective of Kraft Heinz can be found in Appendix I.

[7] The Case Fill Rate is defined as the percentage of demand, measured in cases, that can be directly supplied out of inventory.

3.3.3. Scope in terms of Cost

A cost assessment has been done to determine what kind of costs might be influenced by changing the frozen horizon. The full assessment can be found in Appendix J. The assessment has been used to philosophize about the possible effects of the frozen horizon on costs. Conclusions have been formed to develop more insight in the effect of the frozen horizon from a general perspective. This has guided the scoping in terms of what costs to include in the thesis.

The relation of both schedule stability and customer service with cost will not be discussed in this thesis as has been argued above. From the cost assessment can be concluded that replenishment cost and inventory cost can be affected by changing the frozen horizon. Inventory cost is affected through the effect of the frozen horizon on the (un)certainty of the production schedule and thus the safety stock requirements to reach the service level target. In addition, the (un)certainty in a production schedule might also affect the replenishment decisions and thus the replenishment costs.

Replenishment cost is intertwined with inventory cost as replenishment decisions directly affect the involved inventory. As has been argued, the replenishment rule will not be included in the scope. Although the rule itself is not a variable, the period of a Period Order Quantity replenishment rule could still be open for discussion. The effect of the frozen horizon on the order frequency for raw materials, and thus the order size, can be investigated. For finished goods, the production lot size is mostly determined by the Minimum Production Quantities and this is not affected by the Frozen Horizon.

Frozen Horizon	Raw Material Safety Stock	Finished Good Safety Stock	Raw Material Cycle Stock	Ordering Cost
↑	↓ ↓	↑	↑	↓
↓	↑ ↑	↓	↓	↑

Figure 6: Effect of changing the frozen horizon on safety stock, cycle stock and ordering cost.

The general philosophized statements on the effect of the frozen horizon on cost are grouped in Figure 6. Here, raw materials refer to all ingredients and packaging (direct materials) that are bought from a supplier and used in the production of finished goods. Finished goods refer to the end product that has completed the production process and can be used to satisfy customer demand. Semi-finished goods are not considered as they are not present within most production systems of Kraft Heinz.

3.3.4. The Reason for the Frozen Horizon within Kraft Heinz

The literature review has shown that nervousness can lead to reduced customer service, increased bullwhip effect, additional production plan adjustment efforts, lack of coordination in supply chains, less effective support activities and a loss in schedule confidence. Introducing a frozen horizon can reduce the negative effects of nervousness, however, these reasons are not all relevant for Kraft Heinz.

Within Kraft Hein the Material Requirement Planning (MRP) logic is used to propagate the demand for the finished goods to the related raw materials (i.e. ingredients or packaging materials). In many real life systems, certain components are build-up out of other sub-components, thus creating a multi-level bill of material structure. In these systems, nervousness amplifies the uncertainty for the lower levels requirements within the own organisation. Short term requirement changes on finished good levels, could trigger the requirements for the production of components with lead times longer than the available time until the requirement. Therefore, it is difficult to plan on such uncertainty. The frozen horizon ensure a certain production schedule and reduces the nervousness for lower levels. However, for Kraft Heinz, the bill of material structure is rather simple and therefore the frozen horizon is not aimed at reducing the nervousness within the production system for lower level components and sub-assemblies.

For Kraft Heinz, the introduction of the frozen horizon for the first week of the planning horizon is indeed to mitigate the problems as highlighted by the literature. However, the problem assessment has shown that the extension of the frozen horizon is mainly aimed at creating a stable plan for raw material procurement. As long as the frozen horizon is longer than 1 week, the length does not affect the efficiency of the production schedule. A reduction of the frozen horizon from 2 weeks to 1 week does not lead to additional costs related to changing the production plan (besides raw material costs). Additional problems from an unstable schedule would arise if the frozen horizon is less than 1 week. Changes within the week to come would reduce the efficiency of the production plan when having to break off productions that are already running. Finally, changes within the first week complicate the task of allocating human resources. It can be concluded that the reason for the frozen horizon within Kraft Heinz might deviate from the general perspective of the literature on the frozen horizon.

3.4. Thesis Assignment

This paragraph discusses the goal of the thesis (§3.4.1) and the actual assignment (§3.4.2).

3.4.1. The Goal of the Thesis

It has been stated that there exists a sentiment within Kraft Heinz that the inventory level can be improved by adjusting the frozen horizon length. The literature suggests the frozen horizon is used as a tool to reduce nervousness and not necessarily aimed at improving inventory levels. At Kraft Heinz, the frozen horizon is set to ensure a certain production schedule and the frozen horizon has been implemented to increase raw material control and availability. The thesis aims to increase the knowledge of the interaction between the frozen horizon and costs in certain systems, filling a gap in the literature. The increased knowledge will be aimed at systems that share the same characteristics as Kraft Heinz.

Thesis Goal

Investigate and map the effect of the frozen horizon length on costs for systems that have characteristics similar to the factories of Kraft Heinz.

The characteristics of the two echelon make-to-stock environment are restricted to stochastic demand, commonality in raw materials, linear & joint cost structures, perishability of goods, production & storage constraints and uncertainties from demand & lead times.

3.4.2. The Assignment

To accomplish the goal, a model that measures the effect of the frozen horizon on costs has to be created. It should be applicable to and based on the characteristics of the manufacturing sites of Kraft Heinz. In addition, the model will be tested within the Kraft Heinz environment. Certain system characteristics can differ significantly from plant to plant, while other aspects are very similar. A pilot case, which is an adequate representation of the Kraft Heinz factories, has been selected.

Thesis Assignment

1. Develop an analytical expression (or mathematical model) that can be used to map the effect of the frozen horizon on costs for systems that are similar to the factories of Kraft Heinz in Europe.
2. Test the model within the Kraft Heinz environment and determine & implement a cost optimal frozen horizon.

The optimality in the latter part of the assignment description refers to the frozen horizon that leads to the least cost solution of the analytical expression. However, in order to create a model, assumptions have to be made about the reality. Determining a cost optimal frozen horizon within this framework, does not equal a cost optimal solution in real-life.

3.5. Research Questions & Methodology

The research questions for the thesis are based on the thesis assignment. First the research questions are presented (§3.5.1), then the method used to answer these questions is summarized (§3.5.2). More details on the questions and methodology can be found in Appendix J.

3.5.1. Research Questions

The general question, "*what is the cost optimal frozen horizon length*?", cannot be answered without considering the system in which the frozen horizon is implemented in more detail. The assessment of the current situation and performance of the pilot case (or case study) will be used as a baseline measurement for the comparison of the results of changing the frozen horizon. The first question focuses on the case study and will be answered by doing a detailed case analysis (see Chapter 4).

1. **What is the current situation at the case study?**

The next two questions are aimed at the general effect of changing the frozen, given more detailed information on the case study.

2. **What is the effect of changing the frozen horizon on the execution of the rolling schedule and the ordering policy?**
3. **What is the effect of the frozen horizon on cost, considering the system characteristics?**

The third questions should have resulted in a model that can be tested at the case study, therefore research question 4 is:

4. **What is the optimal setting for the frozen horizon length in terms of costs for the case study?**

The optimal setting refers to the frozen horizon that results in the least cost solution of the model. Given the framework of assumptions used in creating a model this does not necessarily give an optimal real life solution. The final question refers to the sensitivity of the model and helps identifying the focus for the company.

5. **What is the main cost driver in setting the frozen horizon?**

3.5.2. Methodology

To answer research question 1, empirical research has been used to investigate the current state of Alfaro. In addition, the reflective cycle by Van Aken (2004) is used to approach the presented problem and research questions. The first part of the reflective cycle can be found in earlier chapters in which the frozen horizon problem has been introduced. The class of problems is parameter setting in a production scheduling environment. Within this class the thesis is focused on a specific parameter; the frozen horizon length. The problem, the initial scope, the research questions and methodology have been discussed in this Chapter. The next chapter, Chapter 4, discusses the detailed analysis of the case study. Chapter 5 presents a general model. It is the plan/the design phase of the regulative cycle. The results of applying the model to the case study are discussed in Chapter 6. Finally, Chapter 0 reflects on the results and limitations of the research, presents the recommendations and discusses the acquired design knowledge.

4. Detailed Case Analysis

The factory 'Alfaro' has been chosen as the pilot case. An analysis of Alfaro has been done and this next section summarizes the main topics: Products and Network (§4.1), Demand and Forecast (§4.2) and Inventory Replenishment (Production Planning and Procurement systems) (§4.3). Paragraph 4.4 discusses the current cost situation at Alfaro and the last paragraph presents the relevant model characteristics (§4.5). The extended case analysis can be found in Appendix N.

This chapter also answers the first research question: *"What is the current situation at the case study?"*.

4.1. Products and Network

Alfaro is, in Kraft Heinz-terms, a medium-size factory located in Spain. The site is split up into two sections: 'Tomato Based Sauces' and 'other Sauces' (e.g. mayo and mustard). It has several filling/packaging lines and multiple kitchens that feed these lines. More than 250[8] packaging materials, 100 ingredients and 200 finished goods, also referred to as Master Schedule Items[9] (MSI's) by Kraft Heinz, had a forecasted demand in 2016. The main demand for these finished goods is coming from the Spain market. An ABC analysis has been done to group both the raw materials as well as the finished goods. Similar to a Pareto analysis, the ABC analysis rates the items on importance and groups them in three groups (A, B and C) (Jacobs, 2011). In this thesis it has been decided to rate the items in terms of their Annual Consumption Value, $ACV = annual\ usage * unit\ cost$. This valuation is common for inventory categorization as it identifies the items that have the largest impact on the company's overall inventory cost performance (Jacobs, 2011). Amongst others this approach allows for a comparison among materials with different units of measurement.

Alfaro operates in a make-to-stock manufacturing environment, producing a variety of perishable finished goods through multiple manufacturing steps. The factory receives raw materials from several suppliers and supplies up to 6 different warehouses (in Spain, France, the UK, the Netherlands, Italy and Poland). The network is displayed in Figure 7 and a more extensive discussion on the network can be found in paragraph N.3 of Appendix N. The majority of the finished goods are going to one specific warehouse. The network is characterized by a two-echelon system in which a trade-off exists between raw material stock at the sites (or even at the supplier) and finished good stock at the warehouses. There does not exist much multiplicity in which the warehouses are in the same tier/echelon and transhipments are possible within that same tier (see also Literature Study Part II).

Constraints exists in raw material storage capacity and production capacity for finished goods. All products for the Spain market are stored in a warehouse next to the factory where there is ample storage space. Multiple finished goods share the same raw materials and therefore so-called commonality exists.

[8] For confidentiality reasons the numbers used throughout this detailed analysis are made less specific.

[9] A Master Schedule Item (MSI) is a sellable finished good and consists of a unique combination of ingredients, packaging and labelling.

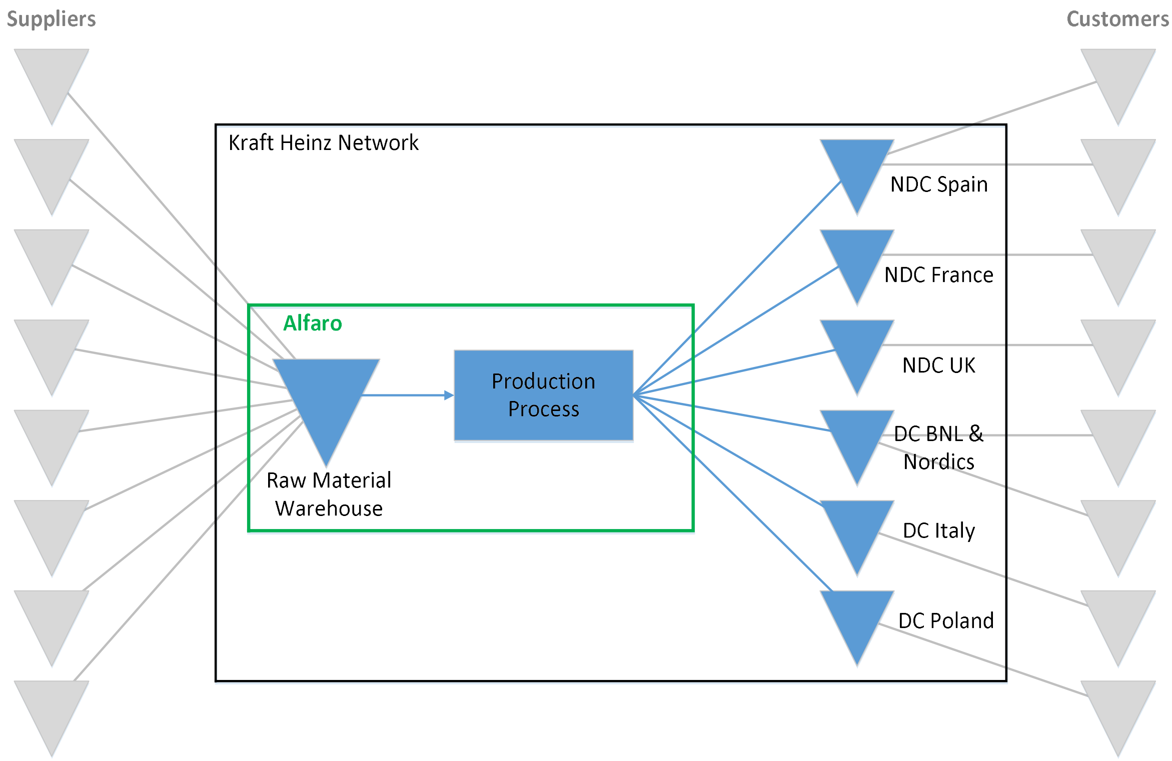

Figure 7: Network of stockpoints before and after the manufacturing process in Alfaro. An arbitrary number of suppliers and customers is displayed in this simplified overview. (N)DC = (National) Distribution Center.

4.2. Demand and Forecast

The demand is stochastic and varies over time. Based on the demand analysis, the demand process is assumed to be stationary. The demand pattern for the raw materials and finished goods of Alfaro can be categorized according to the scheme by Syntetos, Boylan, & Croston (2005) (Appendix N.5). The demand for future periods is forecasted and the forecast error (i.e. the difference between forecast and actual demand, originating from any demand estimation procedure) can be used as an input for determining the safety stock level. Inventory control systems generally assume that forecast errors are normally distributed and independent (Syntetos et al., 2005). The normal distribution is a continuous probability distribution that is characterized by two parameters, the expectation, μ, and the standard deviation, σ. The distribution of the forecast error is important in calculating the safety stocks and therefore a sample of raw materials and finished goods have been analysed. The results of the demand analysis and forecast error analysis, sorted according to the ABC item categories as described above, are displayed in Table 3.

For raw materials, the results show that while the A items have a smooth demand, the B and C items have mainly intermittent and lumpy demand. For the finished goods, the A items most belong to the smooth demand category. The B and C finished good items can belong to either the smooth or the erratic demand category on monthly level (which is the only real demand information available).

Based on the statistical tests of normality done on a sample of forecast errors, it is assumed that the forecast error follows the normal distribution (Appendix N.6). The forecast errors for the raw material C items don't follow this distribution, but as these items represent a low Annual Consumption Value the assumption will be followed for this thesis.

Table 3: Forecast Error Distribution and Demand Category per ABC item category

ABC Item Category	Raw Materials		Finished Goods	
	Forecast Error Distribution	Demand Category (Demand Bucket)	Forecast Error Distribution	Demand Category (Demand Bucket)
A items	Largely normal distributed	Smooth (weekly)	Normal distributed	Smooth (monthly)
B Items	Partly non-normal partly normal distributed	Mainly Intermittent and Lumpy (weekly)	Normal distributed	Smooth or Erratic (monthly)
C Items	Largely non-normal distributed	Mainly Intermittent and Lumpy (weekly)	Normal distributed	Smooth or Erratic (monthly)

4.3. Inventory Replenishment; Procurement & Production Planning

Two types of inventory replenishments are discussed, raw material replenishment and finished good replenishment. The procurement and production planning systems within Alfaro determine these replenishments and the interpretation of the inventory and replenishment costs.

The key questions an inventory control system attempts to answer are, ‘when should a replenishment order be placed?’, ‘how large should the replenishment order be?’ and ‘how often should the inventory status be reviewed?’ (Axsäter, 2015; Silver, 1981). The three main parameters are the review interval, the reorder or safety stock level and the replenishment quantity/lot size. These parameters affect the inventory and replenishment cost. While the central S&OP team decides on the finished good safety stock levels and the production lot sizes, the local material schedulers in Alfaro decide on the raw material safety stock levels and the order quantities. The contracts with the suppliers are managed by the central procurement team in Zeist. This is highlighted to show the different stakeholders involved in deciding on the replenishments of both raw materials and finished goods.

Silver, Pyke, & Peterson (1998) recognized the review period (R) as a key decision variable in an inventory control system. The inventory state is either reviewed periodically (i.e. every X periods, in hours, days, weeks etc.) or continuously (i.e. after every demand event) (Minner, 2000). Systems with fast moving items often apply a periodic review policy (Minner, 2000). Continuous review systems require less safety sock to provide the same level of customer service, as periodic review systems need to cover the uncertainty of the demand over the lead time plus one review period (Syntetos, 2001).

Both the planning and procurement process will be discussed in more detail below. First, the production planning is discussed as customer demand triggers the production of finished goods. This is followed by the procurement system as the production of finished goods triggers the procurement of raw materials. This section also answers the second research question “What is the effect of changing the frozen horizon on the execution of the rolling schedule and the ordering policy?”.

4.3.1. Production Planning Process

The production schedule is generated daily by the Planning Software for the liquid[10] part of the Planning Horizon (PH), which is 2 years for Kraft Heinz. The tool uses information from the ERP system, like demand forecasts and inventories, and is guided by several system parameters, like the Minimum Production Quantities (MPQ's) and capacity restrictions. The Planning Software suggests weekly production quantities and subsequently the supply planners use an excel tool to reschedule and optimize the suggestions. The customer demand is on the Master Schedule Items in the warehouse locations and this demand is cascaded down through the MRP logic to the components. The supply planners are responsible for planning the liquid period and freezing a new part of the production schedule. The production schedulers at the sites are responsible for the day-to-day planning within the frozen interval. The current setting for the frozen horizon length within Alfaro is 21 days.

The setup structure on the production side is characterized by a joint cost structure. Major setups are required between families of products (e.g. recipe changes), while minor setups are required between certain items (e.g. label changes).

A different horizon affects the flexibility and uncertainty of the production schedule. However, a shorter horizon does not necessarily affect the efficiency of the production plan. The efficiency can still be achieved through lot sizing rules. Batches of 1 item are not suggested because of predetermined MPQ's. Schedulers indicate that as long as the frozen horizon is not shorter than 1 week (which might lead to instances where production is interrupted amidst a run), the schedule will keep its efficiency. Changing the production plan within the same week would also complicate the human resource allocation.

Review Period

In the ERP system information on the stock situation is available virtually real-time. The production schedule in the liquid period is automatically updated each night by the Planning Software. Once a week the plan is reviewed by planners and the MFD/frozen horizon is extended with 1 week. It can be stated that the inventory position is reviewed (with new information on stocks and the production plan) periodically every night by the Planning Software. However, this review does not induce the fixing of the production plan or changes within the frozen horizon. On a more detailed level the schedule is analysed by supply planners once a week when fixing an additional week. Relating this to the literature on the review method of an inventory control system, it can be concluded that the inventory system for finished goods is reviewed periodically (and not continuously) with a review period of 1 week.

4.3.2. Procurement Process

The Period Order Quantity rule is mainly used within Alfaro to replenish the materials. In terms of way of working, the stakeholders at the factories indicated during the interviews that their ordering policies would not change under a different frozen horizon. Yearly contracts are made for almost all materials and quantities can be called-off on a daily or weekly basis. Ordering cost consists of a fixed replenishment cost (K) and a linear unit cost (c) component, i.e. ordering cost $= K + c * z$, with z

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[10] The liquid period refers to the time period within the planning horizon that is not frozen.

the number of units ordered. Given the MOQ, the fixed costs are relatively small compared to the total unit cost component and therefore the ordering frequency does not have a large effect on the ordering cost. The ordering cost becomes a linear function of the ordering quantity, which is typical for suppliers that employ a MOQ (Zhao & Katehakis, 2006). The order frequency is also not affected by changing the frozen horizon and the ordering process is not governed S&OP. Therefore, it is concluded that the order lot size will not be affected by changing the frozen horizon and it has been decided to leave the lot size out of the scope of the thesis.

Review Period

For raw material that have a total lead time shorter than the frozen horizon, new procurement decisions can be made daily on the inventory position[11]. Within the frozen horizon, it is possible to schedule material arrivals based on the fixed daily production schedule. Materials that can only be delivered every so many periods (because suppliers might want to group deliveries), have a review period similar to the delivery intervals. Based on interviews with local buyers and an analysis of the number of replenishments, it is assumed that materials can be delivered on a weekly basis.

Raw materials that have a lead time longer than the frozen horizon are also reviewed daily. However, as it is not known what day of the week the production of certain finished goods will be outside the frozen horizon, the demand is grouped on the first day of the week. Therefore, for the latter group, the arrivals are planned once a week. For these materials, the review period is also 1 week.

Inventory System

To conclude, the inventory positions are reviewed periodically, the demand is random and any unmet demand is considered to be backordered. As soon as the inventory position drops under the reorder level (s) a replenishment is triggered that is constricted by an MOQ/MPQ and incremental quantities[12]. The reorder level is defined as the safety stock level plus the (forecasted) demand during replenishment lead time. Replenishments of materials happen according to the Period Order Quantity rules. The ordered quantity (Q) is equal to the demand over a certain period (D) plus the undershoot (U)[13], constricted by minimum quantity (Q_{min}):

$$Q = \begin{cases} Q_{min}, & D + U \leq Q_{min} \\ D + U, & D + U > Q_{min} \end{cases} \tag{1}$$

For a single item single echelon environment with stochastic demand this is similar to the system studied by Zhou et al. (2007) which can be modelled with the (R, s, t, Q_{min}) policy. Zhao & Katehakis (2006) show that optimal policies for these systems are too complicated to implement in practice. According to Kiesmüller, Kok, & Dabia (2011) the policy by Zhou et al. (2007) can be approximated by the more simple (R, S, Q_{min}) policy as presented in their paper.

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[11] The inventory position equals the inventory on-hand plus the scheduled receipts (or 'goods in transit') minus the backorders. Typically inventory control systems are based on the inventory position rather than the inventory on-hand as it takes some time before a replenishment arrives (Donselaar & Broekmeulen, 2014).

[12] If more than the MOQ or MPQ is ordered, the order quantity can be upped with certain specified quantities.

[13] The undershoot is the difference between the reorder level and the inventory position at the moment of ordering (Donselaar & Broekmeulen, 2014)

4.4. Current Cost Situation

The service perspective is used in setting the safety stocks, i.e. instead of defining a shortage cost and minimizing the sum of total cost (ordering, holding and shortage), a target is set for product availability. It has become clear that within Alfaro the general conclusions on the effect on safety stock levels still hold, but the cycle stock cost and replenishment cost are not included. Therefore, for the thesis, the current cost situation at the Alfaro factory can be described by the inventory value and cost and the corresponding safety stock models. Within Kraft Heinz the yearly inventory carrying cost are set to a certain percentage (h) of the average inventory value. The average safety stock inventory for finished goods and raw materials will be represented by capital letters M and P respectively.

Within Kraft Heinz the fill rate is used to measure product availability. As orders are always in cases (and not in single items), the metric is referred to as Case Fill Rate (CFR). It is a percentage of the total demand (in cases) directly satisfied out of inventory. For most raw materials as well as finished goods safety stock is kept within Alfaro. The following section elaborates on the current safety stock settings. For a more extensive introduction on safety stocks the reader is directed to the literature review by Crolla (2016).

Raw Materials Safety Stock

For Raw materials (i.e. packaging and ingredients) within Kraft Heinz no models are used in determining the appropriate safety stock levels. Each factory has its own, mostly experienced based, way of setting the safety stock levels. Therefore, it will be required to introduce a safety stock model to measure the effect of changing the frozen horizon on the raw material levels.

Finished Goods Safety Stock

Finished good safety stock settings have mainly been based on the experience of the supply planners. There is a project in place to introduce a new model for setting the safety stocks, however, currently it is not in use. This model is integrated in the Planning Software and can be used a decision support tool for the supply planners who are responsible for setting the finished goods safety stocks. The individual planners will make the final call regarding the actual settings. Finished goods are mostly kept in distribution centres and not at the sites. Safety stock settings are specified in the planning systems as a cover in days. For example, given a safety stock setting of 4 days and a weekly demand of 700 cases, the cover would be 400 cases. This means that the actual safety stock level in terms of cases may deviate according to the demand.

4.5. Model Characteristics

The goal is to find the effect of the Frozen Horizon on cost. To keep the focus on this single parameter it has been decided that the frozen horizon is the main variable in the research and the lot size (both production and order quantity) will be out of scope. Certain system characteristics do not interact with the frozen horizon or the considered costs. The case study has been taken as an example to identify the relevant characteristics and costs for the research. The characteristics and parameters that influence the cost trade-off are displayed in Table 4. The effect on costs is explained as well in the right column.

From the interviews, it was concluded that the main uncertainty in the case of the factories of Kraft Heinz arises from the demand side and not from internal processes or supply of raw materials.

Uncertainties can arise from several sources, but e.g. quality issues rarely happen and when issues occur the resulting problems are relatively large. Protecting against situations relating to quality problems with safety stock will not be beneficial. Therefore, it was concluded that the following uncertainties will be considered in determining the appropriate safety stock levels:

- Demand Uncertainty/Forecast Error (for raw materials as well as finished goods),
- Transportation lead times (finished goods)

Table 4: Case study characteristics that influence associated costs

Category	Interpretation	Effect on cost
Uncertainties	Demand: uncertain and independent of other items. Transportation lead times: uncertain.	More uncertainty increases the need for Safety Stock.
Commonality of raw materials	For the TBS part, almost all products use some form of tomato paste. The share of commonality of that material is rather high. For the other sauces the commonality share is smaller.	Commonality could reduce the uncertainty in raw material demand and thus affect Safety stocks.
Perishability	All finished goods have a shelf life. A trade Best Before End (BBE) Date[14] states what the last date is before which the product must be sold to direct customers (not the consumer). Raw materials can also have a shelf life.	A Shelf life affects the allowed amount of inventory that can be kept.
Lead Time	The time between the initiation and the completion of a process.	The Lead Time is an input for the safety stock calculations.
Constraints	Inventory constraints are applicable for the warehouses on the raw material as well as finished goods side. Specific materials will have different constraints.	Inventory constraints affects the allowed amount of inventory that can be kept.

[14] A Trade Best Before End Date (last selling date from Kraft Heinz to Retailer) is thus different from a Best Before End Date for the consumer that specifies the date before which the product should be consumed.

5. General Model

Earlier chapters have clarified that the thesis focuses on the effect of the frozen horizon on safety stocks and the related inventory cost. The frozen horizon length affects the uncertainty of a production plan and therefore the raw material/component safety stock requirements. In parallel, the frozen horizon length affects the possibility of a production plan to react to uncertainties. Therefore, it affects the lead time of the finished goods and the associated finished good safety stocks.

First, this chapter discusses the conceptual model in §5.1. Then the general model that maps the effect of the frozen horizon on inventory cost is given in §5.2. By presenting this general model, research question 2 is answered. Finally, the model assumptions are discussed in §5.3.

5.1. Conceptual Model

The frozen horizon ensures a certain production plan (thus reducing the instability of the schedule) and increases the raw material procurement and delivery efficiency. However, uncertainty will remain in the system, from e.g. uncertain customer demand or uncertain lead times. Safety stocks protect against uncertainties and ensure that the customer service level targets are reached. Jacobs (2011) states "the difference between the average demand during lead time and the reorder point[15] is called safety stock". Costs are involved in holding safety stocks. The expenses associated with maintaining any type of inventory are referred to as the inventory carrying cost (Bowersox, Closs, & Cooper, 2002). The cost for holding safety stocks is calculated by multiplying the *annual inventory carrying cost percentage* by the *average inventory value* (Bowersox et al., 2002). Inventory is often valued at purchase or standard manufacturing cost rather than the selling price (Bowersox et al., 2002). Cost included in the inventory carrying cost are cost of capital, insurance cost, operating/storage cost, obsolescence cost and taxes (Bowersox et al., 2002).

The reorder point, and thus the safety stock level, is influenced by four main factors: the demand rate, the replenishment lead time, the uncertainty in demand and in lead time and the management policy regarding the acceptable level of customer service (Jacobs, 2011). Changing the frozen horizon changes the size of the uncertainties for raw material requirements as well as the possibility of the schedule to react to uncertainties on finished goods requirements. A longer frozen horizon decreases the production schedule uncertainty (and thus the dependent demand uncertainty), leading to less raw material safety stock requirements. However, with a longer frozen horizon, the responsiveness of the system is also reduced. It will take the production schedule longer to react to changes induced by uncertainties. For a shorter frozen horizon the opposite can be stated. Therefore, the following general conclusions are formed (as elaborated on in the cost assessment in Appendix K):

1. Increasing the Frozen Horizon will increase the costs associated with holding Finished Good safety stocks and will reduce the costs associated with holding Raw Material safety stocks.
2. Decreasing the Frozen Horizon will decrease the costs associated with holding Finished Good safety stocks and will increase the cost associated with holding Raw Material safety stocks.

[15] The reorder point (ROP) refers to a stock position at which a new order is placed.

This trade-off between raw material and finished goods safety stock will be modelled by a quantitative model. This is a model that is "based on a set of variables that vary over a specific domain, while quantitative and causal relationships have been defined between these variables" (Bertrand & Fransoo, 2002) and it maps the effect of the frozen horizon on inventory cost. The model quantifies the thoughts described in the conceptual model through an analytical expression of cost. Within this analytical expression it is possible to 'optimize' the frozen horizon length in terms of cost in several systems with similar characteristics as the factories of Kraft Heinz by inserting the real-life values for the corresponding variables in the expression. The determination of the frozen horizon is subject to certain assumptions that will be discussed as well.

5.2. Frozen Horizon Effect on Inventory Cost

Safety stock formulas use a safety factor and the variance of the demand during replenishment lead time. The Frozen Horizon affects the latter parameter and therefore the safety stock requirements. Minner (2000) defines lead time as "the time span between an order release and the completion of processing or delivery, in other words availability of the products at the stockpoint to satisfy customer demands". The lead time reflects the critical time period during which the available stock cannot be influenced and therefore it warrants protection against uncertainties (Minner, 2000). As discussed the demand is stochastic and stationary. The single period demands are assumed to be identically and independently distributed (i.i.d.).

First, the frozen horizon has an impact on the uncertainty for raw materials taken into account in the model. We define the Lead Time for a raw material (LT_r) as the time (in number of periods) from ordering the raw material at an external supplier until the material is readily available for production at the factory. As the inventory status is reviewed periodically, the review interval also needs to be taken into account in determining the uncertainty over the lead time. Therefore, the variable $Time_r$ is introduced:

$$Time_r = (LT_r + R_r - FH)^+ \tag{2}$$

With the subscript r referring to a raw material, and;

$\mathrm{FH} =$ Frozen Horizon (in number of periods), i.e. the number of periods of the planning horizon that are fixed. Can only be a positive integer.

$\mathrm{R_r} =$ Review period of raw material r (in number of periods)

$\mathrm{x^+} = \max(0, \mathrm{x})$

The review period reflects, as discussed earlier, both the inventory review interval as well as the delivery interval. If the frozen horizon is longer than the review period plus the lead time of the material, then there is no demand uncertainty for the material: $Time_r = 0$. If the frozen horizon is shorter than the review period plus the lead time of the raw material, then only the uncertainty after the duration of the frozen horizon needs to be taken into account.

Second, the frozen horizon has an impact on the total accounted lead time of finished goods, denoted as $Time_f$:

$$Time_f = (FH + LT_f + R_f) \tag{3}$$

With the subscript f referring to a finished good, LT_f is the Lead Time for finished good f and R_f is the review period of finished good f. Here, LT_f is the time (in number of periods) from starting the production of f until it is readily available at the warehouse. Increasing the Frozen Horizon (as well as the Review Period and the Lead Time) decreases the change to react to changes and the uncertainty that needs to be covered.

The goal is to reduce the overall costs associated with safety stock on both the raw material (RM) as well as finished goods (FG) side. The equation that should be minimized, boils down to:

$$TC_{SS} = \sum (C_{SS_{RM}} + C_{SS_{FG}}) \tag{4}$$

In which
$\mathrm{TC_{SS}}$ = Total Cost for safety stocks in €/Period
$\mathrm{C_{SS_{RM}}}$ = Cost associated with the safety stocks for Raw Materials (RM) in €/Period
$\mathrm{C_{SS_{FG}}}$ = Costs associated with the safety stocks for Finihsed Goods (FG) in €/Period

Inventory carrying cost are calculated over a certain period (often a year), hence the Total Cost is in $€/Period$. Equation (4) can be broken down into separate parts. The cost for holding RM safety stock is the sum of the safety stocks for all separate raw materials, as follows:

$$C_{SS_{RM}} = \sum_{r=1}^{m} (h_r * P_r * SS_r) \tag{5}$$

With
$\mathrm{r} = (1, \ldots, \mathrm{m})$, referring to a Raw Material
m = number of RM's
$\mathrm{SS_r}$ = safety stock for r in unit of measurement
$\mathrm{P_r}$ = unit cost of r in €/Unit of measurement
$\mathrm{h_r}$ = inventory carrying percentage, i.e. the cost for carrying 1 euro worth of r for 1 period (often an annual percentage).

N.B.: given that raw materials in the process industry can often be measured in kilo's, meters and units, the unit of measurement can have several definitions.

Next, the cost for holding finished good safety stock is given by:

$$C_{SS_{FG}} = \sum_{f=1}^{x} (h_f * P_f * SS_f) \tag{6}$$

With
$\mathrm{f} = (1, \ldots, \mathrm{x})$, referring to a Finished Good
x = number of FG's
$\mathrm{SS_f}$ = safety stock for f in units
$\mathrm{P_f}$ = unit cost of f in €/Unit
$\mathrm{h_f}$ = inventory carrying cost for f

The Fill Rate

The system characterization clarified that the fill rate is used as the product availability measure of both raw materials as well as finished goods. This measure is important in determining the safety stock requirements. As discussed, the fill rate it is the fraction of demand directly satisfied out of inventory. We follow the definitions of De Kok (2012) for the fill rate (P_2):

$$\mathrm{P}_2 = \text{ fraction of demand satisfied directly from the shelf} \tag{7}$$

$$\mathrm{P}_2 = \text{ 1 – fraction of demand delivered as a backorder} \tag{8}$$

$$\mathrm{P}_2 = 1 - \frac{\text{expected quantity backordered in a replenishment cycle}}{\text{expected demand in a replenishment cycle}} \tag{9}$$

The equations that follow are based on the modelling of a single product in a single stock location. Local policies will be applied in which each stage manages its own inventory and fill rate. For each item, whether it is a raw material or finished goods, the requirements to reach a certain P_2 value will be considered. In presenting the approximation formulas for the safety stock levels, the framework of concepts by Silver et al., (1998) will be followed. De Kok (2012) makes the assumptions of Silver et al. (1998) explicit and these will be discussed below.

First, it is assumed that the replenishment quantity is constant and equal to Q and subsequent replenishments cannot overtake. "The average demand during a replenishment cycle should be equal to the average replenishment quantity during a replenishment cycle"(De Kok, 2012). It has also been proven that for ordering multiples of Q, the approximations still hold (De Kok, 2012). Backorders arise when the demand during the lead time is higher than the reorder level, and thus P_2 can be written as:

$$P_2 = 1 - \frac{E[(D_L - s)^+]}{Q} = 1 - \frac{1}{Q} E[(D_L - s)^+] \tag{10}$$

With
$\mathrm{D_L} =$ stochastic demand during the lead time
$\mathrm{E}[\dots] =$ expectation
$\mathrm{Q} =$ replenishment quantity
$\mathrm{s} =$ reorder level

For any continuous demand distribution $f(x)$ the expected number of items short, or expected backorders, is given by the following expression:

$$E[B] = \int_x^{\infty} (x - s) f(x) dx \tag{11}$$

In case of deterministic Lead time (L) and single period demand having a normal distribution (with mean μ and standard deviation σ), the demand during the lead time (D_L) is also normally distributed with mean $\mu * L$ and variance $\sigma^2 * L$ (and thus standard deviation $\sigma * \sqrt{L}$). Every normal distribution is a version of the standard normal distribution (which has a mean $\mu = 0$ and standard deviation $\sigma = 1$). If X is a normally distributed variable with mean μ and standard deviation σ, then variable $Y = \frac{X - \mu}{\sigma}$ will have the standard normal distribution.

Therefore, as explained by De Kok (2012), on the additional assumptions that the net inventory after arrival of an order is positive and the demand over the lead time is normally distributed, P_2 can be written as follows:

$$P_2 = 1 - \frac{\sigma * \sqrt{L}}{Q} * E\left[\left(\frac{D_L - \mu * L}{\sigma * \sqrt{L}} - \left(\frac{s - \mu * L}{\sigma * \sqrt{L}}\right)\right)^+\right] = 1 - \frac{\sigma * \sqrt{L}}{Q} * E[(Z - k)^+] \qquad (12)$$

Here, Z has the standard normal distribution. Given this distribution, the expected backorders can now be denoted by the loss function ($G(k)$):

$$E[(Z - k)^+] = G(k) = \int_k^\infty (x - k)\phi(x)dx \qquad (13)$$

For a standard normal distribution the probability density function, $\phi(y)$, is given by:

$$\phi(x) = \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{1}{2}x^2\right)} dx \qquad (14)$$

Thus, we get;

$$G(k) = \frac{1}{\sqrt{2\pi}} \int_k^\infty (x - k) e^{\left(-\frac{1}{2}x^2\right)} dx \qquad (15)$$

The cumulative standard normal distribution $\Phi(y)$ is given by

$$\Phi(y) = \int_{-\infty}^{y} \phi(x)dx = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{y} e^{\left(-\frac{1}{2}x^2\right)} dx \qquad (16)$$

$G(k)$ from (15) is equal to:

$$G(k) = \int_k^\infty (y - k)\varphi(y)dy = \int_k^\infty y\varphi(y)dy - \int_k^\infty k\varphi(y)dy$$
$$G(k) = -\varphi(y)\Big|_k^\infty - k\big(\Phi(\infty) - \Phi(k)\big) = \varphi(k) - k(1 - \Phi(k))dy \qquad (17)$$

This loss function is tabulated in Appendix R, but equation (17) can also be calculated with the following excel formula:

$$G(k) = \mathrm{NORMDIST(k, 0,1,0)} - \mathrm{k} * (1 - \mathrm{NORMDIST(k)}) \qquad (18)$$

A target is set for the fill rate (P_2) which the inventory control system is trying to reach. We are interested in the requirements in terms of safety stock to reach this fill rate. Still given the situation of deterministic lead times and normally i.d.d. demand, the safety stock level (SS) is defined as the difference between the reorder level and the demand during the lead time as follows:

$$SS = s - \mu * L \qquad (19)$$

Now define k_β, referred to as the *safety factor*:

$$k_\beta = \frac{s - \mu * L}{\sigma * \sqrt{L}} \tag{20}$$

And hence;

$$SS = k_\beta * \sigma * \sqrt{L} = k_\beta * \sqrt{\sigma^2 * L} \tag{21}$$

Denote the target for the fill rate P_2 as β. Now, from equation (12) we get:

$$\beta = 1 - \frac{\sigma * \sqrt{L}}{Q} * G(k_\beta) \tag{22}$$

$$1 - \beta = \frac{\sigma * \sqrt{L}}{Q} * G(k_\beta) \tag{23}$$

$$G(k_\beta) = \frac{(1-\beta) * Q}{\sigma * \sqrt{L}} \tag{24}$$

With the parameters (β, Q, σ, L) a value can found for $G(k_\beta)$. The numerical value for k_β can be found in the earlier mentioned table in Appendix R. The safety factor only makes sense for positive values.

Up until now it was assumed that the lead times are deterministic. From the detailed analysis it became apparent that the standard deviation of the lead time for raw materials is close to zero and therefore this parameter will be assumed to be deterministic. However, this is not the case for finished goods. In addition, forecasted demand figures are used and therefore the standard deviation of the forecast error should be used instead of the standard deviation of the demand. When taking this into account equation (21) becomes (De Kok, 2012; Donselaar & Broekmeulen, 2014):

$$SS = k_\beta * \sqrt{\sigma_D^2} = k_\beta * \sqrt{\sigma_e^2 * \mu_L + \mu_d^2 * \sigma_L^2} \tag{25}$$

With

$\sigma_D^2 =$ variance of demand over the lead time

$\sigma_e^2 =$ variance of forecast error per period

$\mu_L =$ mean lead time in periods

$\mu_d^2 =$ mean demand squared per period

$\sigma_L^2 =$ variance of lead time per period

Considering the stochastic character of the lead time of finished goods, equation (24) becomes:

$$G(k_\beta) = \frac{(1-\beta) * Q}{\sqrt{\sigma_D^2}} \tag{26}$$

One of the assumptions here is that both the forecast as well as the replenishment lead time are stochastic, independent and normally distributed. The interpretation of the lead time is given by equation (2) and (3) for raw materials and finished goods respectively. Although the replenishment lead time for raw materials, LT_r, is considered to be deterministic, the replenishment lead time of finished goods, LT_f, is stochastic with a normally distribution and its own mean and standard deviation.

Variance of Forecast Error

Let Y_i denote the observation over period i (i.e. the actual value) and let $F_{j,i}$ denote the forecast at time j for period i. Then the forecast error is defined as $e_{j,i} = Y_i - F_{j,i}$ (Hyndman & Koehler, 2006)[16]. For the variance of the forecast error, σ_e^2, the mean squared error is used:

$$\sigma_e^2 = Mean\ Squared\ Error = \frac{1}{n}\sum_{i=1}^{N}\left(Y_i - F_{j,i}\right)^2 \tag{27}$$

Where:

$\mathrm{N} = \text{Number of periods}$
$\mathrm{j} = 0, \dots, \mathrm{i}$ (as a forecast can only be given in periods preceding the end of period i)
$\mathrm{i} = 1, \dots, \mathrm{N}$

5.2.1. Total Objective Function

The safety stock levels calculated with equation (25) for both raw materials and finished goods are an input for the cost functions in equations (5) and (6), and consecutively the total cost function in equation (4). Combining the discussed expressions leads to the total cost function in equation (28). The objective is to minimize the total cost by changing the Frozen Horizon. The parameters present in this objective function are grouped in Table 5. The model shows the effect of the frozen horizon on inventory costs related to safety stocks, answering to the first part of the third research questions “What is the effect of the frozen horizon on cost, considering the system characteristics?”.

Table 5: Parameters used in the total objective function

Parameter	Description
k_β	Safety Factor
σ_e^2	Variance of forecast error
μ_d^2	Mean demand squared
σ_L^2	Variance of replenishment lead time
LT_r	Lead time for raw material r
LT_f	Mean for finished good f
R_r	Review period for raw material r
R_f	Review period for finished good f
FH	Frozen Horizon
P_r	Unit cost of raw material r
P_f	Unit cost of finished good f
h_r	Inventory carrying cost of raw material r
h_f	Inventory carrying cost of finished good f
m	Number of raw materials
x	Number of finished goods

The total objective function:

$$TC_{SS} = \sum \left[\begin{array}{c} h_r * \sum_{r=1}^{m}\left\{P_r * \left[k_\beta * \sqrt{\sigma_e^2 * (LT_r + R_r - FH)^+}\right]_r\right\} + \\ h_f * \sum_{f=1}^{x}\left\{P_f * \left[k_\beta * \sqrt{\sigma_e^2 * (FH + LT_f + R_f) + \mu_d^2 * \sigma_L^2}\right]_f\right\} \end{array}\right] \tag{28}$$

[16] For more information on forecast accuracy measures and the forecast error, see Appendix L and Literature Study Part II (Crolla, 2016).

5.3. The Model Assumptions

The model does not explicitly take into account all system characteristics of Kraft Heinz. The second part of the 3rd research questions refers to the system characteristics as the model should be applicable to systems similar to those of Kraft Heinz. The commonality of raw materials is indirectly taken into account when computing the Mean Squared Error of the raw materials, as the variability of the error should reduce when multiple variability sources are combined. Certain assumptions have been made in constructing the model that do not completely reflect the real life environment. Some of the assumption are more extensively discussed in Appendix Q and in Chapter 6 the assumptions are discussed and tested for the pilot case. The assumptions mentioned in this chapter are:

I. The demand is stationary.
II. The demand has a normal distribution with expectation μ_d and variance σ_d^2.
III. The single periods demands are identically and independently distributed.
IV. The forecast error has a normal distribution with expectation μ_e and variance σ_e^2.
V. No capacity constraints are present (in terms of inventory or production).
VI. The items are not perishable.
VII. The service level of raw materials does not affect (or interact with) the service level of finished goods. Each station optimizes its safety stock level locally.
VIII. The replenishment quantity is constant.
IX. Subsequent replenishment orders cannot overtake.
X. There exists no undershoot.
XI. The net inventory is positive after the arrival of a replenishment.
XII. All unmet demand is backordered.
XIII. The lead time for raw materials is deterministic
XIV. The lead time for finished goods has a normal distribution with expectation μ_L and variance σ_L^2.

6. Case Study

The Case Study has been used to test and validate the model and generate several scenarios for Kraft Heinz. Data from the factory Alfaro in Spain has been used to test the model. First, in §6.1 the gathering of the data is presented. The model inputs are presented in §6.2 and the assumptions are discussed in §6.3. Finally, the scenarios and the related sensitivity analysis will be presented in respectively §6.4 and §6.5.

This Chapter also aims to answer the following research questions, "What is the optimal setting for the frozen horizon length in terms of costs for the case study?".

6.1. Gathering the Data

The data has been gathered through the Planning Software, the ERP system, interviews with stakeholder and several offline reports. A macro model has been created based on the general model presented in Chapter 5. It uses the inputs from all raw materials and finished goods of Alfaro.

Some data, like the forecast error was not readily available. Especially, the 'forecast accuracy' for raw materials has not been monitored or measured. For finished goods the forecast error was gathered over multiple forecast accuracy reports. For raw materials it has been decided to compare weekly production schedules to determine the forecast error. With the finished goods production schedules the demand for raw materials is determined through the explosion of the Bill of Materials. The schedule at the time of ordering a raw material has been compared to the schedule of the week the material was consumed (referred to as 'consumption' week). It has been assumed that the 'consumption' week production schedule represents the actual demand for the raw materials. The difference between the schedules is assumed to be the forecast error. This means that the lag (as described in equation (27)) depends on the lead time of the raw material. Based on the availability of data, the production plans of 10 weeks together with the BOM and lead time information of the raw materials have been used to determine the forecast accuracy. Finally, one of the difficulties has been that not all data was well maintained and thus different values might be present across systems.

6.2. Model Inputs

The values for the parameters of the objective function (equation (28)) are gathered for the model. The inputs are discussed below, starting with the main variable of this thesis, the frozen horizon.

Frozen Horizon (FH)

This variable of the objective function has been varied to see the effect on the raw material and finished goods safety stocks and on the total cost associated with holding this inventory.

Some notes on the this variable. First, although the frozen horizon can technically take the value of any positive integers, practically the system allows only frozen horizons that are multiples of the replanning interval of 1 week. However, to see the effect of the frozen horizon more clearly, the time period is set to 1 day for the model. Second, in the literature the frozen horizon is defined just after the replanning interval. However, for finished goods the relevant part that needs to be covered, is the time of the production schedule that is fixed at the moment the decision is taken, i.e. at the review moment just before freezing an additional period. At the review moment, the relevant frozen horizon is actually the size of the frozen horizon minus the replanning interval. For raw materials, it is the other way around. Just after freezing an additional week, new certainty is added to the production plan. Therefore, the relevant frozen horizon is the frozen horizon length as defined in the literature.

Safety Factor (k_β)

The safety factor is determined by finding the loss function $G(k_\beta$with equation (26). For this equation the fill rate or Customer Service Level target is required. For all raw materials and finished goods this target has been set to 98.5%, therefore $\beta = 0.985$. In addition, the replenishment quantity, interpreted as the Average Replenishment Quantity (Q_A), is used and determined as follows:

$$Q_A = \frac{Demand\ over\ 12\ months}{Number\ of Replenishments\ over\ 12\ months} \tag{29}$$

For raw materials, the demand over the last 12 months is divided by the number of replenishments over the same period. There is not a proper procedure to estimate the number of replenishments in the future for raw materials, therefore it assumed that if the demand grows, the number of replenishments grows as well, levelling out the effect on the replenishment quantity. For finished goods, the Planning Software creates a production plan up to 2 years. Therefore, the demand for the next 12 months and the expected number of replenishments is used to calculate the average replenishment quantity. The expected number of replenishments is assumed to be similar to the number of planned productions, which is a reasonable assumptions given that a single production is mostly for a specific location thus resulting in a single replenishment.

The variance of the demand over the replenishment lead time (σ_D^2) is an input for the loss function as well and is calculated as follows:

$$\sigma_D^2 = \begin{cases} \sigma_e^2 * (LT_r + R_r - FH)^+, & \text{Raw materials} \\ \sigma_e^2 * (FH + LT_f + R_f) + \mu_d^2 * \sigma_L^2, & \text{Finished goods} \end{cases} \tag{30}$$

With these inputs a numerical value is found for $G(k_\beta)$. As discussed, either with the table in Appendix Q or the excel function of equation (18), the corresponding k_β value can be found.

Variance of the Forecast Error (σ_e^2)

Equation (27) is used to determine the Mean Squared Error for both raw materials and finished goods. A total of 10 weeks of data was used to determine the forecast error for raw materials on a weekly level. The lag is related to the lead time of the raw material. The forecast for finished goods is only done on a monthly level, therefore these forecast figures were used to determine the variance of the forecast error for finished goods. A total of 7 months (due to data availability) was used to determine the variance of the forecast error. The lag for finished goods is set to $i - 1$, this means that for example the forecast released at the start of April is compared to the actual demand in May. The time period used by the other variables in the objective function is days, therefore variance of the forecast error per day was used.

Mean Demand Squared (μ_d^2)

The average demand per day has been calculated based on the forecasted future requirements of the upcoming 12 months.

Variance of Replenishment Lead Time (σ_{LT}^2)

For raw materials a value of 0 days is used. Not much data was available to check this assumption. However, based on interviews with the stakeholders at the site, it was concluded that raw materials are mostly delivered on time. In addition, the goods receipt processing time (GRPT) that is present for raw materials can be sped up in case of a late delivery, therefore any late deliveries do not directly impact the availability of raw materials.

The variance of the replenishment lead time for finished goods has been set at 2 days. The planning system plans on a weekly level and assumes that production happens on a Wednesday. However, in reality that order can be scheduled by the schedulers at the site on any day of the workweek. Accordingly, orders can arrive up to 2 days earlier or later. The deviations of the lead time in comparison to Wednesday are: -2, -1, 0, 1, 2; referring to Monday until Friday. In addition, an analysis has been done on a dataset of several deliveries. For a part of the volume the transportation time is not relevant as the warehouse is next to the factory. However, for the other warehouses an additional 1 day variance is assumed.

Time Raw Materials (Ti $_r$)

For the time taken into account for raw materials, equation (2) ($Time_r = (LT_r + R_r - FH)^+$) is used. The review period (R_r) for all raw materials is set to 1 week. The lead time of raw materials (LT_r) is made up out of the time between ordering at the supplier and the delivery at the factory (denote as DT_r, i.e. delivery time) plus the Goods Receipt Processing Time ($GRPT_r$) [17]: $LT_r = DT_r + GRPT_r$. The first part is a contractual agreement with the supplier, while the second part refers to the time required for quality checks and administrative tasks at the warehouse of the factory. The materials have a quarantine period in which they are not ready for production as the quality of the materials needs to be checked. This quarantine period is included in the GRPT.

Time Finished Goods ($Time_f$)

The time taken into account for finished goods consists of the review period (R_f = 7 days), the lead of the finished good (LT_f) and the Frozen Horizon ($FH + LT_f + R_f$). The lead time of the finished good takes into account the production time (PT_f), the transportation time from the factory to the warehouse (TT_f, i.e. transportation time) and the processing time at the warehouse before it is readily available to be sold to a customer ($GRPT_f$): $LT_f = PT_f + TT_f + GRPT_f$. Similarly to the raw materials, finished goods have a quarantine time in which quality investigations are done and the goods are not released for sales yet. The production time is set to 1 day, as daily transportation to the warehouses is possible. The transportation times are maintained in the system and depend on the warehouse location.

[17] Goods Receipt Processing Times (GRPT) exist for raw materials (generally 3 days) and for finished goods (varies between 0 to 14 days depending on the quarantine time) within Kraft Heinz.

Unit Cost (P_r and P_f)
The standard price at which raw materials are bought is used as an input. For finished goods the *Cost of Goods Sold* is used as an input.

Inventory Carrying Cost (h_r and h_f)
In Kraft Heinz the yearly inventory carrying cost for equal for all raw materials and finished goods and it is given by a certain percentage of the average inventory value. This percentage is used in calculating the cost of holding inventory and includes rent, insurances, taxes, cost of deterioration, cost of capital and cost of handling the items.

Number of Items (m and x)
Based on information from the planning system, the number of raw materials as well as finished goods have been determined. Not all items that have been set up in the system still have a forecasted demand. The group that still has a forecasted demand has been used as an input.

6.3. Assumptions
Besides the assumption discussed throughout the previous paragraph, certain model assumptions are highlighted below. First, the assumptions as discussed in the construction of the general model in Chapter 5 will be discussed (§6.3.1). Then, certain assumptions relevant to this chapter on the validation of the model in the real-life environment of the case study, are discussed (§6.3.2).

6.3.1. Creation of Model – Assumptions
The assumptions discussed during the construction of the model are;

I. **The demand is stationary, (II) has a normal distribution with expectation μ_d and variance σ_d^2 and (III) the single periods demands are identically and independently distributed.**

Through the analysis of the demand it became apparent that in general the demand is rather stationary. However, in some items a certain trend might be recognized. It has been assumed that the single period (1 day) demands are identical. In reality the demand might be higher at certain days of the week. In addition, the demand for raw materials as well as finished goods happens on weekdays and not in the weekend. However, for mathematical reasons the i.d.d. assumption has been used. Although the demand is not present during the weekends, the transportation and quarantine periods can still happen over the weekend. Therefore, it is more useful to use a day as a single time period.

IV. **Forecast Error has a normal distribution with expectation μ_e and variance σ_e^2**

First, the lead time of the raw materials is used to determine the forecast error for raw materials. It has been assumed that the forecast error is evenly distributed over the lead time. However, in general a forecast is less accurate over a longer period then over a short period. In the case of finished goods, it has been decided to determine the forecast error based on a lag of 1 for all finished goods. This has been done as currently most plans are based on that forecast, but in reality with a very long frozen horizon the plans are based on an older forecast.

Second, it has been assumed that there exists no error for raw materials within the frozen horizon, however, this might not be the case in reality. For example, it might be decided to produce more than forecasted because the production runs well.

Third, in gathering the inputs for the model it is assumed that the forecast error includes all errors, negative and positive. Any forecast bias that could be present has not been considered. However, the detailed analysis has shown that on average there was a slight tendency to over-forecast the demand. This would mean that in reality there is a lower requirement for safety stocks.

V. No capacity constraints are present (in terms of inventory or production)

In reality always certain constraints are present, however, both storage and production capacity constraints have not been considered. Generally, the assumption is valid for finished goods safety stock. However for certain raw materials storage limits exist. Especially certain bulk materials like oil and sugar. Luckily their demand is rather stable and the delivery can happen more frequently than once a week. In addition, some lines might have capacity issues that are not taken into account.

VI. The items are not perishable

In the world of food processing, perishability of goods or obsolete stock (because of label changes for example) can always cause a problem. However, mainly lot sizing decisions are the reason for these problems. Safety stock would only result in problems if extreme cases would be chosen for the frozen horizon leading to either very high raw material or very high finished goods safety stocks.

VII. The service level of raw materials does not affect (or interact with) the service level of finished goods

The reason behind this assumption is that it is assumed that in the situation of raw materials not being in stock, this will mainly affect the next production and will not directly affect the finished good availability. In reality, expediting certain orders can often help mitigate problems occurring from the lack of raw materials. For sensitivity purposes, this assumption will be explored in one of the scenarios.

VIII. The replenishment quantity is constant

With the Period Order Replenishment rule, the replenishment quantity changes over time according to the forecasted demand for the next period that should be covered. The assumption is used in the input-output balance by De Kok (2012) in deriving the reorder and safety stock formulas. The balance states that the average demand during a replenishment cycle is equal to the average amount replenished during a replenishment cycle. On the long run, it is assumed this will also be the case for the replenishment systems of the case study.

IX. Subsequent replenishment orders cannot overtake

This is a reasonable assumption as generally replenishments that follow each other have no reason to overtake one another.

X. There exists no undershoot

The replenishment decisions are taken after reviewing the inventory position. As the inventory control system uses a review period of 1 week, there will exist a difference between the reorder level and the inventory position at the moment of the replenishment decision. However, this undershoot has been assumed not to be present as it is complicated to explicitly model and determine the expectation and standard deviation of the undershoot.

XI. The net inventory is positive after the arrival of a replenishment

Given the service level and the usage of minimum replenishment quantities, this assumption is reasonable. The high service level triggers replenishment at an early stage. In addition, the minimum replenishment quantity is often relatively large compared to the single period demand. Therefore, after an arrival it is assumed that the backorder can be covered and the net inventory is thus positive.

XII. All unmet demand is backordered

As has been discussed in the detailed analysis, it can be assumed that unmet demand is backordered under a reasonable level of out of stock situations. As soon as the number of items out of stock reaches a certain level there might be a change customers are actually lost. For the case study, it is valid to assume that unmet demand will be backordered.

XIII. The lead time for raw materials is deterministic

As discussed in the detailed analysis, it is reasonable to assume a deterministic lead time of the raw materials.

XIV. The lead time for finished goods has a normal distribution with expectation μ_L and variance σ_L^2.

Although the production possibilities are not normally distributed over the week, the variance on the production day has been assumed to be 2 days with a normal distribution. In reality this covers the part that production might be a day faster or slower compared to the plan. This would mean that more of a normal curve appears on the total lead time. In addition, a variance on the actual transportation times is present that is characterized by a normal distribution.

6.3.2. Validation of Model – Assumptions

For the validation of the model, new assumptions and considerations arose in terms of inventory cost, data accuracy and the frozen horizon length.

XIII. Inventory cost

Inventory cost for raw materials have been assumed to be equal to inventory costs for finished goods. Although the model can incorporate a different number for the holding cost for raw materials and finished goods this has not been specified by Kraft Heinz. Implicitly it is considered as the value of raw materials is lower compared to finished goods, but the yearly inventory carrying cost percentage is equal.

XIV. Data accuracy

Data gathering for all the inputs has shown that the data consistency and accuracy can be quite a problem for the organization. Among others, lead times, Minimum Replenishment Quantities, inventory values and standard prices are not always well maintained in the system causing deficiencies in the data accuracy.

XV. $\mathbf{Time_f}$ length

The time taken into account for the finished goods in the objective function, is given by $(FH + LT_f + R_f)$. In reality a shorter time might be assumed, as stakeholders state that enough flexibility exists in the last week of the frozen horizon. The model of this thesis uses the longer frozen horizon and therefore suggests higher levels for safety stocks. It is difficult to incorporate this slushy time-period into a model as no clear definition are used on what changes are allowed.

6.4. Alfaro Scenario

All inputs have been gathered to run the model for Alfaro. This answers to the 4th research question: What is the optimal setting for the frozen horizon length in terms of costs for the pilot case?

When putting the frozen horizon length on the x-axis and the safety stocks of both raw materials as well as finished goods on the y-axis, the graph as depicted in Figure 8 is created. This scenario is referred to as the basic scenario (or scenario 0). The y-axis has been transformed, so as not to show the real monetary values (the proportions are still correct).

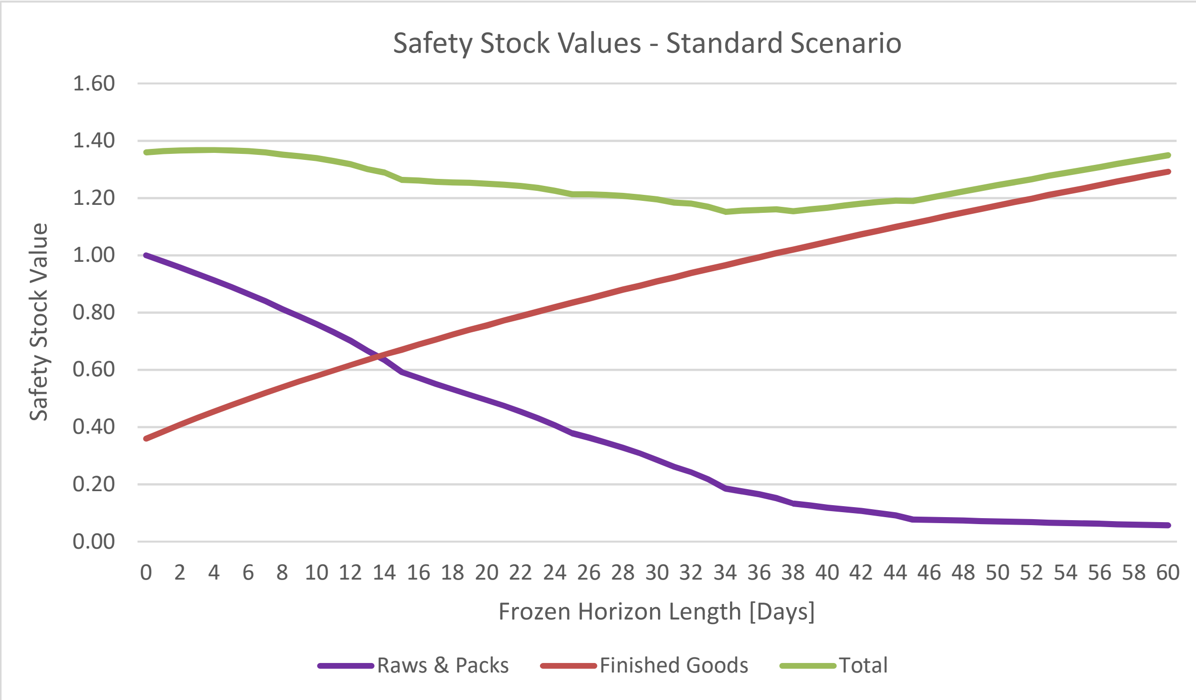

Figure 8: Raw material and finished goods safety stock inventory values for a frozen horizon length of 0 to 60 days.

The graph shows that the finished good safety stock value steadily increases with the increase of the frozen horizon. In contrast, as expected, the raw material safety stock value reduces as the frozen horizon increases. In addition, the decrease is more steep for lower values of the frozen horizon. At some point no raw material safety stock is required as all lead times are shorter than the firmed length of the production plan.

This scenario shows that the there is a minimum total safety stock inventory value around a frozen horizon of 34 days. Although the Frozen Horizon has been described in number of days, it is more realistic to assume frozen horizon lengths that align with the replanning interval of 1 week. So this would represent a frozen horizon of 5 weeks.

6.5. Sensitivity Analysis

This paragraph is aimed at the final research question "What is the main cost driver in setting the frozen horizon?". This is done by using sensitivity analysis, which will be introduced in §6.5.1, followed by the analysis results in §6.5.2.

6.5.1. Sensitivity Analysis Introduction

A definition of sensitivity analysis is given by Saltelli, Tarantola, Campolongo, & Ratto (2004): "the study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input[18]". Such an analysis can be used to identify and prioritize the most influential factors or inputs of a model (Saltelli, Ratto, Andres, Campolongo, & Cariboni, 2008).

A distinction is made between local and global sensitivity analysis. Local sensitivity analysis refers to using derivative based methods (Saltelli et al., 2008). A partial derivative of the output with respect to an input and gives the mathematical definition of the sensitivity of the output to the input (Saltelli et al., 2008). In this case Hill (2012) defines sensitivity analysis as "the process of estimating how much the results of a model will change if one or more of the inputs to the model are changed slightly". Global sensitivity analysis considers the whole variation range of the inputs (Saltelli, Chan, & Scott, 2000).

From the perspective of Kraft Heinz, this analysis helps to direct the focus of the organization. Together with the effort required to improve the variable, the focus of the company can be clarified. For example, if the sensitivity analysis shows that forecast error is a large influence on the total cost associated, the company can take this into consideration when determining the resources for reducing the cost. A trade-off exists in the cost to improve the forecast and the cost gained by an improved accuracy. Interesting variables to consider, that have been fixed in the model, are the effects of changing the forecast accuracy, lot sizes and lead time of raw materials.

6.5.2. Analysis Results

It has been decided to change the value for the following parameters:

1. Variance of the Finished Good Lead Time
2. Inventory Carrying Cost Percentage
3. Raw Material Lead Time
4. Forecast Accuracy
5. Replenishment Quantity
6. Safety Factor Calculation Method
7. Customer Service Level

Scenario 0 refers to the standard scenario as presented in §6.4, the scenarios below deviate a certain parameters one at a time compared to scenario 0.

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[18] In relation to sensitivity analysis Saltelli et al. (2008) classify an input as "everything that can drive a variation in the output of the model".

Scenario 1. Variance of the Finished Good Lead Time

If the base variance of the finished goods lead time (i.e. the variance applicable to all finished good items) is increased by 5, the graph is found as displayed in Figure 9. The RM 0, FG 0 and Total 0 lines refer to the basic scenario for the case study.

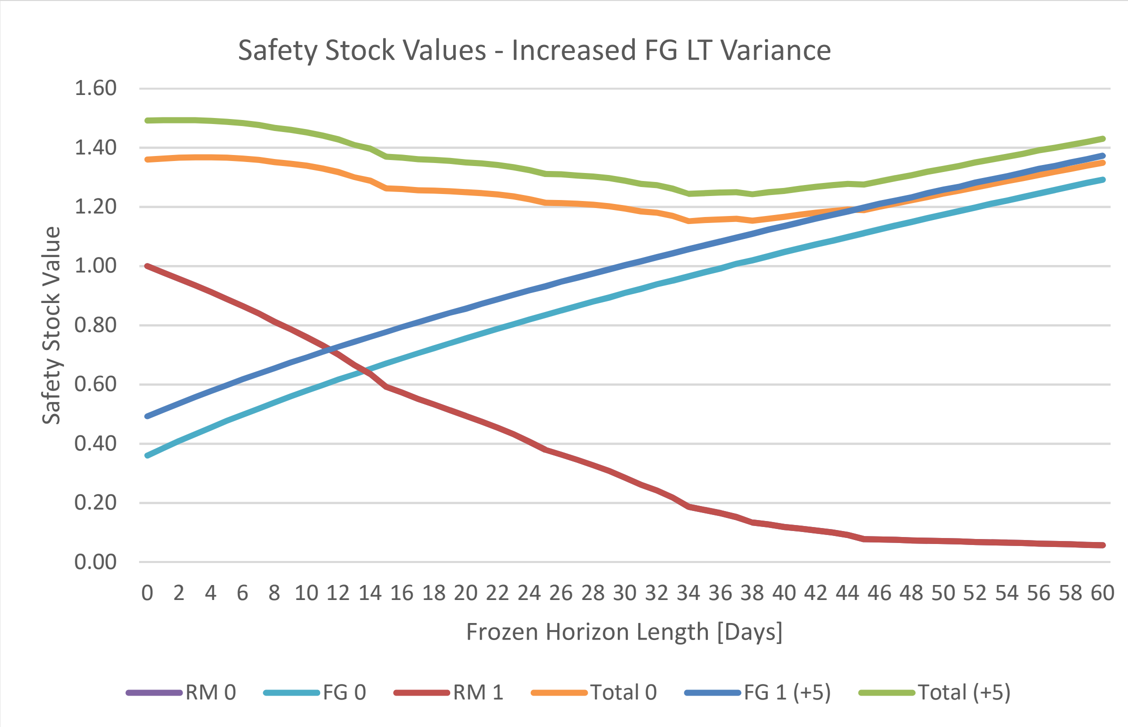


Figure 9: Safety stock values with different standard deviation of the lead time for finished goods

It shows that the FG 1 (+5) (Finished Good Scenario 1, variance +5) line is moved upwards in comparison to the FG 0 line. The total cost is equally risen, while there has been no effect on the raw material line. In this scenario, the minimum does not change.

Scenario 2. Inventory Carrying Cost

If one of the inventory carrying cost values would be increased, the minimum cost point also does not change. However, it does impact the height of the total inventory value within Kraft Heinz. No graph has been generated as it does not give any additional insights.

Scenario 3. Raw Material Lead Time

It has been chosen to reduce the lead time for all raw materials by 5 compared to the current value. This has arisen from the thought that lead times might be renegotiated with suppliers and therefore reduced. The other variables remain the same as in scenario 1. Running this scenario, results in a minimum cost with a frozen horizon of 29 days. In Figure 10 two lines are added to the basic scenario; **(1)** in dark blue raw material safety stock values with a raw material lead time of 5 days shorter than the current values (RM -5) and **(2)** the total cost in green for the 5 days shorter scenario (Total -5). The total line in green shows that the minimum moves to the left (less number of frozen days) when the lead times for the raw materials are shorter. This result is intuitive as more raw materials will have their lead time shorter than the frozen horizon.

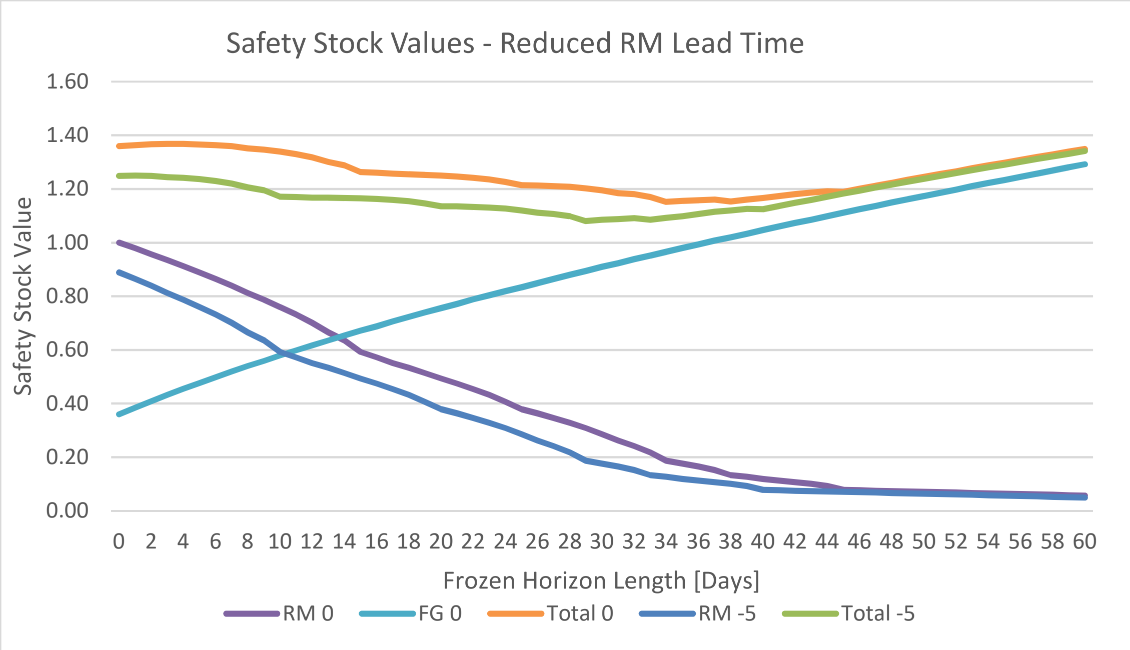


Figure 10: Scenario with shorter raw material lead times

Scenario 4. Forecast Accuracy (Finished Goods)

An organization could decide to invest in capabilities to make more accurate forecasts of the demand. This parameters is one of the main inputs for the model. In reality this forecast accuracy is related to the accuracy of raw material. However, for scenario purposes it is decided to only lower the forecast error for all finished goods; with 10% and 20%. The graph is displayed in Figure 11, with FG 0.9 referring to a forecast error of 90% of the original value. It shows that the minimum shifts to the right, toward a longer frozen horizon(around 38 days). The effect on the safety stock is moderate.

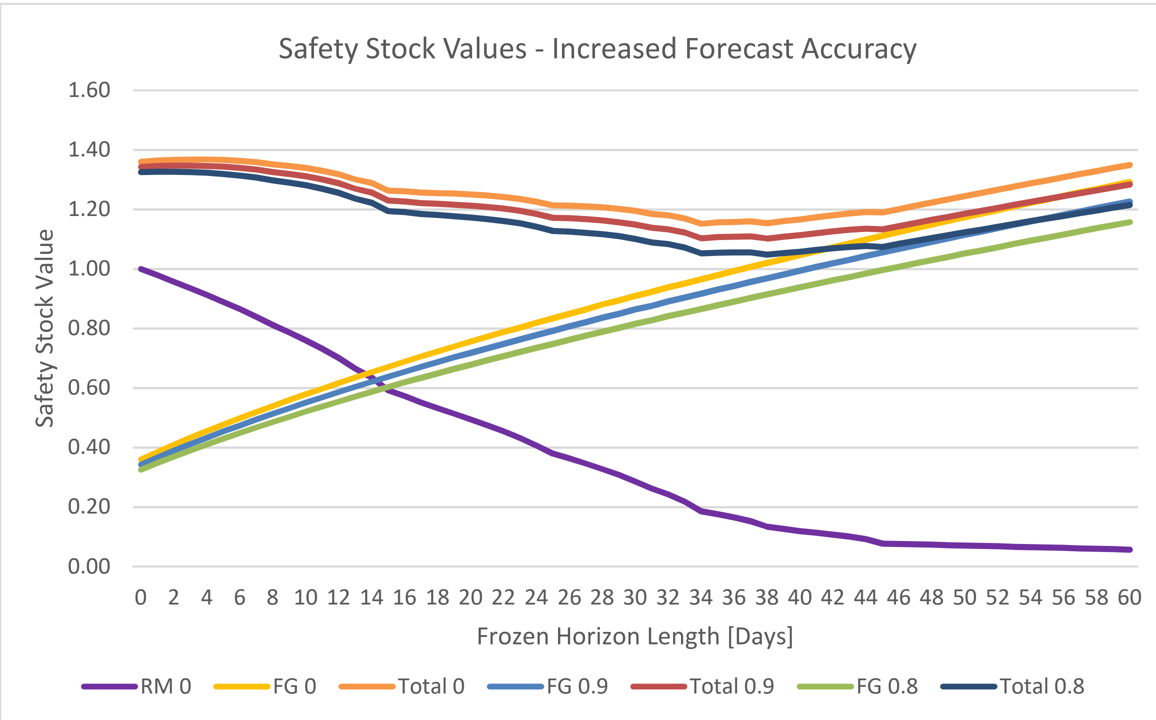


Figure 11: Scenario with a smaller forecast error for finished goods

Scenario 5. Replenishment Quantity (Finished Goods)

The number of replenishments can also be changed and this affects the replenishment quantity Q. As has been discussed in the section on the general model the replenishment size affects the safety factor and therefore the safety stock level. By multiplying the number of replenishment for finished goods by 2 and the graph as depicted below is formed (Figure 12). It shows that the newly added line (FG Q), with replenishment quantities half the size of the original scenario, rises faster than the FG 1 line. Also in this scenario the minimum is not affected. It shows that the safety stock level increases with a decrease of the replenishment size. The effect on cycle stock should be included to determine the overall effect of on the average inventory level.

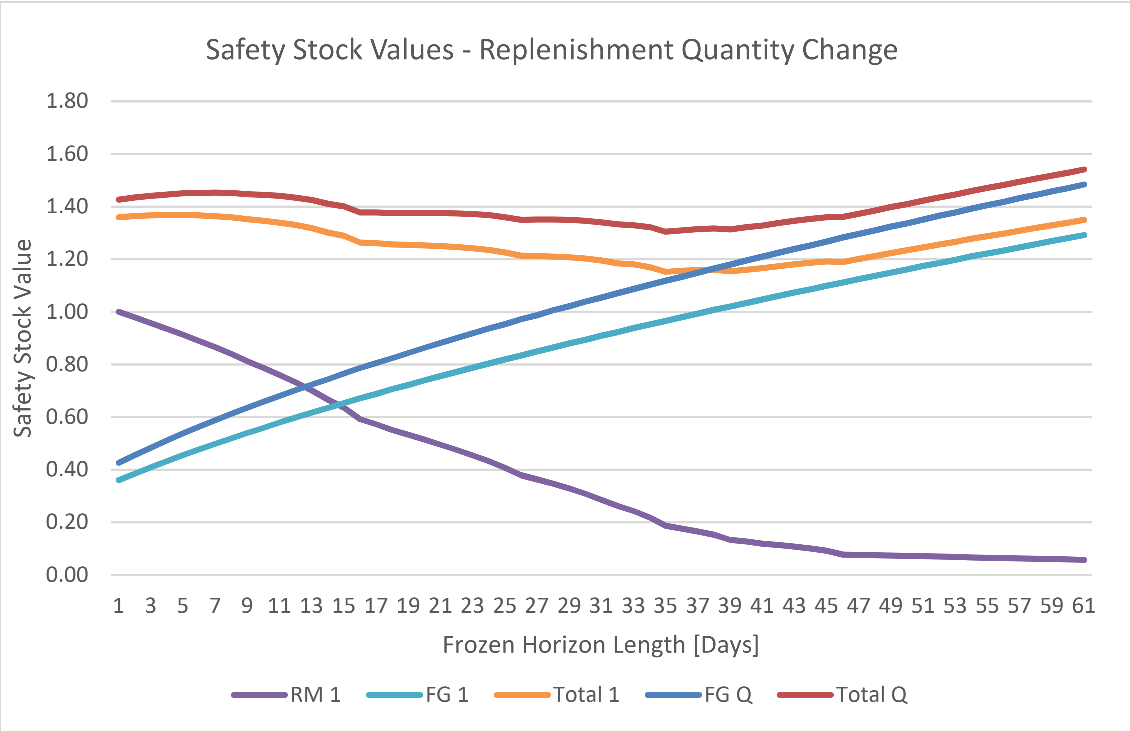


Figure 12: Scenario with different replenishment quantities

Scenario 6. Safety Factor Method

The general model has used the equations as proposed in the literature, however, the Planning Software at Kraft Heinz uses another approximation of the safety factor. It is interesting how this approximation holds up in comparison to the presented model. In the confidential Appendix (Appendix S) the approximation method is shown for the safety factor. Using this approximation results in a very similar safety stock suggestions. Both the standard scenario and the scenario with a different safety factor method are plotted in a single graph in Figure 13.

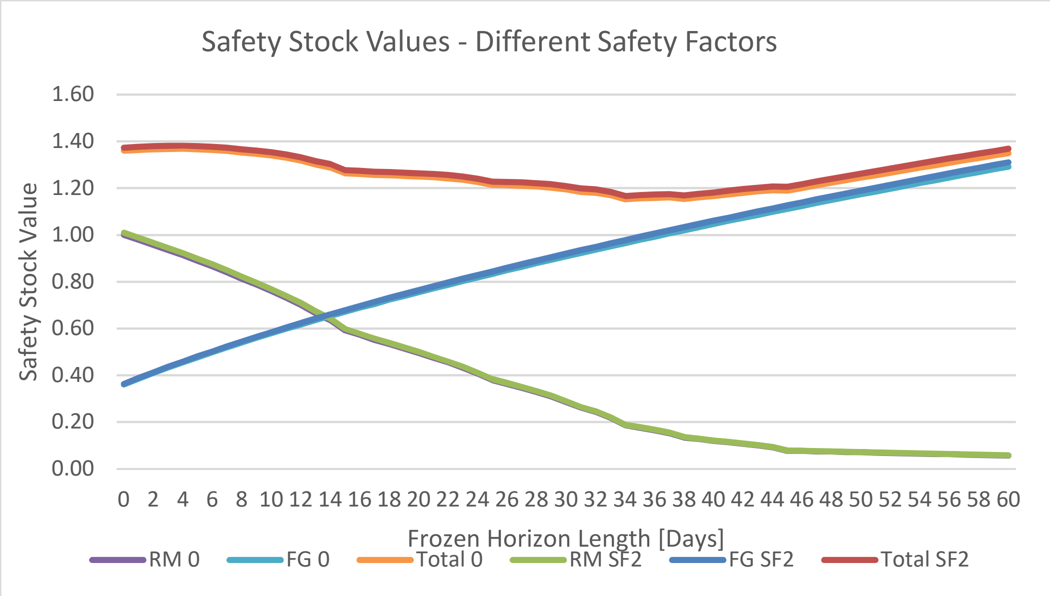


Figure 13: Scenario with different safety factor calculation/approximation

Scenario 7. Customer Service Level Target

Currently all previous scenarios have assumed that both the raw material and finished goods safety stock levels have been determined separately. The following scenario makes the assumption that with a lower raw material service level target (80%) and a higher finished goods service level target (99%) the final customer service level target set by Kraft Heinz can still be attained. The curve as depicted in Figure 14 is found with these settings. It shows that the curve for raw materials changes completely and this has a large impact on the total cost curve as well. From this can be concluded that if a lower customer service level target is required for raw materials, a shorter frozen horizon suffices and can reduce the total costs for safety stocks significantly (Total CSL line).

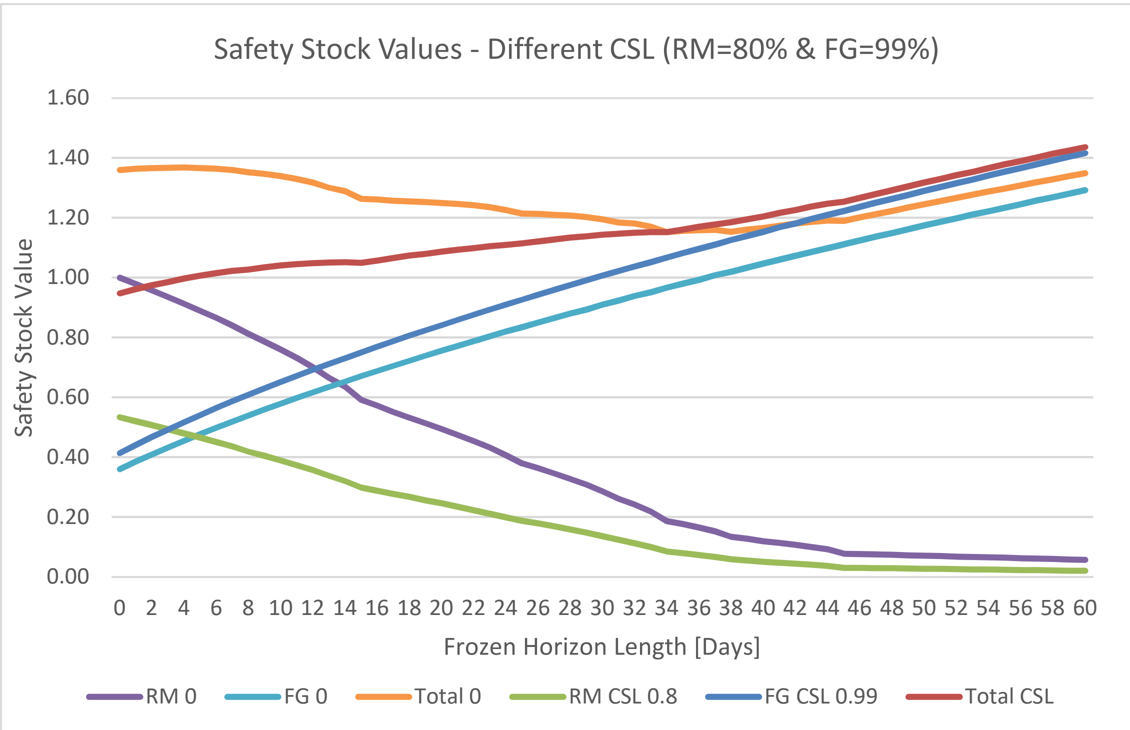
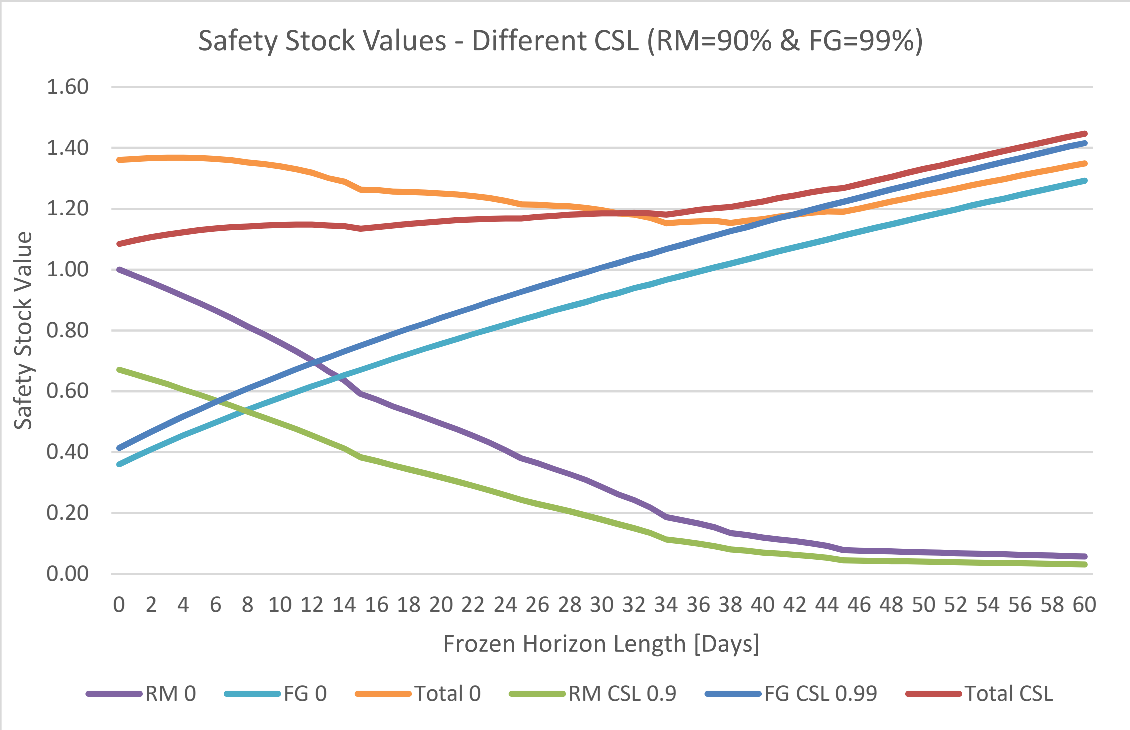


Figure 14: Scenario with different Customer Service Level targets

The effect of a service level target of 80% on the eventual service level of finished goods has not been researched. The last scenario assumes a service level target of 90% for raw materials and the same 99% target for finished goods. However, this scenario shows that for the total cost curve only just drops below the total cost curve of the standard scenario for very short frozen horizons. It has been indicated by the stakeholders that a frozen horizon shorter than 1 week is not feasible for the manufacturing sites in terms of raw material procurement, resource allocation and production plan efficiency.



7. Conclusion and Recommendations

This last chapter, starts with the scientific contributions of this thesis (§7.1), followed by insights and recommendations for the Kraft Heinz Company (§7.2). This paragraph includes a section on the future focus for Kraft Heinz and the implementation of the model. The last paragraph (§7.3) discusses the limitations of the current research and the opportunities for future research.

7.1. Scientific Contribution

The scientific contribution of this thesis can be measured by its newly added knowledge to and closing the gaps in the literature on the frozen horizon. The contribution of this thesis is the modelling of the trade-off between raw material safety stock and finished good safety stock based on the frozen horizon length. Both types of inventory are combined in an analytical expression that shows that cost savings can be made by choosing the appropriate frozen horizon length. The environment discussed in this thesis has included uncertainties in replenishment lead time and demand and focused on both raw material as well as finished good inventory. Previous research only included demand uncertainty and finished goods inventory and was mainly based on simulation models. In addition, previously no explicit effect of the frozen horizon on safety stocks (or reorder levels) has been mentioned. This thesis has presented an analytical expression of the effect of the frozen horizon on safety stocks, filling a gap in the literature.

7.2. Insights and Recommendations for Kraft Heinz

Based on the research, the insights for and recommendations given to Kraft Heinz apply to the effect of the frozen horizon on safety levels and inventory cost, data accuracy and availability, safety stock models and the sensitivity of safety stock levels to several parameters.

7.2.1. The effect of the frozen horizon

First, for Kraft Heinz clarifying the theoretical approach of setting a safety stock level has been a beneficial practice. The effects of the parameters incorporated in the safety stock model are now better understood. Training the main stakeholder (supply planners and schedulers) on the usage of the model is useful for the correct interpretation of safety stock suggestions. This research has clarified the effect of the frozen horizon on related raw material and finished good safety stock. The results have shown that the involved cost could be reduced by introducing a longer frozen horizon.

The current safety stock levels for finished goods are lower than the propositions by the model. For a frozen horizon of 21 days (the current frozen horizon length of the case study), the difference is about 13%. This is assumed to be related to the slushy zone at the end of the frozen horizon and the usage of operating flexibility. Operating flexibility refers to measures like overtime or accelerated production to cope with variability. The complexity arises in explicitly modelling operating flexibility. In real-life production environments often multiple methods are available that create operating flexibility.

In a similar way, the real-life safety stock values for raw materials are less than the model suggests. This difference is related to operating flexibility from suppliers, the fact that a part of the raw material stock is managed by the supplier and that in reality the customer service level target for raw materials might not need to be 98.5%. The difference is about 35% between the actual and suggested total raw material value.

The results of the case study have been presented to the management and manufacturing site. The differences mentioned in the previous paragraph have had their influence on the interpretation of the model by the management. The involved stakeholders indicate that it is difficult to determine whether the impact on raw material safety stock will be according to the model. For example, for some materials the safety stocks are managed by the suppliers and therefore discussions must be done with them. This decreases the possibility to swiftly change the safety stock settings. In addition, the site fears very high raw material safety stock requirements with a shorter frozen horizon and therefore the inventory capacity constraints might be difficult for certain materials, like oils. Multiple raw material contracts have incorporated a lead time of 14 days. Taking into account the goods receipt processing time, this corresponds to the current frozen horizon of 3 weeks. The planning and procurement department rely on operational flexibility being present. In case of out of stock situations, buyers often try to contact the supplier and logistical parties to get the materials at the factory within the set lead time. Given the targets to reduce the inventory levels, this has already been taken into account to drive down the actual safety stock level. Therefore, it makes the site hesitant to change the frozen horizon.

Furthermore, one could argue that, given the uncertainties about the model output, the total cost is relatively stable in the range of a frozen horizon of 15 to 44 days. The cost mainly starts to rise from approximately 44 days onwards, when the reduction of raw materials inventory value is flattening but the finished goods inventory value keeps rising steadily. With a rather flat total cost curve the emphasis might lie more on the production schedule flexibility. Given that the S&OP department is looking for more flexibility rather than less and the effect on the safety stocks is not very certain, the determination of the frozen horizon length is not a clear cut case. Therefore, there will remain a discussion between the parties that want the opposite with the frozen horizon length.

7.2.2. Data accuracy and availability

During the execution of this research, data inefficiencies were found. It has been recommended to make the data more easily available and work on data integrity. This thesis has led to initiatives to improve the data integrity and availability. No raw material forecast accuracy was maintained before the start of this project. As this is one of the main inputs for determining the raw material safety stock, a project was started to capture this metric for raw materials across Europe. This clarifies the impact of the forecast and the production schedule on the usage and availability of raw materials.

7.2.3. Additional Focus for Kraft Heinz

The cost associated with the safety stocks have been the main costs involved in the research. Safety stock levels can be improved in multiple ways apart from changing the frozen horizon settings. As we have seen in the formulas on safety stock, influencers are among others the forecast accuracy, the lead time, the customer service level target and the replenishment size.

Investigation in the minimum order quantities and minimum production quantities will be beneficial in finding cost optimal lot sizes. With the introduced model it would be possible to investigate the effect of the lot size on the safety stock requirements. Second, the forecast accuracy can be improved by better techniques and improving the communication with the customers and markets. This will lead to reduced safety stock requirements in general. However, forecasting uncertain demand will remain a difficult task. Third, renegotiating contracts with suppliers to achieve shorter lead times, lowers the safety stock requirements. Theoretically, in an environment with only demand uncertainty a material with a lead time shorter than the frozen horizon does not need safety stock. When the lead time is longer then the frozen horizon, reducing the lead time reduces the uncertainty and therefore reduces the safety stock requirement. However, discussions with the procurement team have clarified that changing procurement contracts is an intricate and slow-moving process.

7.2.4. Implementation

Among others important for the implementation of the model is the upkeep of the model itself. In general, the data gathering is time consuming and finding an automatic way would be beneficial to the usefulness of the model. The lack of a measurement for the forecast accuracy of raw materials complicates the data gathering part. To improve the usability of the model, this should be simplified.

7.3. Limitations & Future Research

The limitations of this research are at the same time indicators for opportunities for future research. The main parts left out of this thesis and are interesting for further investigation are discussed below.

7.3.1. Uncertainties

In this thesis only uncertainty in finished good lead times and demand have been considered. In reality, for raw materials supply uncertainties (like disruption and yield uncertainty) exist. In addition, inefficiencies in the internal process, amongst others quality issues, have an effect on the finished good output and availability. Including additional uncertainties in the model offers an opportunity for future research.

No differentiation has been made between timing and quantity uncertainty. More investigation and a more accurate measurement system are required to be able to clearly define the differences in uncertainty. This would ensure that certain uncertainty can be targeted more clearly. It has been assumed in the model that safety stock is the appropriate protection against uncertainty as the literature is not conclusive about which method to use (see also safety stock versus safety lead time).

7.3.2. Slush Zone

The optimization of the slush zone of the frozen horizon has not been discussed. There might be a chance to optimize the production schedule by fixing the timing of production within the slush zone, but not the quantities. This eliminates any timing uncertainty, therefore reducing the total uncertainty. In such a system, the timing information and forecasted quantities can be shared with the supplier. However, the fixing of a schedule might not be beneficial for the full system. There might be an opportunity to specify certain slush zone rules for higher utilized lines. These options have not been discussed and might be an opportunity for future research.

7.3.3. Safety Stock versus Safety Lead Time

As the literature is not conclusive in what situation to use safety stock or safety lead time, it has been chosen to only apply safety stock. However, Van Donselaar (1989) states lot sizes in MRP systems create lumpy requirements for components and in case of lumpy demand safety lead time is more effective to cover timing uncertainty. In the situation of Kraft Heinz lumpy demand can occur through the explosion of lot sized requirements of the finished goods to the raw materials. In addition, a relatively small forecast error in the finished goods, can trigger changes in the timing requirements of finished goods.

In certain cases, the Minimum Production Quantities might be so high compared to the demand that the production is for example planned every 6 months. This means that every time it is produced the MOQ is produced and the quantity uncertainty is very limited. This is shown in Table 6 below.

Table 6: Lumpy demand

Period	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Production	10	0	0	0	0	0	10	0	0	0	0	0	10	0	0	0

If raw materials used in these finished goods are unique to this product, the demand for the finished good directly leads to lumpy demand for the raw material. In other cases, where raw materials are used in multiple finished goods, the total demand might be relatively stable as lumpy demand arising from a certain finished good might be balanced out by the demand from other finished goods. If there would be some quantity uncertainty, the lack of actual output versus the forecasted output only shifts the requirement of the next production to a more recent period. A future area of research is, when is the demand for raw materials lumpy enough so that safety time is more useful than safety stock.

7.3.4. Stochastic Service approach versus Guaranteed Service approach

In terms of the multi-echelon approaches as discussed by Graves & Willems (2003) a different assumption can be taken on the usage of safety stock. This thesis has followed the stochastic-service (SS) approach by assuming that safety stock is supposed to protect the performance of the system against all demand variability (Graves & Willems, 2003). In contrast, the guaranteed-service (GS) approach assumes that safety stock only has to protect against a maximum reasonable variability (Graves & Willems, 2003). This approach assumes that operating flexibility can cope with variability above a certain level (Graves & Willems, 2003). The complexity in the latter approach arises in explicitly modelling operating flexibility. In the effort to drive down inventory costs, safety stocks can be reduced by acknowledging that a production system can buffer parts of the variability through operational flexibility. This has not been taken into account in this thesis, but offers an opportunity to reduce inventory levels for the Kraft Heinz Company.

7.3.5. Material Requirement Planning

As discussed in the literature review, Material Requirement Planning does not take into account any information on the availability of raw materials (Van Donselaar, 1989). Although MRP is very commonly used, as an alternative Van Donselaar (1992) introduces the concept of Line Requirements Planning (LRP) in which demand information for the final customer is transferred directly to each of the stages in supply chain. The demand for the final item is distorted in the MRP concept as the demand is first turned into planned orders and then exploded to the next stage (Van Donselaar, 2000). LRP increase the efficiency of planning the component requirements. However, changing this approach requires a major overhaul of the planning systems. This has not been considered but might be an interesting area for future research.

7.3.6. Replenishment Rules

During the scoping of this research it was concluded that replenishment rules are out of the scope. Determining the correct replenishment and optimizing lot sizes are separate problem that have had much attention in the literature. Including the replenishment rule can be an interesting extension of this research. In addition, as has been concluded in the cost assessment, increasing the lot sizes might increase the inventory cost related to cycle stock, but it can also decrease the cost associated with safety stocks. This balance is an interesting field for future research and would make the model multi-variate.

7.3.7. Capacity Constraints

As shortly highlighted in the literature studies, queuing theory might offer an opportunity to incorporate the effect of capacity constraints on the lead times. It offers an opportunity for future research to more accurately depict real-world systems.

7.3.8. Production cycles

Production cycles are not present in the case study. However, in some factories there are production cycles. Incorporating production cycles will impact the analysis, but it has not been considered in the model.

7.3.9. Optimization Note

The Cambridge dictionary definition of *optimize* is “to make something as good as possible”. Supply Chain Operations Planning (SCOP) problems refer to coordinating material and resource release decisions in the supply chain such that predefined customer service levels are met at minimal cost (Spitter, 2005). Although the thesis assignment did not directly relate to the coordination of materials and decision on the release of resources, the frozen horizon does interact with these production planning aspects. The aim for the production schedule is to reach a customer service level under minimal cost. SCOP problems under uncertain demand are “highly complex and optimal control is even beyond mathematical tractability” (Spitter, 2005). As discussed in the Literature Review Part II (Crolla, 2016), finding an optimal solution for a real-life Supply Chain Operations Planning (SCOP) problem with uncertainty in demand is not feasible. In combination with the assumption made, that are prone to creating a model, it can be concluded this thesis has mapped the relationship of the frozen horizon with cost within a selected framework. Optimizing the frozen horizon with the proposed analytical model, does not guarantee a real-life optimal frozen horizon length.

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Appendix A. Thesis Topic in Relation to the Master Program

This part elaborates on the Master program ‘Operations Management and Logistics’ to determine the thesis topic’s position in the curriculum. It also highlights the importance of a rigorous as well as relevant research outcome.

Operations Management and Logistics

Operations form the base of every organization (TU/e, 2015). According to the Institute for Operations Research and the Management Sciences (INFORMS), Operations Research (or operational research) is a discipline that deals with the application of advanced analytical methods to help make better decisions (INFORMS, 2015). The term is used interchangeably with Management Science, which is defined as “an interdisciplinary branch of applied mathematics, engineering and sciences that uses various scientific research-based principles, strategies, and analytical methods including mathematical modelling, statistics and algorithms to improve an organization's ability to enact rational and meaningful management decisions” (INFORMS, 2015). Operations research, industrial engineering and operations management are overlapping disciplines, often concerned with determining a maximum (such as performance) or minimum (such as cost) (INFORMS, 2015).

The Eindhoven University of Technology states that Operations Management and Logistics is a multidisciplinary field that comprises disciplines such as product development, quality management, logistics, information systems and human resource management (TU/e, 2015).

Topic Position in the Curriculum

The frozen horizon is an important aspect of production planning in manufacturing systems. Many courses of the master program (like *Modelling and Analysis of Manufacturing Systems, Supply Chain Operations Planning* and *Design of Operations Planning and Control Systems*) are related to some form of planning. In addition, production planning decisions are usually made by human planners that are assisted by decision support systems (Gasser, Fischer, & Wäfler, 2011). Courses like, *Designing Effective Performance Management Systems* have elaborated on the human resources aspect of planning. Topics within production planning and scheduling, like deciding on the optimal frozen horizon length, require scientific research based principles and analytical methods covering logistics, applied mathematics and information systems with the goal to improve the organization’s performance.

The Philosophy of Science

As part of the program Operations Management and Logistics, emphasis has been put on the aim of scientific research. The philosophy behind management science plays a role on several levels. The aspect particularly applicable to the master’s thesis, concerns the debate among scholars about the purpose or relevance of management science (Gulati, 2007). Whereas some state that science should be practical and applicable (i.e. relevant research), others state that science should aim for general rather than specific results (i.e. rigorous research). The relevant approach focusses on specific, prescriptive statements and entails data driven research. In contrast, the rigorous approach aims for descriptions and general explanations in highly idealized models. The main complaints are that rigorous research becomes irrelevant to practice, whereas relevant research does not present general explanations of a phenomenon (Katzav, 2014).

Shrivastava's (1987) criteria for rigor and relevance can be used to close the gap between the two sides of the debate (see Table 7 for an overview on the criteria). These criteria can aid in determining gaps in terms of the rigorousness and relevance of the research that has been done. In addition, they will be used throughout the master's thesis to present a balanced research that is rigorous as well as relevant, as the thesis is supposed to be a research and design assignment.

Table 7: Criteria for assessing rigor and practical usefulness of research programs, adapted from (Shrivastava, 1987)**.**

Criteria	Description
Rigor	
Conceptual Adequacy	The extent to which the research program applies the knowledge developed in their base discipline to generate theoretically adequate conceptual frameworks, raise theoretically interesting issues and choose appropriate research settings and methods for empirical examination of research questions.
Methodological Rigor	The research model used, ranging from subjectively oriented interpretive techniques using qualitative or descriptive data, to objectively oriented methods using analytical mathematical modelling techniques and quantifiable data.
Accumulated Empirical Evidence	The extent of accumulated evidence lends credibility to research findings and legitimizes them to other researchers. It provides a basis for accepting research findings as being empirically validated and thereby grounded in objective or projected reality.
Relevance	
Meaningfulness	The extent to which research findings capture and adequately describe organizational reality.
Goal Relevance	The extent to which its primary variables are relevant to organizational and managerial goals.
Operational Validity	The extent to which research results are operationalize through concrete actions or decisions. The tendency of researchers to generate non-specific, generalizable and broadly applicable knowledge reduces the operational validity and goal relevance of research results.
Innovativeness	The extent to which the research leads to new and non-obvious results.
Cost of Implementation	The cost associated with implementing the results of a research. Prohibitively expensive solution in terms of time and money are unlikely to be implemented in practice.

Appendix B. Main Topics Extended Literature Review

The extended literature review, or Literature Study of the Frozen Horizon Part II, has been guided by questions that were raised throughout the preparation and execution of this thesis. The main questions refer to uncertainty, the cost of nervousness, inventory (cost), safety stock (models) and single versus multiple echelon systems. For detailed information on these topics the reader is directed to the full report by Crolla (2016). The main topics, if not included in the main body of text of this thesis, are summarized below.

What is inventory and what costs are related to inventory?

The goal of inventory management or control is to avoid large stocks while preventing stock outs (Minner, 2000). The purpose of an inventory control system is "to determine when and how much to order […] based on the stock situation, the anticipated demand, and different cost factors" (Axsäter, 2015). Silver (1981) explicitly recognized the importance of the review interval, i.e. how often the inventory status should be determined, as a key decision variable in an inventory control system. Inventory can be split into Raw Materials, Work-In-Process and Finished Goods. Six main functional types of inventory are identified: pipelines stock (i.e. stock in transit), cycle stock (i.e. average stock during a cycle), anticipation stock (i.e. stock in anticipation of e.g. demand changes or limited capacity), congestion stock (i.e. stock held to satisfy demand during congestion of resources), safety stock (i.e. stock used as a buffer against uncertainties) and decoupling stock (i.e. inventory between stages to buffer against unaligned production/supply rates). Lot size rules and replenishment decisions interact with inventory levels (on both raw materials and finished good side) as they balance unit variable- and inventory carrying cost with ordering or set up cost.

What is safety stock and what models exist to determine appropriate safety stock levels?

Safety stock is, on average, the amount of inventory per material that is kept to deal with uncertainties, prevent stockouts and assure a certain level of product availability (King, 2011; Silver et al., 1998). "Product availability reflects a firm's ability to fill a customer order out of available Inventory" (Chopra & Meindl, 2007). A stock out occurs if a customer order arrives that cannot be satisfied with the available inventory (Chopra & Meindl, 2007). Two criteria are often used in measuring product availability: the probability of not stocking out in any given replenishment order cycle, i.e. cycle service level (CSL), and the desired level of customer service in satisfying product demand immediately out of inventory, i.e. the fill rate (Benton, 2013; Chopra & Meindl, 2007; Jacobs, 2011). Each service measure has its own method of determining the correct safety stock level. A takeaway from this section is that if the safety stock is increased, both CSL and fill rate will increase, while if the lot size is increased, the CSL will stay the same but the fill rate will go up.

Important parameters in the safety stock models are the forecast error (in terms of size and distribution) and the lead time. The quality of the forecast affects the uncertainty experienced in the system from the demand. Different forecast accuracy measures are discussed in the literature review, but the actual forecast process is out of the scope of this research.

What are single and multi-echelon systems and how does this affect safety stocks?

Multi-echelon or multi-stage systems refer to systems with multiple stages that are linked with each other through supply-demand relationships (Klosterhalfen, 2010). In such a system, each stage can potentially hold inventory (Eruguz, Sahin, Jemai, & Dallery, 2016). Multi-echelon systems require a different approach compared to single-echelon systems. In multi-stage systems a decision has to be made where to locate buffers and how to divide the stock over these points (Minner, 2000). Multi-echelon approaches consider all stages in the supply chain (from the external supplier to the final customer) at the same time to make optimal inventory decisions (Klosterhalfen, 2010). Multi-echelon systems can be classified as serial, assembly (convergent), distribution (divergent), tree (general acyclic system) and general systems (general cyclic system) (Minner, 2000; Snyder, 2008). In serial systems, each stage has at most one predecessor and one successor, in assembly systems each stage has at most one successor and in distribution systems each stage has at most one predecessor. Tree systems have no restriction on neighbours but cannot have 'cycles', whereas general systems have no restriction on both neighbours and cycles (Snyder, 2008). This last difference is shown in Figure 15.

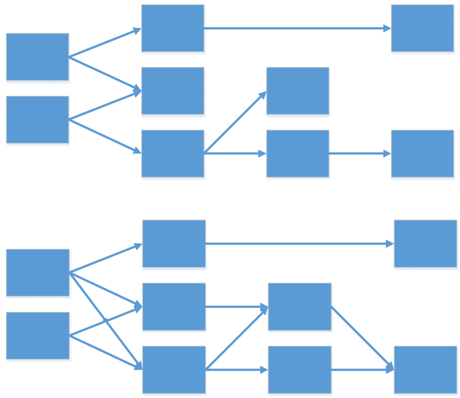

Figure 15: A tree system (top) and a general system (below) with no restrictions

What is a sensitivity analysis and how should it be done?

A sensitivity analysis is "the study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input[19]" (Saltelli et al., 2004). A distinction is made between local and global sensitivity analysis. Local sensitivity analysis refers to using derivative based methods (Saltelli et al., 2008). A partial derivative of the output with respect to an input and gives the mathematical definition of the sensitivity of the output to the input (Saltelli et al., 2008). In this case Hill (2012) defines sensitivity analysis as "the process of estimating how much the results of a model will change if one or more of the inputs to the model are changed slightly". Global sensitivity analysis considers the whole variation range of the inputs (Saltelli et al., 2000). The sensitivity analysis can be of interest from an organizational perspective to determine the focus of improvement effort.

[19] In relation to sensitivity analysis Saltelli et al. (2008) classify an input as "everything that can drive a variation in the output of the model".

Appendix C. Rolling Horizon Schedule within Kraft Heinz

The planning periods within Kraft Heinz are build up as displayed in Figure 17. The slush period used within Kraft Heinz is not fully aligned with the definition used in the literature. Order timing is not really frozen within the slush period, only the computer program is not able to replan this part of the schedule although it is not within the frozen period. Within Kraft Heinz the frozen period is characterized by the responsibility of the production schedule being at site level and therefore it cannot easily be changed by a supply planner from Zeist.

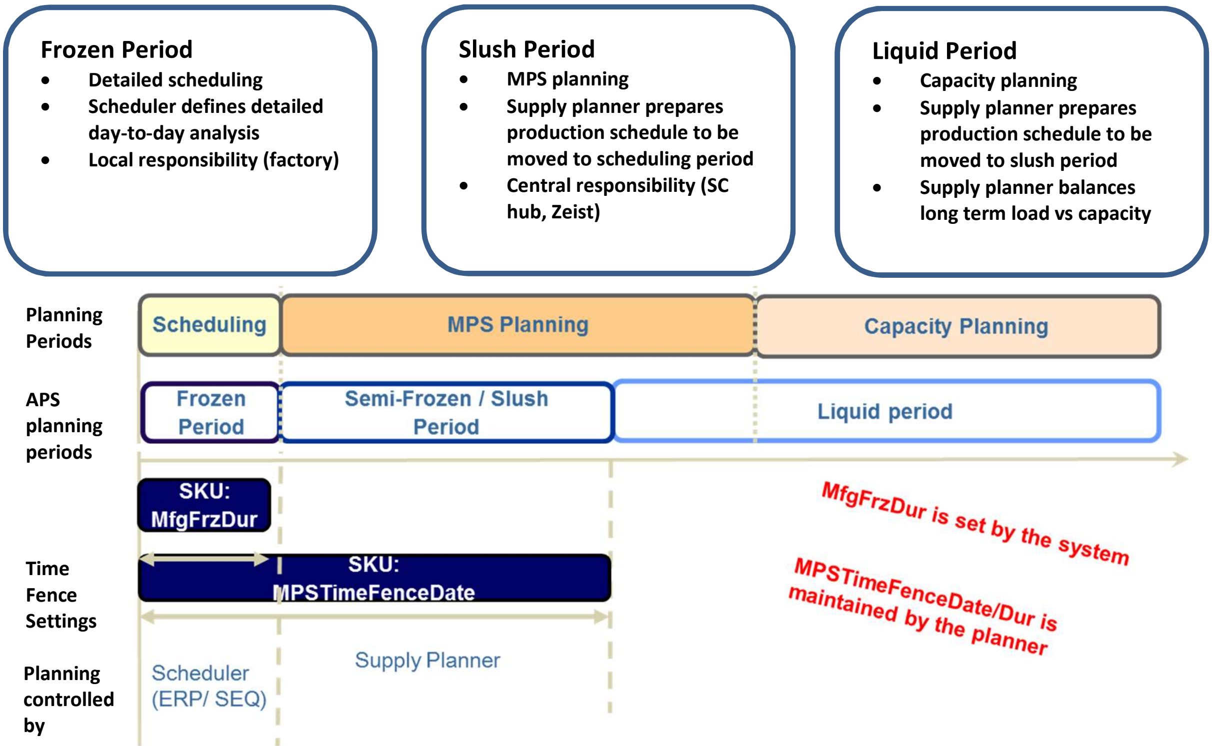

Figure 17: Planning Horizons within Kraft Heinz

The Frozen Horizon

The Frozen Horizon (FH) is also referred to by the Sales and Operations Planning department as the *Manufacturing Frozen Duration* (MFD). Within Kraft Heinz, the frozen horizon or interval length differs per manufacturing site. In general, three main groups can be identified according to the system settings in the Planning Software used within S&OP:

1. A Manufacturing Frozen Duration of 7 days
2. A Manufacturing Frozen Duration of 21 days (Most factories)
3. A Manufacturing Frozen Duration of 28 days

The frozen horizon or interval can be defined either just before or just after the rescheduling (Crolla, 2016). In this thesis the latter option will be used.

Finally, the replanning interval within Kraft Heinz is equal to 1 week. Given a MFD of 3 weeks this means that the 4th week will be firmed on the Friday the end of week 1. Although, the handover from supply planner to scheduler is on a Wednesday, the daily planning is not fixed until the end of the week.

Frozen Horizon Violations

The frozen horizon is not always considered to be completely firm. For example, given a Manufacturing Frozen Duration (MFD) of 21 days, the planning is only really fixed for the first 2 weeks and the schedule for the 3rd week can be changed if necessary. Therefore, the MFD consists of a frozen horizon plus a slush period of 2 weeks. Some rules are in place for changes that can be made to the production plan within the Frozen Horizon. For issues from demand or supply that cannot be covered by safety stocks or will lead to Best Before Date risks (i.e. deteriorating stock) changes can be requested by the supply planners or factory scheduler. Two kind of changes have been identified by Kraft Heinz:

- Add or Cancel a Master Schedule Item (i.e. a finished good that has a unique combination of ingredients, packaging and labelling) from the plan. These changes require a formal process in which approval is required by the certain managers.
- Change in volume for a Master Schedule Item from the plan. These changes only require a formal approval if the change is more than 10% of the overall plan and this cannot be recovered during the rest of the frozen horizon due to capacity constraints.

These kind of changes correspond to the quantity versus setup changes as discussed in the literature.

Appendix D. Interviews with Stakeholders

Interviews have been used to gather information about the manufacturing locations and get insights on the effect of the frozen horizon. A general interview guide approach has been used during which prepared questions are discussed, but some flexibility in phrasing, order and follow-up questions is allowed to anticipate on answers. McNamara (2006) states that such a semi-structured interview ensures that the same general areas of information are collected from each interviewee. It provides more focus than the conversational approach but still allows a degree of freedom and adaptability in getting information from the interviewee.

Two main parties are involved and affected by the frozen horizon and therefore two interviews have been drafted. The first is prepared for the supply planners at Zeist, the second is for someone in charge at the manufacturing location (most of the time the interviewee was a scheduler, who oversees the detailed daily production schedule). In total 10 supply planners, 2 supply planning managers and 6 manufacturing site representatives were interviewed. Results are summarized across several appendices.

As the research was based in Zeist, the interviews with the supply planners were conducted face-to-face. The interviews with the manufacturing sites were done through mail or conference call. The more factual questions (Interview – Supply Planner Questions 2, 3 and 4) were asked to the supply planners to get to know the factory.

Interview – Supply Planner

1. Could you tell me something about your role, what do you do?
2. What kind of products are produced at your factory?
3. How many production lines are at your factory, and what is their average utilization?
4. Is there any seasonality in demand/supply? Could you elaborate?
5. Would you prefer a shorter or longer horizon? And why?
6. What would change for you when;
    a. The frozen horizon is increased?
    b. The frozen horizon is reduced?
7. What costs would be influenced if the frozen horizon is increased/reduced?

Interview – Manufacturing Location

1. What is your role?
2. Do you prefer a shorter/longer horizon? And why?
3. What would change for you (and the plant in general) when;
    a. The frozen horizon is increased?
    b. The frozen horizon is reduced?
4. What costs would be influenced if the frozen horizon is increased/reduced?
5. What are the main sources of uncertainty for the production plan as well as procurement?
    a. Source: supply, internal/process or demand? Type: quantity or timing?
6. Are there many changes within the official frozen horizon? If so, what kind of changes?
7. Can you tell me about the raw material procurement process and its challenges?
8. Could you tell me something about the storage capacity? Or any other resource limitations?

Appendix E. Manufacturing Locations

The physical manufacturing sites are in Kitt Green (UK), Telford (UK), Worcester (UK), Alfaro (Spain), Utrecht (The Netherlands), Elst (The Netherlands), Seclin (France), Latina (Italy) and Pudliszki (Poland). The frozen horizon length can vary across lines within one site. Some frozen horizon are not considered completely frozen as changes are possible in the last week within the MFD.

The sites produce different product categories, from baby foods, quick serve meals to sauces and beans. Certain sites have been split up to improve the planning process. This means that sites might be split up according to the products they produce. Factories often produce local products, e.g. certain products produced in Latina are only sold to the Italian market and Utrecht produces many products only for the Dutch market. However, certain products are for the entire European market.

Appendix F. Frozen Horizon Insights from Interviews

Interview have been taken with the supply planners and the manufacturing locations on the effect of changing the frozen horizon on their way of working. Interviewees within Kraft Heinz indicated that the frozen horizon does not affect the efficiency of the production plan and the total changeover times (as long as the frozen horizon is minimum 1 week, i.e. the replanning interval).

Supply Planners

Interviews made clear that a short frozen horizon is preferred by the supply planners. They indicated that more flexibility will result in the possibility to change the production schedule earlier. As the forecast is most of the time higher than the actual demand, a shorter horizon will enable faster respond time to decrease the production quantities and thus prevent additional excess inventory.

Manufacturing Locations

In contrast to the planners, the manufacturing locations prefer a longer frozen horizon. They state that a longer horizon results in more certain and stable production plan and increases their control on raw material inventory. The main costs mentioned by the manufacturing locations involved in changing the frozen horizon are as follows:

1. Raw material procurement (the effects are discussed from the perspective of reducing the frozen horizon, the effects will be opposite for increasing the horizon)
    a. Lead times related to the frozen horizon: a shorter frozen horizon will require renegotiation of the procurement contracts or require additional safety stocks. It will lead to additional costs on the procurement side to ensure faster delivery or extra costs on inventory.
    b. Lead times longer than the frozen horizon: a shorter horizon will result in more materials that are already on order before the schedule is frozen. Reducing the frozen horizon will lead to problems for long lead time ingredient availability. Changes in the plan will lead to excess inventory and additional costs to get materials in with less lead time than standard.
    c. Lead times shorter than the frozen horizon: as contracts are often made for a full year the combining order won’t have a significant effect on the ordering costs.
2. Some factories work with temporary workers and therefore a shorter frozen horizon will lead to higher uncertainty and additional issues and costs concerning personnel. However, a shorter frozen horizon is not mentioned in influencing any other labour costs.
3. Because of limited storage capacity some factories need to store at the suppliers. Additional inventories, which might be required when reducing the frozen horizon, therefore lead to additional storage costs. However, this is not a common problem across the factories and therefore it will not be considered.
4. Shorter horizons lead to difficulties in finding solutions for quality and supply issues. It is possible this will increase the need for safety stocks and thus influence inventory costs.
5. A onetime investment will be required to change the systems and processes to incorporate the new frozen horizon.

In interviews with the managers at Zeist it was suggested not to include the forecast bias in the inventory models as it is a responsibility of the demand departments to avoid any forecast bias. In their task of improving this, the bias should be assumed to be not present.

In terms of way of working, the stakeholders at the factories indicated during the interviews that there ordering policies would not change under a different frozen horizon. The schedule will be less stable and will have more flexibility when having no frozen horizon. The stability of a production plan can be partly fixed by lot sizing rules, constraints or production cycles; therefore, the efficiency of the production plan does not necessarily decrease.

Appendix G. System Characteristics – Rolling Horizon Perspective

Sahin, Narayanan, & Robinson (2013) specify six categories to characterize the systems from a rolling horizon perspective: (1) Deterministic versus Stochastic demand, (2) Capacity resource constraints, (3) Setup structure, (4) Number of Items, (5) Number of manufacturing levels and (6) Number of planning layers. Generally, the manufacturing sites of Kraft Heinz in Europe have the following characteristics:

1) **Deterministic versus Stochastic demand**

The demand is forecasted and not known beforehand, i.e. **stochastic demand**. Deterministic demand would refer to scenarios in which the demand is known. As the MRP approach is used to propagate the demand to the raw material, the demand for raw materials within the frozen horizon is actually known. The production plan is fixed and therefore the material requirements for that production is known. However, the total system demand is viewed as stochastic.

2) **Capacity resource constraints**

There are **resource constraints** in terms of storage and production capacity. The tightness of the capacity constraints differs a lot per manufacturing location and production lines, but might be of importance in setting the frozen horizon length (Xie, Zhao, & Lee, 2003). Restriction might also be present on employee availability. In some factories, temporary workers are used. Scaling up in production capacity can prove to be difficult when temporary workers cannot be attracted quick enough.

3) **Setup structure**

The setup structure refers to the cost and time related to each replenishment. Two types of replenishments exist for Kraft Heinz: the replenishment of raw materials through ordering and the replenishment of finished goods through production. To clarify this part, first, the literature on this subject is refreshed and will be used as basis for the identification of the system. The setup structure is also part of the system characterization from an inventory perspective in Appendix I, but is grouped under this section.

Replenishment rules define the inventory replenishment plans, i.e. the timing and the size of replenishments (Tunc, Kilic, Tarim, & Eksioglu, 2011). The size of a replenishment is also referred to as the lot size. A lot or batch is a quantity of products bought or produced together. Thus, the lot size refers to both order quantities and production quantities[20]. The lot size determines trade-off between inventory cost and setup cost. The effect of the lot size on the setup cost depends on the setup structure. Combining products in a lot aids in achieving economies of scale and the following cost are influenced (derived from Axsäter (2003) and Chopra & Meindl (2007)):

- Unit cost, i.e. the purchase cost of the material or the production cost in €/unit. The unit cost may vary with the lot sizes used, e.g. quantity discounts may exist for raw materials.
- Ordering or Setup cost, i.e. the cost incurred each time an order is placed or a production is run (in €/replenishment).

[20] Schmidt, Münzberg, & Nyhuis (2015) defines a production lot as “the number of products processed on a production system without interruptions from the processing of other products”.

  - Ordering cost refers to costs associated with administration or labour cost to receive the order (Chopra & Meindl, 2007).
  - Setup cost in production refers to costs associated with changing the machines for a new batch/lot and include e.g. cleanings cost, tool costs and ramp-up cost (Schmidt, Münzberg, & Nyhuis, 2015).
- Holding cost, i.e. cost of carrying one unit of inventory for a certain time-period (in €/unit/period). An increasing lot size increases the total holding cost for cycle stock but does not change the holding cost per unit. Often the holding cost is expressed as a percentage of the unit value.

The total cost thus consists of purchase/production cost plus ordering cost plus holding cost. Often it is not required to find an economically optimal lot size, as "the lot size decision is not very cost sensitive in regards to deviations from the optimum" (Schmidt et al., 2015). Chopra & Meindl (2007) also state that an organization is "often better served by ordering a convenient lot size close to the economic order quantity rather than the precise EOQ.

Referring back to the setup structure, several options exist, although Sahin et al. (2013) only discuss two, a fixed setup and a joint setup structure. In the fixed setup structure the cost does not vary with the order or production lot size. Therefore, the cost per unit decreases with an increasing lot size. An example in production is as follows: regardless of the number of items produced, always a cleaning of 2 hours is required at the start of the production. The joint setup structure concerns the joint replenishment problem[21] and refers to determining the inventory replenishment policy (for both production and purchasing) of multiple items that share a common setup.

The characterizations by Karimi et al. (2003), Silver (1981) and Snyder (2008) are used for the characterization from an inventory perspective. Karimi et al. (2003) differentiate between simple and complex setup structures. A simple setup is one in which the "setup time and cost in a period are independent of the sequence and the decisions in previous periods" (Karimi et al., 2003). Complex setup structures have setups that depend on the sequence of the products. Similarities in a group of items might create a family or major setup. When changing within a family an item or minor setup might be required. The joint setup structure as discussed above includes both major and minor setups.

Within Kraft Heinz yearly contracts with suppliers are made for almost all materials and quantities can be called-off on a daily or weekly basis. Therefore, unit cost are largely fixed throughout the year and the lot size does not affect this cost. Ordering cost consists of a fixed replenishment cost (K) and a linear unit cost (c) component, i.e. ordering cost $= K + c * z$, with z is the number of units ordered. Given the MOQ, the fixed costs are relatively small compared to the total unit cost component and therefore the ordering frequency does not have a large effect on the ordering cost. The ordering cost

[21] The goal of Joint Replenishment Problems (JRPs) is to determine the time-phased replenishment schedule that minimizes sum of ordering/setup and inventory costs for a product family (Narayanan & Robinson, 2010). A joint cost is incurred each time one or more items in the product family are replenished and an item cost is charged for each item replenished (Narayanan & Robinson, 2010).

becomes a **linear** function of the ordering quantity, which is typical for suppliers that employ a MOQ (Zhao & Katehakis, 2006).

For finished goods, setup/changeover times exist between certain families of items (e.g. recipes or formats) and can vary from minutes to multiple hours. These setups are taken into consideration when determining the lot sizes. Both kitchens and filling lines require major cleaning operations (multiple hours) whenever a recipe change is planned. A change in format, e.g. change in bottle size (hours), requires less changeover times. Changing the labels requires a minor setup, taking only a couple of minutes. To reduce the number of changeovers, some production lines use production cycles, e.g. certain products might be produced every 4 weeks to reduce the setup times. The setup structure on the production side is characterized by a **joint cost structure**.

4) **Number of items**

Multiple items are produced at the sites. Here, an item refers to a sellable finished good and it consists of a unique combination of ingredients, packaging and labelling.

5) **Number of manufacturing levels**

This categorization refers to the number of entities responsible in replenishment planning. The supply planners are responsible for planning the production until it is handed over to the schedulers at the site. Within the frozen horizon, the schedulers at the sites are responsible for the day-to-day planning. Although supply planners as well as schedules are involved in planning activities, one could view this system as a **single planning layer** system as both planner and scheduler are employees of Kraft Heinz and from the same entity. However, information sharing and collaboration between these groups is very important to guarantee smooth coordination about the replenishments.

6) **Number of planning layers**

Most finished goods are have undergone several operations and processing steps. Semi-finished goods exist, but overall the production process consists of a rather straightforward production line. The sites all seem to have a **multiple-level manufacturing system** as multiple processing stages are involved. A single-level manufacturing system would refer to a situation in which the items are produced by a single operation (Sahin et al., 2013).

Appendix H. System Characteristics – Manufacturing Perspective

A manufacturing system is an objective-oriented network of processes through which entities flow (Hopp & Spearman, 2000). For manufacturing systems mostly prescriptive models are used which are derived from a set of mathematical assumptions and seek to optimize the design and control of the production system (Hopp & Spearman, 2000). This approach differs from the goal of sciences such as physics and chemistry that try to explain or describe phenomena with the fewest elementary conjectures (Hopp & Spearman, 2000). The first literature study also discussed this gap between rigorous and relevant research. In this thesis, the goal is to present a mathematical model that shows the relationship between the *Frozen Horizon* and *Cost*. To enable optimization of the design and control of a system, it should be characterized and classified. It must be recognized that models give a simplified version of the real environment. The goal is often to find an optimal result, but some modelling problems will be too difficult to solve (i.e. NP-hard). In this case a heuristic approach is used, in which the goal is to find a satisfactory or sufficient solution.

Several methods can be used for characterizing a manufacturing system. For example, Groover (2007) classifies manufacturing systems based on 4 factors:

1. Type of operations performed; Processing operations versus Assembly operations, and the type of processing or assembly operations.
2. Number of workstations and system layout; One station versus more than one station. For more than one station, variable routing versus fixed routing.
3. Level of automation; Manual or Semi-Automated workstations that require full-time operator attention versus fully automated that require only periodic worker attention.
4. Part or product variety; All work units identical versus variations in work units that require differences in processing.

In the paper by MacCarthy & Fernandes (2000) various classifications of production systems are discussed and they propose a multi-dimensional classification based on four main groups with eight dimensions:

1. General Characterization
    A. Enterprise Size
    B. Response Time
    C. Repetitiveness
    D. Automation Level
2. Product Characterization
    E. Product Description (product structure, level of customization, number of products)
3. Processing Characterization
    F. Processing Description (type of buffers, type of layout, type of flow)
4. Assembly Characterization
    G. Types of Assembly
    H. Types of Work Organization

These eight dimensions are discussed below for the manufacturing sites of Kraft Heinz. More details about the used classification can be found in MacCarthy & Fernandes (2000).

A. Enterprise Size

The most relevant descriptor for production planning and control systems is the number of employees. The Kraft Heinz company is considered a large enterprise with thousands of employees. On site level, the locations vary from small enterprises with less than 50 employees (e.g. Worcester) to large enterprises with more than 800 employees (e.g. Kitt Green).

B. Response Time

The response time refers to how an enterprise wants to attend to its customers' needs. The production system is for most sites make-to-stock in which the response time to the customer equals the distribution time of the finished goods. One of the factories is largely a make-to-order production facility.

C. Repetitiveness

An item is repetitive if it consumes a significant percentage of the annual available time of the production unit (at least 5%). A production system is repetitive if at least 75% of the items are repetitive items. Kraft Heinz sites vary between semi-repetitive (between 25% and 75% of the items are repetitive), repetitive systems and mass production systems. In this definition, a mass production system refers to a system in which almost all products are repetitive. Per production line in each location the system category can differ. Some lines are dedicated to only a small number of products, making it a mass production system. Others produce many different products, but still in rather high volumes and thus belong to either a semi repetitive or repetitive system.

In the case of Alfaro (as can be concluded from the ABC analysis in Appendix N) many items account for only a small percentage of the demand over the year and thus do not consume 5% of the yearly production time.

D. Automation Level

The production processes are largely automatized. The lines are specialized and the equipment used is often dedicated to a certain process. The employees are involved in setting up, cleaning, maintenance and control, quality checks etc. Corresponding to the Multi-station automated system with fixed routing category as identified by Groover (2007).

E. Product Characterization

Most locations produce different product categories (among others sauces, canned meals, drinks and infant feeding) and most products are available in many different flavours and sizes. The number of different finished goods produced at a side range from a handful to several hundreds. The produced volumes are overall rather high and for all products a minimum forecasted yearly demand (a hurdle rate) exists for it to be considered for production.

Furthermore, several finished goods share a common raw material. For example, sauces can be put into packaging with different sizes and thus end up in a variety of end products.

- Structure: the products have a multi-level structure, consisting of ingredients, packaging, label and tray. This is often a rather simple multi-level structure. Sites might have small semi-finished goods inventories within the production process.

- Level of Customization: The products are standard and the customers cannot interfere in the product design.
- Number of products: Multiple different products are produced at all sites.

F. Processing Characterization

First, the type of operations will be described (§F.1), followed by the processing characteristic structure used by MacCarthy & Fernandes (2000) (§F.2). In addition, the product-process matrix by Hayes & Wheelwright (1979) (§F.3) and the distinction by King, Kroeger, Foster, Williams, & Proctor (2008) on discrete versus process industry (§F.4), will be discussed to clarify the characterisation.

F.1 – Description of Operations

In general, the operations performed in the factory are quire straightforward. Simplified, the following steps occur; Ingredients are often combined in large batches in a so-called kitchen to produce a certain product. The product is put in a bottle/can/glass/sachet of different shapes and sizes on a filling line. If necessary, a product gets labelled. The last step is to package the materials, this comes often down to putting the products in trays, wrapping the trays and putting everything on a pallet.

An example of a flow in a factory is drawn in Figure 18. Its shows a glass packaging line. The kitchen area has been simplified to a single box in which the ingredients are combined and heated. The filling line starts with depalletizing pallets filled with empty jars. The jars are rinsed and then filled from the kitchen. A capper closes the jars, after which a sleeve (a kind of label) is attached that is shrunk in an oven. The jars are put in a tray and consecutively put on a pallet before moving into the outbound warehouse.

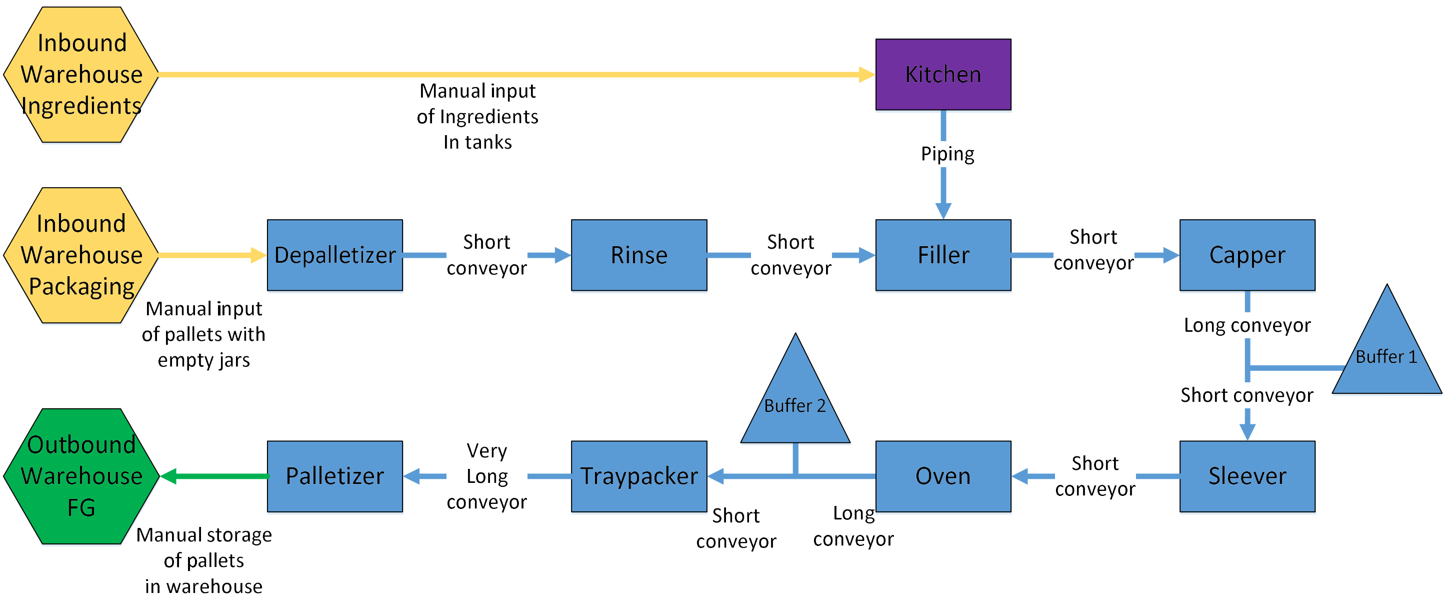

Figure 18: High level glass filling line

Lines can be dedicated to a certain product category and some products can only be produced on a specific line. However, also flexible lines exist that can produce multiple items. In this case, production can be taken over from other lines e.g. during maintenance. Some lines share a single packaging line or a single kitchen, resulting in a bottleneck on the shared resource.

F.2 – MacCarthy & Fernandes (2000)

Second, in terms of the categories by MacCarthy & Fernandes (2000), the following can be stated:

- Type of Layout: a product layout in which the processes are in the order of the production sequence is present in most sites. The kitchens lead to the filling lines on which (while moving) the can/glass/carton is filled (and might get a label) and moved to the packaging lines.
- Type of buffers: buffers exist before and after the full production process in the factory. Some sites might have minor buffers between production stages.
- Type of flows: there exists a unidirectional multi-stage processing, with some lines having filling machines in parallel (non-dedicated lines).

F.3 – Product-Process Matrix

Third, the well-known product-process matrix by Hayes & Wheelwright (1979) can also be used to characterized the system. In the position of Kraft Heinz in the matrix is depicted in Figure 19. A distinction is made between the product structure and the process structure. In general, within Kraft Heinz, the production volumes are rather high. Yearly a lot of Heinz Tomato Ketchup bottles are produced, but certain specific sauces might have a relatively small yearly production volume. The value of Work in Process is relatively low. The product structure at Kraft Heinz is positioned under 'Few Major products, higher volume'. However, in this case the product-process matrix has become less relevant, as the number of products produced by Kraft Heinz can hardly be grouped under 'Few Major Products'.

In terms of the process structure a difference exists between the *discrete flow* on the filling and packaging lines and the *continuous flow* in the kitchens. The filling lines as well as the packaging lines have a *connected line process structure*. This structure is characterised by processes that are arranged according to the progressive steps by which the product is made (Jacobs, Chase, & Chase, 2013). A continuous flow is similar to the connected line, but the flow is continuous (such as with liquids) rather than discrete (Jacobs et al., 2013). The discrete manufacturing at the filling and packaging lines is in contrast with the kitchens that are represented more adequately by a continuous flow. This so-called process manufacturing deals with the creation of recipes and formulas.

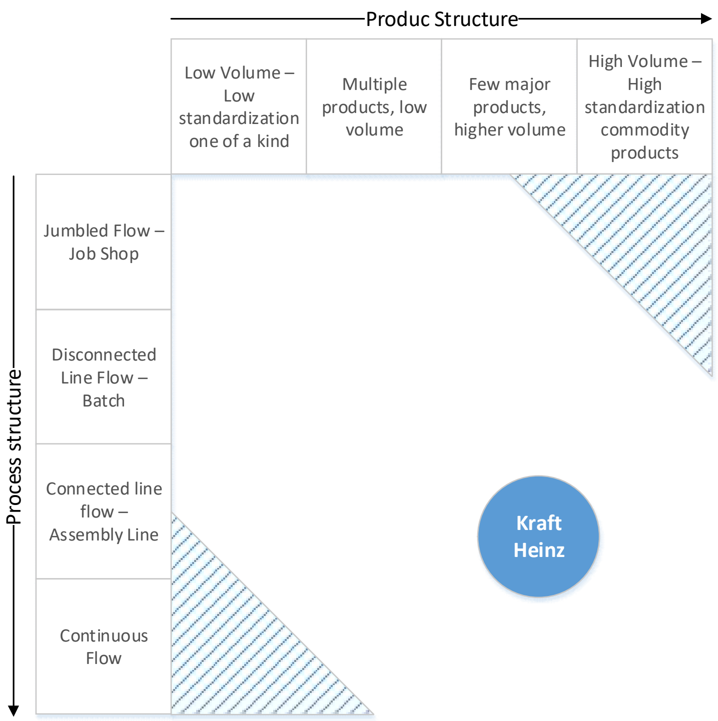

Figure 19: Product Process Matrix adapted from Hayes & Wheelwright (1979)

F.4 – Assembly versus Process Industry

To build more on the classification above, the explanations by King et al. (2008) are discussed below as they are valuable to clarify manufacturing processes. They state that manufacturing processes can be grouped into two categories: discrete parts assembly manufacturing and process industry manufacturing. The first refers to the manufacture of individual parts and components, examples include automobiles and computers. The second category refers to industries characterized by processes including mixing, blending, baking and chemical reactions. Finished goods of the process industry are either solids packaged, e.g. rolls or sheets, or they are in powder or liquid form packaged in bottles, buckets or tanks. Examples of these finished goods are paint or processed foods and beverages.

Although the two categories are often differentiated based on either having a discrete or continuous process, the process industry can have both (King et al., 2008). As is the case for Kraft Heinz, the manufacturing process starts with a continuous process and ends in discrete processing. King et al. (2008) argue that a better characterization of the difference is the number of parts types (i.e. the product variety) through the process. While assembly manufacturing starts with large number of raw materials and ends with a few finished goods, process manufacturing ends with a large number of finished goods from only a few raw materials. Additional characteristics of the process industry include:

- High volume, high variety and high variability

  To explain high variety, which is often not associated with the process industry, an example is given by King et al. (2008): A soft drink bottler used to bottle millions of cases per year of a single product, but now it has a portfolio including caffeine free, sugar free, lemon flavour, packaged in different sizes and shapes. Therefore, the product-process matrix by Hayes & Wheelwright (1979) is becoming less relevant.
- Capital intensive (in contrast, assembly processes are labour intensive)
- Throughput is limited by equipment (assembly processes are limited by labour)
- Processes are difficult to stop and restart
- Product changeovers issues are complex.

  While the primary wastes in assembly manufacturing changeovers are often time and labour, process industry often losses materials, cleaning fluids and additional laboratory testing time.

These additional characteristics also apply to the factories of Kraft Heinz and therefore it is concluded that the sites are part of the process industry.

G. Types of Assembly

MacCarthy & Fernandes (2000) distinguish between nine types of assembly. On one hand, a so-called mixing assembly exists for the kitchens as multiple ingredients are combined and mixed in a tank. On the other hand, the filling and packaging lines are characterized by a paced assembly line. The line only stops for changeovers, but the conveyors have a certain speed as soon as it is running. The operators may move to perform their tasks.

H. Type of Work Organization

Workstations and the tasks to be performed at each workstation are often defined within Kraft Heinz. A differentiation is made between individual work, i.e. the number of workers is equal to the number of workstations, team work, i.e. workstations are predefined and each is operated by a team consisting of multiple workers, and self-managed work groups, i.e. similar to team work but the group has autonomy to allocate the work within the group (MacCarthy & Fernandes, 2000).

Generally, team work is used within Kraft Heinz. Certain tasks are assigned to a workstation plus operator and therefore there is no full autonomy on the work inside the group. Certain production lines can have individual work with rotating operators.

Additional characterization

In addition to the previously discussed characterization, the quality of the materials and products is discussed below.

Quality

Often raw materials first must undergo a quality check or process at the plant. The materials have a certain quarantine time before they are released for production. The total goods receipt processing time (GRPT) includes this quarantine time used for inspections and other administrative tasks.

The GRTP time for finished goods also includes inspections and administrative process time. The quarantine time implies that the goods cannot be sold before this period has ended. Depending on the item, the quarantine time can also be partly completed during the transportation from plant to warehouse.

Appendix I. System Characteristics – Inventory Perspective

In addition to the previous characterizations of a system, an inventory perspective will be taken as inventories play an important role in the presented problem. The purpose of an inventory control system is "to determine when and how much to order […] based on the stock situation, the anticipated demand, and different cost factors" (Axsäter, 2015).

The following characteristics influence the complexity of inventory problems: (1) the planning horizon (finite versus infinite), (2) number of stages (single versus multi-echelon) (3) number of products, (4) capacity/resource constraints, (5) type of demand (deterministic versus stochastic, independent versus dependent), (6) setup/cost structure, (7) inventory shortage (backordering versus lost sales), (8) shelf-life of items, (9) time-varying parameters (static versus dynamic) and (10) nature of supply process (known or random lead times and supplied quantities) (Karimi et al., 2003; Silver, 1981; Snyder, 2008). Based on the definitions from the literature, the characteristics are discussed below.

1) **The planning horizon**

The planning horizon refers to the amount of time an organization will look into the future when preparing a production plan. This horizon is finite and has a maximum of 2 years within Kraft Heinz. The production plan is each day revised for the full planning horizon. However, mainly the first couple of months are considered in any planning decisions. Only if for example stock has to be build up for a certain season, it is necessary to look ahead for a longer period.

2) **Number of stages**

Stages are stocking points along the supply chain. The supply chain of a manufacturing location can be categorized as a two-echelon system in which a decision should be made on how to divide the inventories over the factory (Raw Materials) and the warehouses (Finished Goods). Two echelon systems require a different approach than single echelon optimization. Currently safety stocks are locally 'optimized' and in addition to safety stocks some factories employ safety lead time for raw materials (by shifting the requirement date up to 5 days before actual production).

3) **Number of products**

This topic has been discussed in the previous chapter. All locations produce multiple products.

Each item, whether it is a Raw Material or a Finished Good, has a specific European Product Number (EPN). Raw materials are materials purchased from external suppliers and waiting for first processing (Minner, 2000). Raw materials are used in the production of goods and the two main categories are ingredients and packaging. Finished goods are products that have completed the production process and that can be sold to a customer. The term Master Schedule Item (MSI) is used within Kraft Heinz and refers to a Finished Good that has a unique combination of ingredients, packaging and labelling. Therefore, two products with the same content and in the same packaging but with a label in different languages will be two different MSI's (with different EPNs). A Stock Keeping Unit (SKU) is a finished good that is kept at a specific warehouse. The forecasted demand is on SKU level and the safety stocks for finished goods is also kept on SKU/warehouse level.

4) **Capacity/resource constraints**

Constraints exist in production capacity and storage. Depending on the production line, the yearly utilization can vary. For example, Kitt Green might be building soup stock in November and December for the winter months in which the demand for soup is much higher. The effect of the resource constraints differs significantly between sites and lines.

Storage capacity at the plants for raw materials might be limited, resulting in the necessity to store materials at the supplier (which is more expensive). The finished goods inventories are generally kept at major warehouses where capacity restrictions are not an issue. A shelf life exists for finished goods as well as for most raw materials.

5) **Type of Demand**

Kraft Heinz mainly operates in a make-to-stock environment, but a small percentage of the orders are also made on order. Generally, the demand is uncertain and therefore forecasted figures are used to determine the production quantities. Whereas some products have a very fluctuating demand (Drinks and Soups, e.g. Karvam Cévitam sales are weather related), other products have a rather stable demand (Tomato Ketchup).

Finished goods are sold to customer. Customers range from retail stores, distributors and food service chains. The people that consume the products are referred to as consumers. As the consumers do not directly buy from Kraft Heinz, the buyer and consumer are different entities. From the literature review it became clear that three options exist when the demand cannot be met from available inventory: the customer is lost, the sales are lost or the demand is backorders. Within Kraft Heinz unmet demand is cancelled. However, generally new orders will be placed and therefore the sales are not lost. In reality high unmet demand will lead to actual lost sales and customers. It is assumed that as long as the target service level is reached there will be no customers leaving Kraft Heinz because of unmet demand.

The demand forecasts are provided in monthly figures for Master Schedule Items on warehouse level. Demand information for the finished goods are propagated down to the Raw Materials through the Material Requirements Planning logic. Weekly or daily numbers are computed by dividing the monthly figure by the number of weeks or days within that month. The forecast figures can be updated daily and can lead to rescheduling, but supply planners indicated that most of the time the forecasts are not adjusted during the month. The forecast accuracy is on finished good level and based on monthly figures. The forecasts can be biased and over-forecasting, i.e. forecasted demand that is higher than the actual demand, is more prevalent than under-forecasting (see also Appendix K). The demand for a manufacturing site is calculated as the sum of the demand for the warehouses it supplies.

A distinction is made between independent and dependent demand. Whereas independent demand is triggered directly by a customer, dependent demand is derived from independent demand, usually higher level items in the bill of material (APICS, 2011). The demand for finished goods is independent as the demand is not related to a higher level (Jacobs, 2011). However, the demand for the ingredients, packaging, labels etc. to produce a finished good is dependent on the demand for that finished good. Therefore, the demand for all components is considered to be dependent (Jacobs, 2011).

Dependent demand items often experience 'lumpy' demand in manufacturing environments through the usages of batch production (Miller & Sprague, 1975). Lumpy demand refers to a demand pattern characterized by some periods with zero demand and irregular periods of non-zero demand. The categorization of demand is further explained in Crolla (2016).

6) **Setup/Cost structure**

For raw materials a linear cost structure exists, while for finished goods a joint cost structure exists. See Appendix G for more information on the setup structure within Kraft Heinz.

7) **Inventory Shortage**

Orders for demand that cannot be met from inventory will be cancelled. However, the sales are not directly considered lost sales as most orders will be replaced by customers. There are no costs defined or considered for actual lost sales.

8) **Shelf-life of items**

Obsolescence refers to stock in good physical condition that can no longer be sold anywhere near its appropriate price (usually due to the introduction of a new competing product) (Silver, 1981). A Trade Best Before date exists for finished goods after which the goods cannot be sold to most customers. However, some customers might buy the items for a lower price after this date (e.g. discounters). The goods are still in good shape but the value is reduced. In addition, deterioration or perishability refers to stock that cannot be used for its original purpose after the passage of a certain length of time (Silver, 1981). Almost all raw materials as well as finished goods within Kraft Heinz can deteriorate. Ingredients are perishable goods, but also labels might have a certain shelf life as they might not be usable for its original purpose after a certain time (e.g. because of new legal requirements).

9) **Time Varying Parameters**

Dynamic parameters refer to parameters that change over time. Uncertainties exist in the internal processes, supply and demand (quantities, timing and quality) and arise from among others seasonality, quality issues, production line performance, supply performance and forecast errors. Seasonality can exist on the demand side (soups demand is higher in the winter; sauces demand is higher in the summer) and on the supply side (fresh tomatoes are only harvested in August and September and thus should be consumed by the production line within that timeframe). These uncertainties make many parameters for an inventory control system stochastic.

Production schedule changes can often still happen in the last week within the MFD and the possibility to change mainly depends on raw material/packaging availability. Especially if the ingredients remain the same and only the bottle/can/label is changed, rescheduling is less difficult. This makes the production schedule even dynamic within parts of the frozen horizon.

10) **Nature of supply process**

The lead time for raw materials varies from a few days to many weeks. Especially for the items that have a lead time of several weeks, the safety stock is high to protect against changes in the production plan. However, some products require no raw material safety stock as the lead time is shorter than the frozen horizon. The risk of having to write off obsolete stock because of the shelf life differs between the products.

Seasonality of raw materials will require high semi-finished good inventory throughout most time of the year to ensure labelling can happen at any time. For example, canned corn is only produced 4 weeks a year. The cycle stock is therefore high. Throughout the year, according to more accurate forecasts the products get labelled. In contrast, the bottle factory that supplies Elst is situated at the other side of the road from the factory. The total bottle stock is therefore relatively small.

10.1 Vendor Managed Inventory

Part of the inventory held at the manufacturing locations of Kraft Heinz are managed by the vendor. This concept is shortly introduced in the literature review. A VMI-consignment is essentially an arrangement whereby the owner of goods, the consignor, delivers its goods to another party, the consignee, for use or for sale by the consignee, with the proceeds of the sale being remitted to the consignor only after the actual use/sale (Fagel, 1996). A typical VMI program involves a supplier monitoring inventory levels at its customer's warehouses and making the replenishment decision, rather than waiting for the customer to reorder the product (Dong & Xu, 2002).

Within Kraft Heinz a distinction is made between Vendor Managed Inventory, in which the inventory is on the account of Kraft Heinz but managed by the Vendor, and Vendor Owned Inventory, which is similar to the concept discussed above, but now the inventory is owned and managed by the vendor.

Appendix J. Research Questions and Methodology

The approach discusses the research questions and methodology in more detail. The general question ("*what is the cost optimal frozen horizon length*?") cannot be answered without considering the system in which the frozen horizon is implemented in more detail.

J.1 Research Questions

The assessment of the current situation and performance of the pilot case (or case study) will be used as a baseline measurement for the comparison of the results of changing the frozen horizon. Without a measurement before the implementation of a model, it will not be able to measure the effect. The first question focuses on the case study and will be answered by doing a detailed case analysis.

1. **What is the current situation at the case study?**
    a. What performance indicators are relevant and important to consider?
        i. What is the current performance of the pilot case (i.e. the baseline measurement)?
    b. How can the inventory control system be characterized?
        i. What replenishment models are used?
        ii. What safety stock models are used?

Research Question #2 is aimed at the effect of changing the frozen horizon in terms of way or working in executing the rolling schedule and the ordering policy.

2. **What is the effect of changing the frozen horizon on the execution of the rolling schedule and the ordering policy?**
    a. Comparing to the situation of no frozen horizon, what effect does the introduction of a frozen horizon have on the execution of the plan and the ordering policy?

This second question is aimed at determining the influence of the frozen horizon on inventory costs, considering the general Kraft Heinz characteristics that include perishability of goods, capacity constraints and commonality of raw materials. In addition, the considered system operates in a two-echelon environment. Research Question #2 is:

3. **What is the influence of the frozen horizon on cost, considering general system characteristics?**
    a. What is the objective function that can be used to minimize the costs?

The previous questions should result in a model that can be tested at the case study. The goal of the thesis is to create an expression that clarifies the trade-off between all relevant costs. Optimizing this formula will result in a frozen horizon length that minimizes the included costs and will lead to the answer of Research Question #4:

4. **What is the optimal setting for the frozen horizon length in terms of costs for the pilot case?**

By applying the model to the pilot case, an optimal frozen horizon can be found (and implemented). This solution will be 'optimal' within the framework of assumptions of the model/ analytical expression and thus does not guarantee an optimal real-life solution. Pilot case specific data should be gathered and used as an input for the model. If data is lacking assumptions should be made.

The research should also be able to highlight and explain the real cost drivers for setting the frozen horizon length. It will be relevant for Kraft Heinz to determine what parameters affect the frozen horizon settings the most and should therefore be the point of attention if they want to change the frozen horizon. Research question #5 is aimed at the sensitivity of the model to the other parameters:

5. **What is the main cost driver in setting the frozen horizon?**
    a. What variables should be improved to reduce cost and benefit setting the horizon?

J.2 Methodology: The Reflective Cycle

Van Aken (2004) mentions that mainstream research "tends to be description-driven, based on the paradigm of the 'explanatory sciences'". More specific for the field of Operations Research, Andrew & Johnson (1982) argued that quantitative and modelling oriented approach was more important in Operations Management but it provided little pragmatic answers. There seemed to be a disconnection between Operations Management academics and practitioners (Meredith, Raturi, & Amoako-Gyampah, 1989). According to Van Aken (2004) doubts about the relevance of this kind of research can be mitigated by complementing it with prescription-driven research, based on the paradigm of the 'design sciences' (Van Aken, 2004). The mission of design sciences is "to develop knowledge that

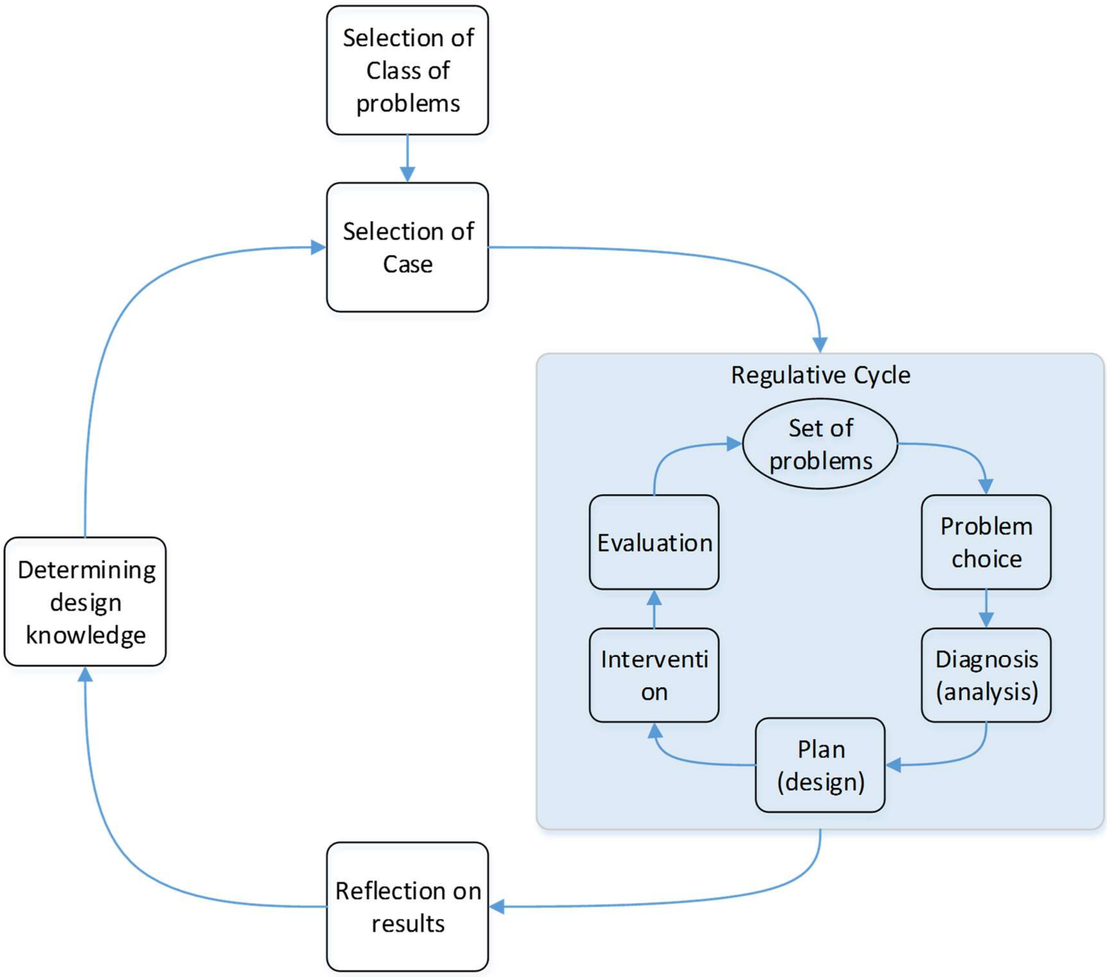

Figure 20: The reflective cycle, including the regulative cycle by Van Strien (1986), adapted from Aken (1994).

can be used by professionals in the field in question to design solutions to their field problems" (Van Aken, 2004).

The presented problem can be generally interpreted, but a factory of Kraft Heinz is used as case study. The reflective cycle by Van Aken (1994) is used to develop a general model. It includes the regulative cycle by Van Strien (1986), which can be used to evaluate the case study. The reflective and regulative cycle are shown in Figure 20. Design and prescriptive knowledge is built through the usage of the reflective cycle (Van Aken, 2004). The regulative cycle (or problem solving cycle) in its turn is used to solve a unique and specific problem (Van Aken, 2004; Van Strien, 1986). The primary goal of a reflective cycle is to design a solution for a problem which can be generalized to similar problems. The typical research product is a technological rule. Van Aken (2004) defines a technological rule as "a chunk of general knowledge, linking an intervention or artefact with a desired outcome or performance in a certain field of application". A technological rule is general, (i.e. "not a specific prescription for a specific situation, but a general prescription for a class of problems" (Van Aken, 2004)), but not a universal law, as its use is limited to a certain field of application (Van Aken, 2004).

Appendix K. Cost Assessment

In Literature Study Part I it was concluded that for most stochastic demand scenario increasing the frozen horizon leads to increased costs, reduced instability and lower customer service level. Costs might increase because of among others inventory, shortage and/or setup cost. Initial expectations of the effect of adjusting the frozen horizon on costs are discussed below based on the fundamental trade-off between **cost, schedule stability** and **customer service**.

K.1 Cost

With increased instability (by reducing the frozen horizon), more **manpower** might be required for rescheduling all activities. In addition, more rescheduling might lead to higher **changeover cost**, through additional changeover time and setup cost. More uncertainty on production quantities may also decrease the possibility to order large quantities and reduce **ordering cost** and it might lead to emergency orders. Both changeover and replenishment costs are related to lot-sizing problems as a trade-off exists between ordering cost related to the order/production quantities and inventory costs. Lastly, the safety stocks will be influenced and the connected **inventory cost**. Associated with the safety stocks, cost can be related to the renegotiation of lead times to reduce safety stock requirements. However, this renegotiation might increase the ordering cost.

As discussed in the literature review, inventory cost per year is calculated as follows (Crolla, 2016):

$$\frac{Cost}{year} = \bar{I} * v * r \tag{31}$$

Where $\bar{I}$ is the average inventory, v is the unit variable cost and r is the cost of carrying one dollar/euro of inventory for one year. The latter, r, includes the lost opportunity of having capital tied up in inventory (as it could also be used to invest or pay of debt) and out of the pocket expenses like insurance, taxes and operating the warehouse (Gass, Harris, & (Eds.), 2012). Similarly, Bowersox et al. (2002) states that the cost for holding safety stocks is calculated by multiplying the *annual inventory carrying cost percentage* by the *average inventory value.*

Replenishment cost have been discussed under Appendix G. The trade-off for replenishment decisions shows that in terms of choosing an order quantity, ordering cost and inventory cost cannot be viewed separately.

K.2 Cost Parameters

The frozen horizon can affect the replenishment and inventory cost through the safety stock levels and the lot sizes/replenishment quantities.

Safety Stock

In the literature on the frozen horizon, only the finished goods safety stocks have been considered. However, in real-life manufacturing situations often safety stocks for raw materials, semi-finished as well as finished goods are used to protect against uncertainties in supply, demand and production. It is expected that safety stocks levels for the raw materials and finished goods will be influenced when the Manufacturing Frozen Duration/Frozen Horizon Length is changed, but the exact extend is unknown. The expected effects on the safety stock levels are based on the following examples, which all have a planning horizon of 7 weeks (see Figure 21):

I. $Manufacturing\ Frozen\ Duration\ (MFD) = 5\ weeks,\ Raw\ Material\ Lead\ Time\ (LT_R) = 2\ weeks,\ Planning\ Horizon\ (PH) = 7\ weeks$

II. $MFD = 5\ weeks,\ LT_R\ =\ 6\ weeks,\ \ PH = 7\ weeks$

III. $MFD\ =\ 2\ weeks,\ LT_R\ =\ 6\ weeks,\ \ PH = 7\ weeks$

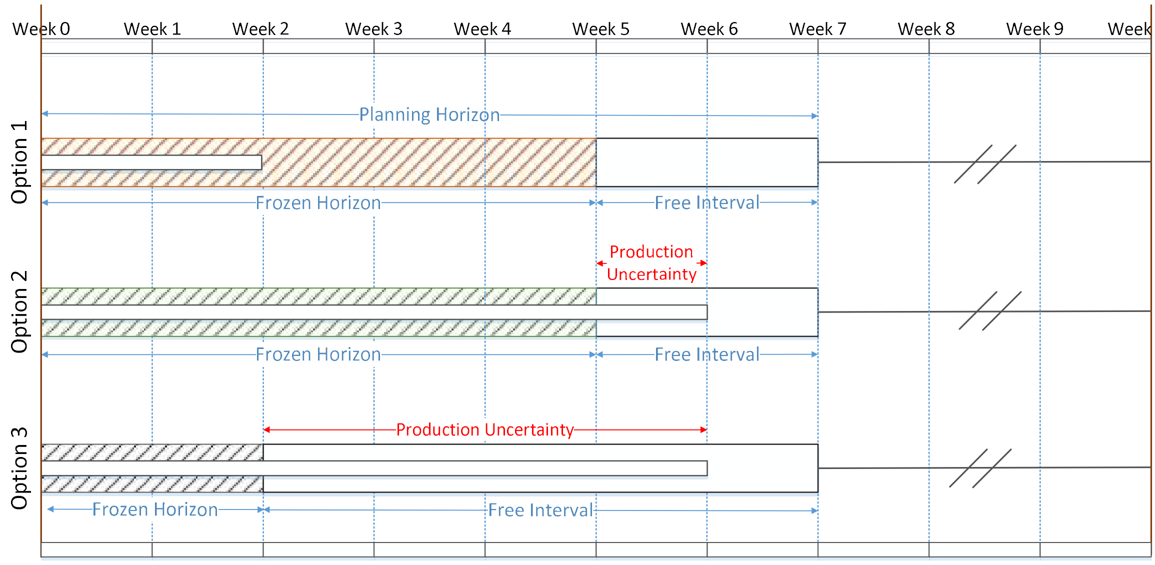

Figure 21: Three rolling schedule examples with different frozen horizons and lead times (LT)

The finished goods safety stock is aimed at among others uncertainties in demand and production. With a frozen horizon safety stocks are required because of the lag in the response by the system to forecast errors (i.e. when the forecasted demand is different from the actual demand). Whenever a forecast error occurs, the production plan can only be revised after the MFD. With a longer frozen horizon, the responsiveness of the system is reduced, so it will take longer to react to changes induced by uncertainties. Therefore, it is expected that a longer frozen horizon increases the required finished goods safety stock levels.

Each case is discussed for the raw material safety stock levels:

I. A frozen horizon ensures a certain production for the duration of the horizon. With a MFD of 5 weeks, the production for the first 5 weeks are fixed. As the demand for the raw materials is directly linked to the production schedule, the demand will be stable within the MFD. In this scenario, the raw material lead time is 2 weeks and thus shorter than the MFD. It is assumed that raw material safety stocks will not be used to protect against uncertainties from the production schedule (i.e. yield loss) or supply issues. Raw materials are bought based on a fixed production plan and thus no safety stocks at the raw material side are required. As the LT is shorter than the MFD, there is enough time to ensure adequate raw material levels.

II. With a LT that is longer than the MFD, uncertainty arises in the production schedule that should be covered by safety stocks. Raw materials take 6 weeks to arrive, but the production plan is fixed for the first 5 weeks. In week 6 a gap of production uncertainty, and thus demand uncertainty for raw materials, has to be bridged.

III. Again, the LT is longer than the MFD. However, in this case the production plan can change after 2 weeks, but it will take 6 weeks for new materials to arrive. As there is more uncertainty about the future production quantities, it is expected that higher raw material safety stock levels are required.

This results in the following general conclusions:

1. Increasing the Frozen Horizon will increase the costs associated with Finished Good safety stocks and reduce the costs associated with Raw Material safety stocks.
2. Decreasing the Frozen Horizon will decrease the costs associated with Finished Good safety stocks and increase the cost associated with Raw Material safety stocks.

Order Quantity/Lot Sizes

Kraft Heinz uses the fill rate as a measurement for the product availability. Besides the trade-off between ordering and inventory cost, the lot size, or order quantity, is also a parameter that influences the customer service level. If safety stock is increased, both the cycle service level[22] and the fill rate will increase (Chopra & Meindl, 2007). If the lot size is increased (under a similar safety stock level) and therefore the number of replenishments is reduced, the cycle service does not change but the fill rate will go up (Chopra & Meindl, 2007). Larger lot sizes will therefore lead to lower safety stock requirements for the same product availability target. Therefore, we can state the following about lot sizes: Increasing the current lot sizes increases the inventory cost related to cycle stock, but it can decrease the ordering cost, decrease the unit variable cost and decrease the cost associated with safety stocks. The opposite is also true.

Frozen Horizon Effect on Ordering Policy

To clarify the context of the Frozen Horizon, it is interesting to compare the situation of having no frozen horizon with the situation of introducing a frozen horizon. In formulating the impact of the frozen horizon on safety stocks three hypothetical cases were discussed. The overview is extended with 'scenario 4', representing the case of no frozen horizon. The scenarios assume a similar system to Kraft Heinz as discussed in earlier chapters, with $Raw\ Material\ Lead\ Time\ (LT_R) > 0$. The following scenarios[23], which all have a planning horizon of 7 periods (in this case weeks), are depicted in Figure 22:

I. $MFD = 5\ weeks,\ LT_R = 2\ weeks,\ PH = 7\ weeks$
II. $MFD = 5\ weeks,\ LT_R = 6\ weeks,\ PH = 7\ weeks$
III. $MFD = 2\ weeks,\ LT_R = 6\ weeks,\ PH = 7\ weeks$
IV. $MFD = 0\ weeks,\ LT_R = 6\ weeks,\ PH = 7\ weeks$

Scenario I, II and III

In scenario 1, there is no production uncertainty as the lead time of the raw materials is shorter than the frozen horizon $(LT_R < MFD)$. The materials can be brought in based on the production plan. If multiple productions are planned within the frozen horizon, multiple raw material orders can be combined to reach scale advantages. Any raw materials safety stock present, is aimed at non-production schedule uncertainty, like uncertainty from the delivery process. As $LT_R < MFD$, there is

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[22] Cycle service is "the fraction of replenishment cycles that end with all the customer demand being met", in which the replenishment cycle is the interval between two successive replenishment deliveries (Chopra & Meindl, 2007).
[23] The numbers used in the scenarios are arbitrary and used to create a more tangible example.

enough time to ensure adequate raw material levels. In scenario 2 and 3 the lead time is longer than the frozen horizon ($LT_R > MFD$), leaving some form of production uncertainty.

Scenario IV

The frozen horizon only affects the uncertainty (in terms of quantity and timing) arising from the production schedule. In the hypothetical case that there is no frozen horizon, the production schedule is not fixed for any future time-period. Omitting the frozen horizon in scenario 4 leaves 'full' flexibility for changes in the production schedule and this means there is zero certainty about future production. If the lead time for raw materials is more than zero, this uncertainty would create the necessity for

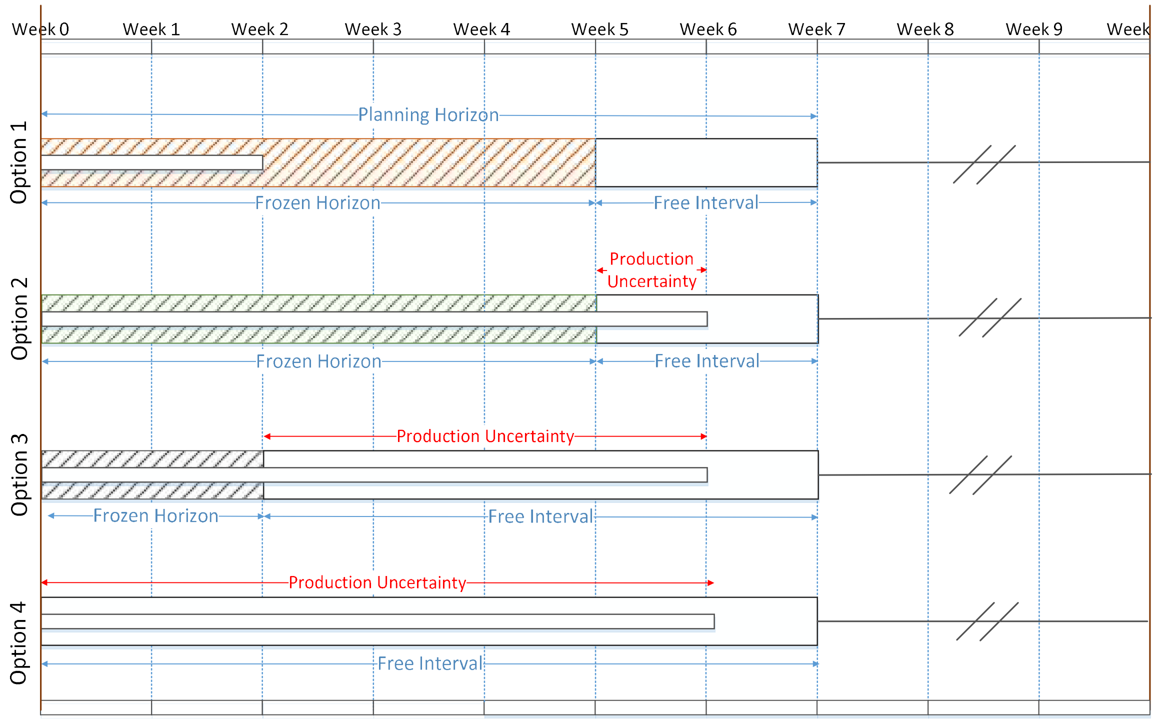

Figure 22: Four different scenarios with constant Planning Horizon, but different Frozen Horizon and Lead Time settings

raw material safety stocks to be able to buffer against changes in the production schedule. In reality this would only work if there is a limited amount of different materials required and the planned productions are fairly stable.

However, production schedules are also constraint by other parameters like Minimum Production Quantities (MPQ) and the used lot size rules. Besides a frozen horizon, fixing lot sizes/replenishment quantities can eliminate quantity uncertainty in the production plan, while fixing production cycles can eliminate timing uncertainty in the production plan. However, both methods might increase the other uncertainty type. In addition, the frozen horizon does not affect the uncertainties arising from supply or from internal processes.

Even though a production schedule is not strictly fixed by a standard frozen horizon, a MPQ can stabilize a schedule. If the MPQ in the scenarios above is 2 weeks' worth of production time, at the start of the production of that lot, the schedule would be stable for the next 2 weeks. However, at the end of that production when the next lot has not started yet, scenario 4 would provide no certainty up until the actual start of the production run.

The comparison of scenarios 1, 2 and 3 to scenario 4, reveals that introducing a frozen horizon decreases the production uncertainty. Depending on the other constraints in the system, the production schedule would be difficult to govern in terms of material availability if there is no certainty on the production plan.

Parameter Setting

Within a given setting for the frozen horizon length, the lot size/replenishment quantity can be chosen. That is, given a frozen horizon of 5 weeks, a planning system can decide on what lot size is best. On the effect of changing the frozen horizon on the preferred lot size setting can be philosophized. Increasing the frozen horizon might increase the lot size for raw materials as there is more certainty about the production plan. This can be explained with two simple example scenarios displayed in Figure 23. A similar setup is taken as the scenarios showed for the safety stock in the examples aboveFigure 21: Three rolling schedule examples with different frozen horizons and lead times (LT). The new example shows two scenarios with a planning horizon of 8 weeks, a lead time on the raw materials of 2 weeks, and a frozen horizon of 6 weeks (option 1) or 3 weeks (option 2). The latter option might decide to order for only the 3rd week as those quantities are known. However, looking at the first option, one might decide combine the orders for the number of weeks that have a firmed production schedule. Therefore, the order quantity covers five times the number of weeks if

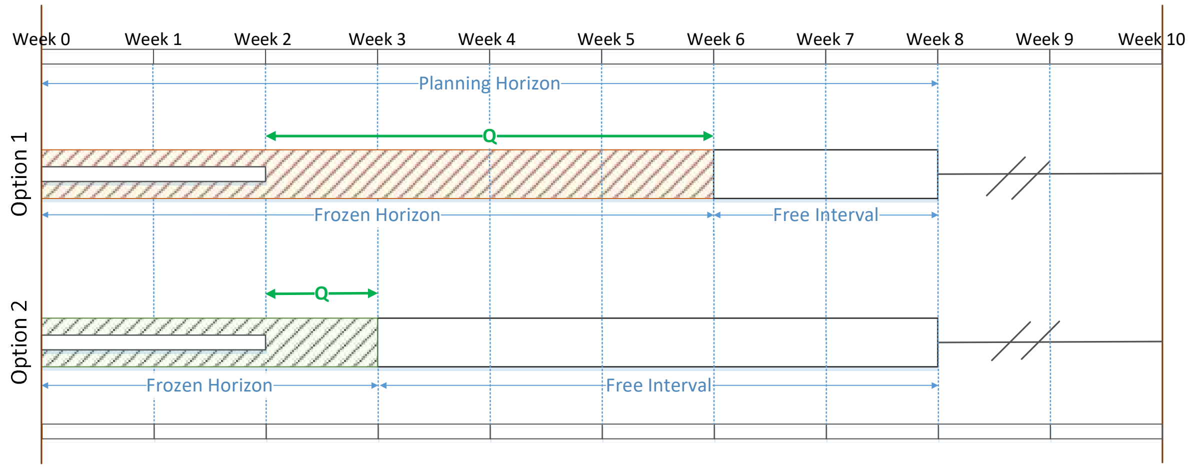

Figure 23: Two scenarios with a different frozen horizon length but similar planning horizon.

option 1 and 2 are compared.

However, an increased frozen horizon does not increase the certainty of the finished good demand. Therefore, the effect of the frozen horizon on lot sizes is not expected to influence the production lot sizes. The following general conclusions can be drafted based on the section above:

1. Increasing the Frozen Horizon is assumed to increase the raw material order quantity and therefore increasing the costs associated with raw material cycle stock, while reducing the cost associated with ordering (including fixed cost and unit variable cost) and raw material safety stocks.
2. Decreasing the Frozen Horizon is assumed to reduce the raw material order quantity and therefore reducing the cost associated with raw material cycle stock, while increasing the cost associated with ordering (including fixed cost and unit variable cost) and raw material safety stocks.

K.3 Cost Trade-Off

If we combine the previously discussed general conclusion, we see the trade-off as presented in Figure 6 of the main text (the considered figure is repeated below in Figure 24). The effect of either increasing or decreasing the frozen horizon on safety stock, cycle stock and ordering cost is displayed. The raw materials safety stock box contains 2 arrows as both sections mention this aspect being affected by the frozen horizon.

Frozen Horizon	Raw Material Safety Stock	Finished Good Safety Stock	Raw Material Cycle Stock	Ordering Cost
↑	↓ ↓	↑	↑	↓
↓	↑ ↑	↓	↓	↑

Figure 24: Repeating Figure 6 from the main text. Effect of changing the frozen horizon on safety stock, cycle stock and ordering cost.

K.4 Schedule Stability

From a theoretical perspective, introducing or increasing a frozen horizon is mainly aimed at reducing the instability of a production plan. Therefore, it is important to determine the cost associated with instability. Decreasing the frozen horizon will result in higher instability and uncertainty concerning the production quantities, but it will also lead to more flexibility in the production planning.

As discussed in the Literature Review, De Kok & Inderfurth (1997) state that both planning stability and customer service should be treated as independent attributes for assessing an inventory control system, as both cannot be replaced by cost or profit values in most practical situations. Kilic & Tarim (2011) also argue that system nervousness should be treated as an independent attribute. This reasoning is in contrast with the pure cost-based inventory models by for example Kropp & Carlson (1984) and Lin & Krajewski (1992). These pure cost based models, which incorporate costs to find the best selection for parameters like the frozen horizon, are discussed in Literature Study II (Crolla, 2016; Kropp & Carlson, 1984; N. P. Lin & Krajewski, 1992). In those papers, it proposed to estimate the cost of changing the Master Production Schedule (and thus the cost of nervousness) by determining what actions would be required to execute the changes and determining the accompanied costs. Through additional interviews it became clear that it is difficult, if not impossible, to estimate the cost of nervousness and the effect of changing the frozen horizon on costs. Therefore, Schedule Stability will be considered an independent attribute of the system from a cost perspective.

K.5 Customer Service Level

Within Kraft Heinz unmet demand is considered lost sales and not backordered. The Customer Service Level is measured by several KPI’s (see Appendix O), but mainly captured by the Case Fill Rate (CFR). The CFR target is fixed on 98.5%.

In general, adjusting the frozen horizon will affect the Customer Service Level as there is either more or less flexibility to adjust the production plan to changes in the demand (or forecast errors). Therefore, attention is required in setting the correct safety stock level to ensure certain customer service levels. An increased necessity of safety stocks to reach a certain level of customer service leads to additional cost. For this thesis, it is decided to only include cost related to safety stocks (and not for example expediting). However, this cost will be grouped under Inventory Cost and therefore not a separate Customer Service Level cost. Referring to the section above, customer service will be treated as an independent attribute of the system from a cost perspective.

Appendix L. Forecast Accuracy & BIAS

Selecting the correct forecast method is important in environments with uncertain demand to be able to plan a schedule efficiently. Although forecasting itself is out of the scope of this thesis, it is interesting to investigate forecast accuracy measures as the forecast error affects safety stock models. In addition, the level of uncertainty is determined by the quality of the forecast (Van Donselaar, 1989).

Forecast Accuracy

In Literature Study Part II forecast accuracy measures are discussed in more detail (Crolla, 2016). Many measures exist for forecast accuracy. Within Kraft Heinz the forecast accuracy is measured as follows:

$$Forecast\ Accuracy\ (FA) = \left(1 - \frac{\sum_{FG} abs[FCST_i\ - ACT_i]}{\sum_{FG}[ACT_i]}\right) * 100\% \tag{32}$$

With
$FG = Finished\ Good$
$FCST = Forecast\ demand\ for\ FG\ in\ month\ i$
$ACT = Actual\ demand\ for\ FG\ in\ month\ i$

This measurement aligns with using the Mean Absolute Error (MAE), also referred to as Mean Absolute Deviation (MAD), as discussed by Hyndman & Koehler (2006):

$$MAE = Mean(|e_t|) = Mean(|Y_t - F_t|) \tag{33}$$

With
$e_t = Y_t - F_t = forecast\ error$
$Y_t = observation\ at\ time\ t$
$F_t = forecast\ of\ Y_t$

To determine the forecast accuracy from the forecast error measure, the following equation is used:

$$Forecast\ Accuracy\ (MAE) = \left(1 - \frac{Mean(|e_t|)}{Mean(|Y_t|)}\right) * 100\% \tag{34}$$

Although this forecast accuracy method is referred to as Mean Absolute Percentage Error (MAPE) within Kraft Heinz, there is a definite difference with the MAPE method. Calculating the forecast accuracy with MAPE is done as follows:

$$Forecast\ Accuracy\ (MAPE) = 1 - Mean\left(\left|\frac{100e_t}{Y_t}\right|\right) \tag{35}$$

The forecast accuracies for finished goods are measured on a monthly basis. The raw material forecast accuracy and bias are not measured and therefore not readily available.

The accuracy is determined with a lag of 1 month. Forecasts are released at the start of every month and are generated for a period of up to 2 years. A lag of 1 month refers to comparing the forecast created at the start of month i (e.g. at the 1st of November) for month $i + 1$ (in this example December). The production planning as well as raw material procurement for month $i + 1$ is mostly done based on a forecast that has been generated in month i. Most sites have a frozen horizon of 3 weeks and should thus be prepared 3 weeks ahead. However, it can also be possible to make decisions on the forecast of month i, if it concerns the last week of the month. In addition, for long lead time raw materials/packaging (e.g. 2 months) information from the forecast done in month $i-1$ will be used in deciding the procurement quantity.

Forecast BIAS

Whereas the forecast accuracy measures the extent of the forecast error, the forecast BIAS measures whether there is a constant deviation from the mean in one direction. Again, a lag of 1 is used. The BIAS is calculated as follows (see the overview of service related Key Performance Indices in Appendix O):

$$BIAS = \frac{\sum FCST - \sum ACT}{\sum ACT} * 100\% \qquad (36)$$

From this calculation, can be concluded that a positive BIAS reflects a situation in which the forecast was higher than the actual demand. This is referred to as over-forecasting, while under-forecasting refers to a forecast that is lower than the actual demand. From an analysis of the European forecast bias number of 2015 can be concluded that there is a tendency to over-estimate the demand, i.e. over-forecast.

Appendix M. Case Study Selection

The aspects that have been considered in ranking the manufacturing sites from the perspective of Kraft Heinz are:

1. **Impact**
   - Frozen Horizon (>2 weeks = green)
   - Safety Stock finished goods (safety stock based on frozen horizon length = green)
   - Volumes (>X[24] tons yearly = green)
2. **Support**
   - Systems (same as Zeist = green) & communication (language barrier)
   - Management support, i.e. ease of implementation (easy = green, more difficult = yellow)
3. **Additional remarks** (Storage, others)

The results of ranking the sites are summarized in Table 8 and Table 9, most plants have been anonymized for confidentiality reasons. The ranking has been used to select the case study, Alfaro.

Table 8: Pilot Case Evaluation (Scoring: green = good, yellow = medium, red = not preferred)

Manufacturing Plant	Impact			Support		Additional	Ranking
	Frozen Horizon length	SS Finished Goods	Volumes	Systems & communication	Management Support	See next table	1 = best option, 9 worst
Site A	28						2
Site B	21						6
Site C	21						7
Site D	21						8
Site E	21						9
Site F	21						4
Site G	7 & 14						5
Site H	21						3
Alfaro	21						1

Table 9: Additional Remarks on manufacturing sites

Manufacturing Plant	Remark
Site A	-
Site B	Currently experiencing challenges.
Site C	Small location, monthly planning. Frozen horizon minor effect, large part make-to-order.
Site D	Processes are not optimal.
Site E	Frozen horizon length recently increased from 2 weeks to 3 weeks.
Site F	Limited storage
Site G	-
Site H	Under pressure of multiple projects. Labelling line and Quick Meal lines could be an option.
Alfaro	-

[24] Number of tons has been left blank because of confidentiality

Appendix N. Detailed Analysis Case Study

Alfaro is a medium-size plant split up in two parts: (1) Tomato Based Sauces and (2) Other Sauces (e.g. mayo and mustard). The frozen horizon is 3 weeks, but the last week is rather flexible, i.e. it is quite easy for supply planners to make changes to the production schedule within the frozen horizon. The analysis of the pilot case includes the following aspects:

1) Materials and Products (ABC analysis, quarantine time, cost of goods sold, procurement)
2) Inventory Planning
3) Alfaro Network
4) Inventory within the Network
5) Demand Information
6) Forecast Error Distribution
7) Production Lines
8) Production Process

The numbers presented in this section are either fictitious or have been made less specific for confidentiality reasons. However, the information given still gives a relevant analysis of the case study.

N.1 Materials and Products

The product produced at this factory are from two major brands: Heinz and Orlando, a Spanish local brand. In terms of items, some examples for Alfaro are:

- Packaging: Cap, Tray, Sticker, Label.
- Ingredients: Vinegar, Onion, Pepper, Caramel, Tomato paste, Sugar, Cayenne.
- Finished Goods/Master Schedule Items: Heinz Caesar Dressing (400 ml), Heinz Tomato Frito (400 gr), Heinz Baked Beans (415 gr), Orlando Tomato Frito (210 gr), Heinz Pizza Sauce (2 l), Heinz Yellow Mustard (220 ml), Heinz Mayonnaise (5 l) (displayed from left to right in Figure 25).

Figure 25: Heinz and Orlando products

The Tomato Based Sauces (TBS) part operates independently from the Other Sauces part, no lines or resources are shared between these separate units. More than 250 packaging materials, 100 ingredients and 200 finished goods had a forecasted demand in 2016. For confidentiality reasons the numbers used throughout this detailed analysis are made less specific. The majority of the finished goods (more than 90%) goes to one specific warehouse. Therefore the number of SKU's is almost similar to the number of finished goods.

ABC analysis

An ABC analysis has been done on the raw materials and finished goods. It rates the items on importance in terms of their Annual Cost Volume Usage, or Annual Consumption Value ($AC = annual\ usage * unit\ cost$) and groups the items in three groups (Jacobs, 2011). It is comparable to a Pareto analysis. It is a useful first step in improving inventory performance as it provides a tool for identifying the items that have the largest impact on the company's overall inventory cost performance (Jacobs, 2011). The items have been sorted on descending ACV values and grouped based on the cumulative ACV values.

The groups have been chosen as follows, in which the A items are the most important to the business and the C items the least important:

- A items: the items in the top 80% of the cumulative Annual Consumption Value.
- B item: the items in the range between 80% and 95%.
- C items: the items in the bottom 5%.

The focus for further analysis will be on the A items. For the raw materials, the analysis resulted in 8% of the items making up 80% of the ACV. The top 5 accounts for 45% of the Annual Consumption, with 1 raw material (a certain tomato paste) accounting for more than 30%. More clearly, from Figure 26 can be concluded that only a small number of ingredients and packaging are responsible for the majority of the annual consumption.

Table 11: Top 5 ABC analysis Raw Materials, ACV = Annual Consumption Value

Description	ACV %
Tomato Paste	>30%
Tetra Brik Small	2%< ACV % <5%
Oil, Sunflower	2%< ACV % <5%
Oil, Soybean	2%< ACV % <5%
Tetra Brik Large	2%< ACV % <5%

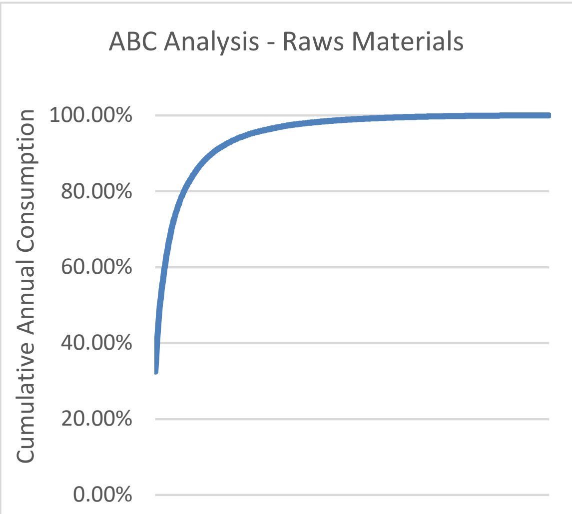

Figure 26: ABC analysis for Raw Materials and Packaging at Alfaro.

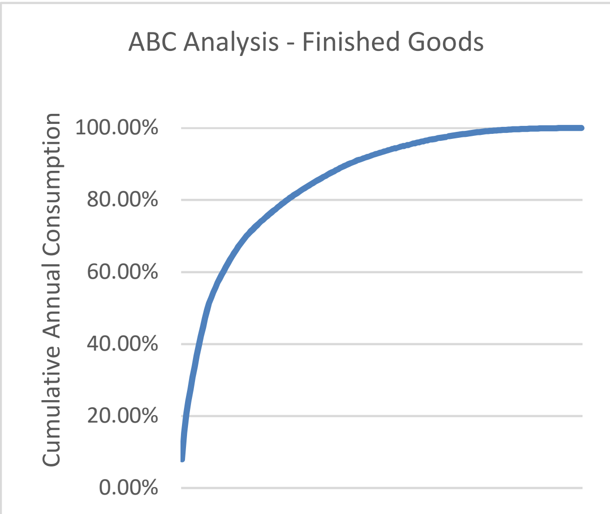

Figure 27: ABC analysis on Finished Goods for Alfaro

For the Master Schedule Items, the analysis showed that about 25% of the total number of finished goods belong to the A category. So, the top 80% ACV is caused by the 25% of the items, with the first 5 items accounting for the top 26% of the ACV. This is also shown in Figure 27. The full top 5 consist of Orlando Fried Tomato in different sizes (see Table 10).

Table 10: Top 5 ABC Finished Goods

Description	ACV %
ORL Fried Tomato Large	5%< X < 10%
ORL Fried Tomato Medium	5%< X < 10%
ORL Fried Tomato Small	5%< X < 10%
ORL Fried Tomato B	<5%
ORL Fried Tomato A	<5%

Goods Receipt Processing Time

Raw materials as well as finished goods have a Goods Receipt Processing Time (GTRP). Most raw materials have a quarantine time of 3 days for Quality Assurance department to check the certificates of the product and test it. Only after this period the ingredients are released for production. For finished goods, the quarantine times range from 4 to 7 days and only after the quarantine period the products are released for transportation to the warehouses.

Detailed Information on A items

A more detailed look has been done on the A items. Examples of some materials are given in Table 12. The given data (with Planned delivery time, Current Safety Stock, Goods Receipt Processing Time (GR Time), Total Shelf Life and Minimum Order Quantity) is fictitious for confidentiality reasons, but representative for the situation.

Table 12: Some Raw Material information, not in order of on importance, all are A items. RAW = Ingredient, PAK = Packaging.

Material Description	Material Type	Safety Stock	Planned Delivery (Days)	Shelf Life (Days)	GR time (days)	Minimum Lot Size
Tomatoes, Diced	RAW	1000	10	360	3	2500
Egg Yolk	RAW	400	6	40	3	200
Oil, Sunflower	RAW	4000	7	200	3	3000
Oil, Soybean	RAW	1500	8	200	3	2500
Starch	RAW	500	10	360	3	2500
Cap, 375ml, Red, Cartons S	PAK	8000	11	360	3	7000

Second, for the Master Schedule Items the more detailed analysis shows the Goods Receipt Processing Times (GRPT), Product Family, Production Line, Minimum MPS (Master Production Schedule) coverage duration (Min. MPS Cov.) and Shelf Life in Table 13. For the finished good items, there is not a minimum fixed quantity specified but a minimum coverage. The minimum production quantity is equal to the average demand in the number of days specified. E.g. a Min. MPS Cov. of 7 days with an average demand of 100 per day, refers to a minimum production quantity of 700.

Table 13: Detailed Finished Good Information of selected A items.

Product Description	GRPT (days)	Line	Family	Min MPS Cov.	Shelf Life (Days)
Tomato Sauce Large	7	BRIK_M3_M4	1000_CARTON	7D	547
Tomato Sauce Small	7	BRIKA1	350_CARTON	7D	547
Tomato Sauce Medium	7	BRIKA2	210_CARTON	7D	547

Cost of Goods Sold

The Master Schedule items have been analysed on Cost of Goods Sold (COGS). The cost breakdown is as follows:

1. Ingredients/Raw materials: total ingredients cost that are used in the end-product.
2. Packaging materials: total packaging cost that are used in the end-product.
3. Subcontracting costs: total costs for all fees paid for subcontracting and outsourcing (in the summary above negligible).

4. Direct Labour: total variable labour cost (mainly operators) for preparing and packaging the end-product.
5. Indirect Line: total variable overhead cost that are associated with the end-product (costs for energy, quality control, waste etc.)
6. Indirect Site: total fixed overhead cost that are associated with the end-product (costs for staff wages, maintenance, write-offs etc.)
7. MFGA (Manufacturing G&A): total fixed supply chain overhead cost that are associated with the end-product. These are determined from Zeist and passed on to/divided over the factories and subsequently included in the standard cost price/COGS.

This analysis has been done over all available Cost of Goods Sold information for 2016. The estimated costs are revised once a year and remain the same for the full year to come. If the analysis is repeated by comparing the total consumption data (for annual consumption also see ABC analysis) for raw materials/packaging with finished goods the added value of production can be calculated.

N.2 Inventory Planning

The planning approach used within the factories is Material Requirement Planning (MRP). It is managed through the ERP and the Planning Software used within S&OP. The demand is on the Master Schedule Items in the warehouse locations and this demand is cascaded down to the components.

Raw Materials

The procurement lead times of the materials are set by the global procurement team in the Supply Chain Hub. This team discusses the lead times of the materials with the suppliers and has own targets of reducing the procurement costs. However, it is not easily possible for the procurement team to propose longer lead times. For most raw materials, contracts are made for the yearly volume. Based on these contracts local buyers at the manufacturing sites can call off the quantities they require. Within Alfaro multiple contracts are based on a lead time of 14 days. Taking into account the goods receipt processing time of 3 days, a lead time of 17 days exists for the materials to be available for production.

The replenishment rules that are set up in the system for the raw materials at Alfaro are displayed in Table 14. Although several options are available, 1 option is mainly used: the 'period lot size according to planning calendar'. This lot size refers to a Period Order Quantity rule, i.e. it states that the order quantity should be equal to the expected demand in a specified period, e.g. 1 month. In addition to these lot size rules there are Minimum Order Quantities set up and rounding values for ordering above the MOQ. The rounding values refer to the increments with which the orders can be increased above the MOQ.

Table 14: Lot-size rules for Raw Materials in Alfaro.

Lot size	Lot size Description
ZC	HNZ According to planning calendar
WB	Weekly lot size
TB	Daily lot size
PK	Period lot size according to planning calendar
EX	Lot-for-lot order quantity
ZK	Period lot size according to planning calendar

Within Alfaro the period for the lot size determination is mostly set to 1 week. Therefore, unless constricted by a minimum order quantity, the ordered quantity equals the forecasted demand of 1 week, plus possible requirements to achieve the correct safety stock level. The raw materials with a lead time longer than the frozen horizon are bought based on the weekly production plan created by the Planning Software every night for materials. The problem with this approach is that all those materials need to be in the factory at the start of the week as it is not known on what day of the week the production will be. Therefore, the requirements are set on the first day of the week. The replanning interval is 1 week: an additional week is frozen every week. When the daily planning is fixed at the end of the week, local buyers have a more detailed plan of the production schedule. This is the moment that raw material orders can be made on a daily level for requirements in the additional week.

Finished Goods

The production schedule is created by the Planning Software and based on among others the forecasts, the inventory, the capacity available, the actual produced quantities and the Minimum Production Quantities (or MOQ). For some finished goods, the Minimum Production Quantity might be sufficiently large compared to the annual demand that only twice a year a production is planned. The procurement activities are based on the production plan and not on the forecasted demand, therefore the lot sizes can create lumpy demand situations for certain raw materials.

The lot sizes for finished goods are based on the demand, the minimum production quantities as specified in the Planning Software and other parameters like the frequency of production (i.e. one can specify to produce an item only once a month). Depending on the capacity available, the system will use larger lot sizes to reduce changeover times. Certain prioritization rules can be in place per factory and line.

Inventory Control

In general, it can be concluded that the inventory position (with additional information on stocks and the production plan) is reviewed on a higher level every night. On a more detailed level it is analysed once a week; for finished goods when fixing an additional week. Relating this to the literature on the review method of the inventory control system, it can be stated that the inventory system is reviewed periodically (and not continuously).

N.3 Alfaro Network

The plant in Alfaro receives raw materials from many suppliers. It holds raw material stock at the site and it delivers finished goods to 6 different warehouses. The main demand comes through the Spain NDC, followed by France, the Netherlands and the UK respectively, see Table 15. This network can be modelled according to the literature on multi-stage systems.

Table 15: Overview of warehouses inside the network of Alfaro. NDC = National Distribution Center, DC = Distribution Center.

Warehouse	Transportation Time (days)	Annual Cost Volume Usage (%)
NDC Spain	0	>50%
NDC France	3	5%< X <30%
DC Benelux	3	5%< X <30%
NDC UK	8	<5%
DC for Italy	3	<5%
DC Poland	4	<5%

The network is shown in Figure 28. The main manufacturing process is depicted as a single blue box as no relevant stocking points are available for Work-In-Process within the production process that can accommodate safety stocks. The stocking points are depicted as blue triangles. The black border clarifies the network of Kraft Heinz, while the green box shows points inside the factory. As discussed before in some situations the raw material stock inside the factory warehouse is managed by the vendor (VMI). In general, we will assume that the raw material stock at the factory is managed and owned by Kraft Heinz. As soon as the finished goods arrive in the warehouses of the customers it is owned by the customers. In addition, Kraft Heinz does not manage any of the finished good inventory levels of the customer and the logistics of the either incoming raw materials or outgoing finished goods are managed by third party logistic companies.

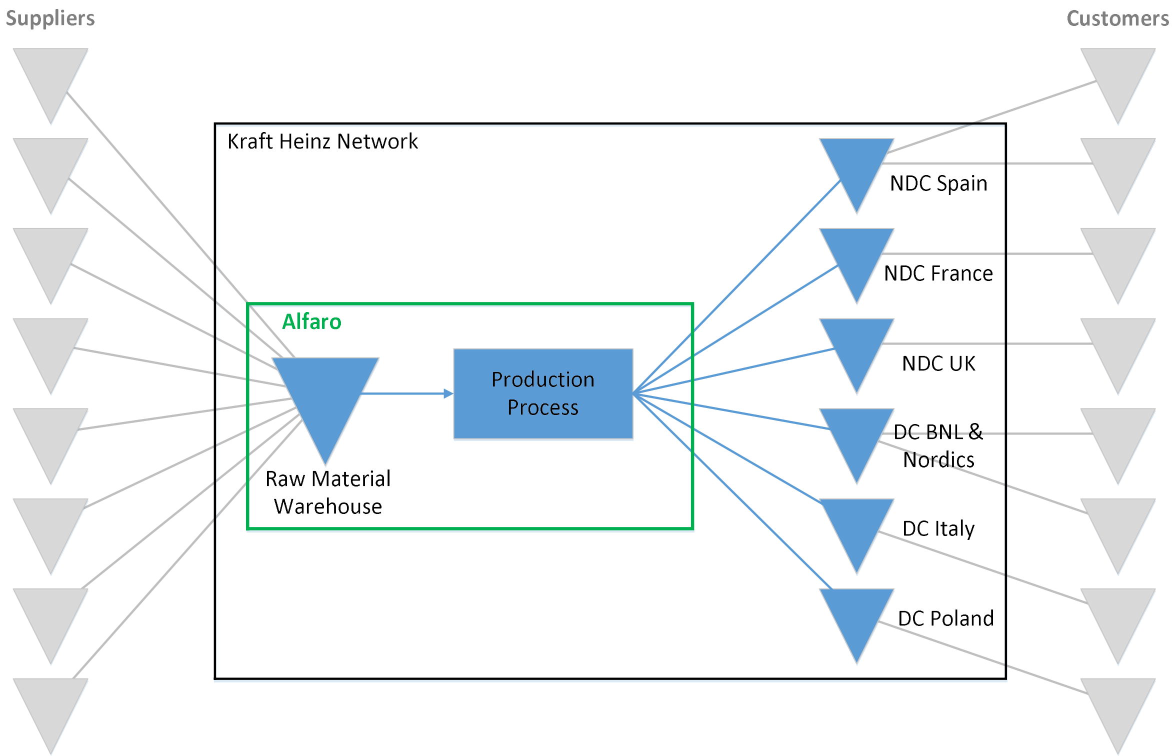

Figure 28: Network with stockpoints before and after the production process in Alfaro. The green box displays the physical Alfaro network. The black box shows the Kraft Heinz network.

From this network, it looks like this is a divergent system. However, if the network is investigated on product level, it can be concluded that only a small percentage of the finished goods is shipped to multiple warehouses. Within the black box, the majority of the products have a network of a single stockpoint before the manufacturing process and a single stocking point after the manufacturing process. According to the literature on multi-stage systems this is referred to as a two stage serial system (see also Crolla (2016)).

A transit time has been agreed upon with the logistic companies. Based on multiple deliveries in 2015, also average real transit time (ART) have been calculated. In addition, the variance of the average real transit time is determined. The variance is also calculated with the highest value left out, this showed that especially the variance for the delivery times to the DC for the Benelux is largely affected by 1 large exception. The Mean Squared Error (MSE), i.e. the average of the squares of the difference between the agreed transit time and the actual transit times, has been calculated. Also for this calculation, the highest value has been left out in the last column. From the analysis is concluded that there is not much variance on the lead time compared to the settings in the system.

N.4 Inventory within the Network

The current situation at Alfaro can be described by its performance on certain Key Performance Indices. The inventory level, consisting of cycle inventory and safety stock, is an important KPI. For Alfaro, the inventory evolution of 2015 is shown in Figure 29.

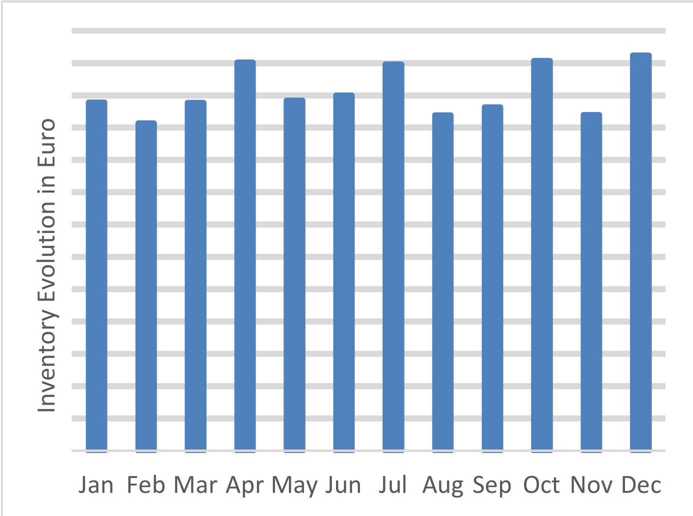

Figure 29: Inventory Evolution Alfaro

Safety Stocks

The current safety stocks for finished goods are based on a combination of an old model and planner experience, while the raw material safety stocks have been determined based on experience of the buyers. Only about 40% of the raw materials have safety stocks set up in the system while all finished goods with a forecasted demand in 2016 have safety stock set up in the system. The safety stocks are put in the planning system as coverage in days, e.g. if the coverage is 10 days, the safety stock level is equal to the forecasted demand for the coming 10 days. This results in fluctuating safety stocks throughout the year. Based on the forecasted demand for 2016 the daily average demand has been calculated and used to determine the average inventory value for raw material safety stocks.

In Kraft Heinz the yearly inventory carrying cost for both finished goods and raw materials are equal and given by a certain percentage of the average inventory value. This percentage will be represented by the letter h. This number is an average value used in calculating the cost of holding inventory and includes the following:

- Rent/utility cost: For warehouses owned by Kraft Heinz (like in Alfaro) there is no direct rent. For External warehouses, there is a fixed cost per pallet with a maximum of a certain number of pallet.
- Insurance
- Taxes
- Cost of deterioration and obsolescence
- Cost of capital
- Cost of handling items

The value for raw materials is not all within the network of Alfaro because of vendor managed inventories. The supplier is responsible for the safety stock levels and these values are often not accurately reflected in the numbers. Safety stock figures are based on the current safety stock settings within the planning program and thus do not consider the VMI's. It is estimated the real value of raw material safety stock is about double the amount reflected in the Planning Software (based on interviews with procurement and raw material planner).

Actual inventory values cannot be disclosed but will be represented by capital letters and comparisons to the base comparison will be made in percentages. The average inventory value for both finished goods and raw materials (consisting of safety stock and cycle stock) will be represented by capital letter W. Based on the current settings in the planning system, the average safety stock inventory value can be calculated. For finished goods and raw materials these will be represented by capital letter M and P respectively. This is reflected in Table 16.

Table 16: Safety Stock inventory values

Material	Yearly Inventory Holding Cost	Average Inventory Value
Safety Stock RM	€ $h * P$	€ P
Safety Stock FG	€ $h * M$	€ M
Total Costs	€ $h * W$	€ $W = M + P$

Planning Software Model for Safety Stocks

In the Planning Software an option became available to generate safety stocks based on system information. It uses a different method to find the k-value from an $G(k)$ value. An approximation formula is used to find the appropriate values for the safety factor. This approximation for the safety factor is similar to using the Loss Function table to find the appropriate Z-values. The approximation formula cannot be disclosed, but the performance of the formula has been compared with the graphed values. A graph and table that compare the Safety Factor to the k-value corresponding with the same $G(k)$ values have shown that the Safety Factor formula is a good approximation finding a k-value. The graph and table with these results can be found in Appendix Q.

N.5 Demand Information

In Figure 30Figure 30: Demand Trend for A item X the demand trend for an A category finished good item is shown in volume per month. It can be concluded that the demand varies across the months, but no real seasonality is present on this item. The demand for other finished goods is similar and no real trends can be recognized.

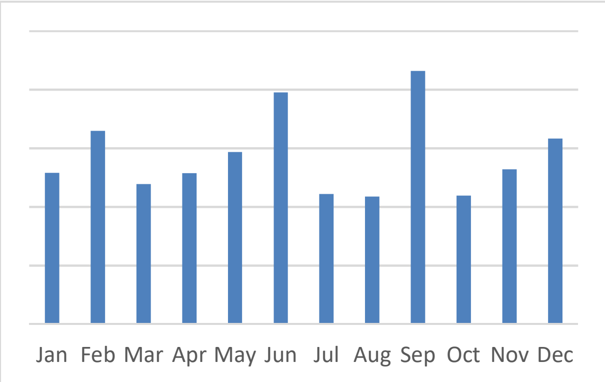

Figure 30: Demand Trend for A item X

Although there is no seasonality on the demand side, some seasonality exists on the supply side. Fresh tomatoes are only harvested August until October. The weather plays an interesting part and creates uncertainty in the actual supply quantity of tomatoes. During ‘season’ (August – October) fresh tomatoes arrive. Around 30% of the fresh tomatoes is used for products that can only be produced with fresh ingredients, such as Crushed Tomatoes. 70% of the fresh tomatoes are used in products that out of the season use tomato paste as an ingredient. In February the contracts for the tomatoes are drafted for the season in August and October. A formal procedure is started in which the full year forecasted demand and production volumes are discussed. The frozen horizon has no real influence on this part of the production planning. About 10% of the sales are created by seasonal-only products, like crushed tomatoes.

In general it can be concluded that the demand for both finished goods and raw materials varies over time but the demand can be assumed to be stationary.

Demand Category

The demand categories, as presented by Syntetos et al. (2005) and discussed in Literature Study part II, can be used for categorizing the demand. By determining both the coefficient of variation (CV^2) and the average inter-demand interval (ADI) of the demand data set, the demand can be placed inside the categorization scheme. The four categories are:

1. Slow moving or Smooth demand, which has no great variation in interdemand intervals and quantities ($p < 1.32$, $CV^2 < 0.49$).
2. Intermittent demand, which has no great variations in quantity but has infrequent demand occurrences ($p > 1.32$, $CV^2 < 0.49$).
3. Erratic demand, which has highly variable demand sizes, but relatively stable interdemand intervals ($p < 1.32$, $CV^2 > 0.49$).
4. Lumpy demand, which is intermittent (i.e. with infrequent demand occurrences) and erratic (i.e. with highly variable demand sizes) at the same time ($p > 1.32$, $CV^2 > 0.49$).

The coefficient of variation is the ratio of the standard deviation (σ) to the mean (μ):

$$CV^2 = \frac{\sigma}{\mu} \tag{37}$$

The average inter-demand interval is the average number of demand periods between two demand occurrences and is defined as follows (Callegaro, 2010):

$$p = \frac{\sum_{i=1}^{N} t_i}{N} \tag{38}$$

With

$\mathrm{N} =$ number of periods with nonzero demand

$\mathrm{t_i} =$ interval between two consecutive demand occurences, i.e. the number of periods the i^th demand occurrence happens after the last one

When looking at demand for the materials within Kraft Heinz a differentiation can be made per item category found through the ABC analysis. It should also be noted that depending on what interval is taken, the demand category changes, e.g. demand figures can be grouped on a daily, weekly or monthly basis. The results in terms of demand category for both raw materials and finished goods are summarized in Table 19.

For raw materials, it shows that while the A items belong to the smooth demand category, the B and C items belong mainly to the intermittent and lumpy demand categories. For the finished goods, the demand information is only available in monthly buckets. As multiple periods are combined, compared to the raw materials, the items are mainly in the smooth or erratic category. If the production information is taken (which is available on a weekly basis but does not represent the demand for finished goods) the items belong more to the intermittent category. N.B. for the C items not enough data was available for a proper demand analysis on a week level as some items are only produced a couple of times per year).

N.6 Forecast Error Distribution

According to Hair Jr et al. (2014) “the starting point of understanding the nature of any variable is to characterize the shape of its distribution”. Assuming a normal distribution in predicting demand variability based on historical data has been a popular assumption and as discussed in Literature Review Part II several reasons exist to model the demand by with a normal distribution. For determining the safety stock, the distribution of the forecast error is important. The forecast error is the only investigated variable, therefore univariate profiling can be applied (Hair Jr et al., 2014).

The small sample sizes available for an analysis on the forecast error complicates the process of drawing clear conclusions in terms of distribution. The graphical analysis of normality is problematic for smaller sample sizes (Hair Jr et al., 2014). As discussed in Literature Review Part II (Crolla, 2016), two main approaches can be used to test whether the distribution of the forecast error follows a normal distribution:

1. Graphical Analysis of Normality
2. Statistical Tests of Normality

A selection of forecast errors has been loaded into SPSS to do the analysis. As an example a packaging materials is taken: plastic bottle 300 gram. Graphical (Normal Q-Q Plot) and Statistical (z score Skewness, z score Kurtosis, Shapiro-Wilk and Kolmogorov-Smirnov) tests have been done. For a more detailed introduction on these tests the reader is referred to Literature Review Part II (Crolla, 2016).

The H_0 (i.e. null hypothesis) of the Shapiro-Wilk and Kolmogorov-Smirnov tests is that the variable is normally distributed (Hair Jr et al., 2014). The forecast error of this particular item is normally distributed as for both tests the significance level is higher than 0.01: Kolmogorov-Smirnov significance level of 0.200 and Shapiro-Wilk significance level of 0.717 (Table 17).

Table 17: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Bottle300gr	.213	7	.200*	.949	7	.717

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Figure 31 shows the normal Q-Q plot for this item. Although the points do not all fall directly on the line, the values are relatively close to it. This points at the distribution being normal as well.

The results for skewness and kurtosis of the distribution are shown in Table 18. The z-values for both Skewness and Kurtosis have been calculated with the following formulas (Hair Jr et al., 2014):

$$z_{skewness} = \frac{skewness}{\sqrt{\frac{6}{N}}} \tag{39}$$

$$z_{kurtosis} = \frac{kurtosis}{\sqrt{\frac{24}{N}}} \tag{40}$$

Most commonly used critical level of the z-score is 2.58. As both are within this range ($z_{skewness} = -0.735$, $z_{kurtosis} = 0.621$) the distribution appears to be normally distributed.

Table 18: Results of Skewness and Kurtosis of distribution

	N	Skewness			Kurtosis		
	Statistic	Statistic	Std. Error	z-score	Statistic	Std. Error	z-score
Bottle300gr	7	-.600	.794	-.735	1.014	1.587	.621

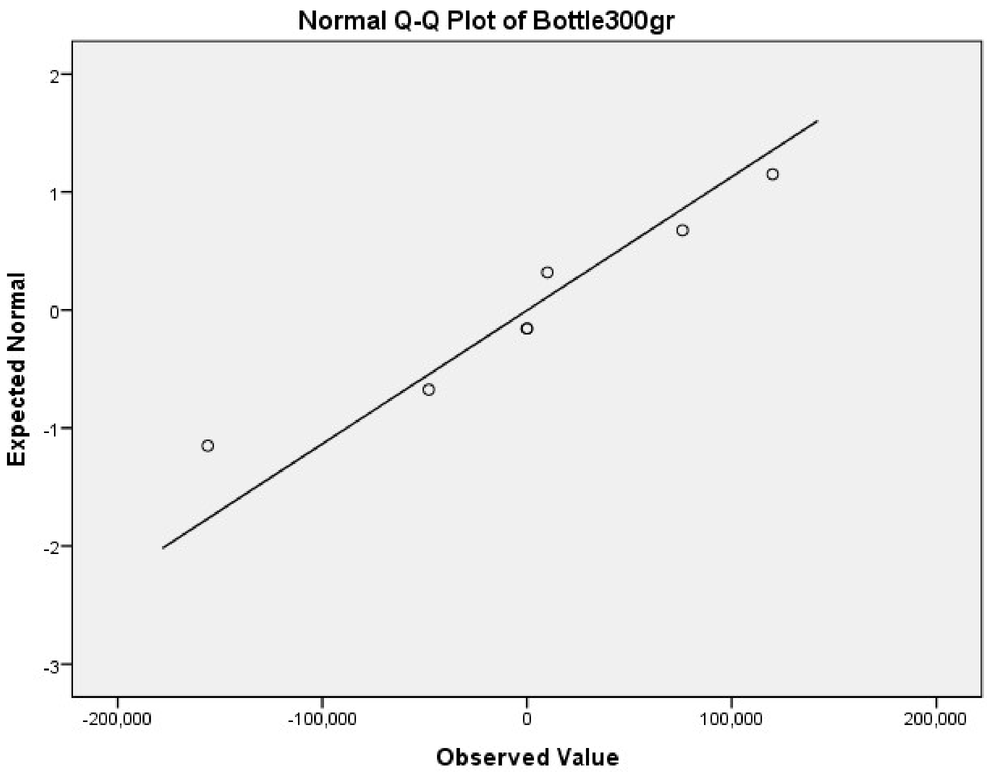

Figure 31: Normal Q-Q Plot

From each ABC category, a sample of items have been selected to do normality tests and the results are summarized in Table 19 together with the corresponding demand categories.

Table 19: Results for the demand categories and forecast error distribution per ABC item category.

ABC Item Category	Raw Materials		Finished Goods	
	Forecast Error Distribution	Demand Category (Demand Bucket)	Forecast Error Distribution	Demand Category (Demand Bucket)
A items	Largely normal distributed	Smooth (weekly)	Normal distributed	*Intermittent (weekly)* Smooth (monthly)
B Items	Partly normal partly non-normal distributed	Mainly Intermittent and Lumpy (weekly)	Normal distributed	*Intermittent (weekly)* Smooth or Erratic (monthly)
C Items	Largely non-normal distributed	Mainly Intermittent and Lumpy (weekly)	Normal distributed	*Not enough data (weekly)* Smooth or Erratic (monthly)

N.7 Production Lines Changeovers

Alfaro has several filling lines. Most lines can produce different sizes of packaging. Changeover times have only been set up in the system for family changes and SKU changes certain lines. Minor changes are not set up in the Planning Software at Zeist. As the detailed (i.e. hourly and daily) planning is done at the sites, the knowledge on the smaller setups is also at the sites. Minimum Production Quantities are based on format or recipe changes (i.e. family change). Therefore, the minimum production quantities are based on the largest changeover times between a family of finished goods items.

N.8 Production Process & Plant Layout

Several processes have been reproduced with flowcharts on a high level. Below, two flowcharts are displayed. Stocking points are depicted by triangles, while actions/process steps are depicted by rounded rectangles. The major stocking points are formed by (untouched) ingredients & packaging and finished goods. Within the process no *work in process* stocking points can be found as it is a continuous line.

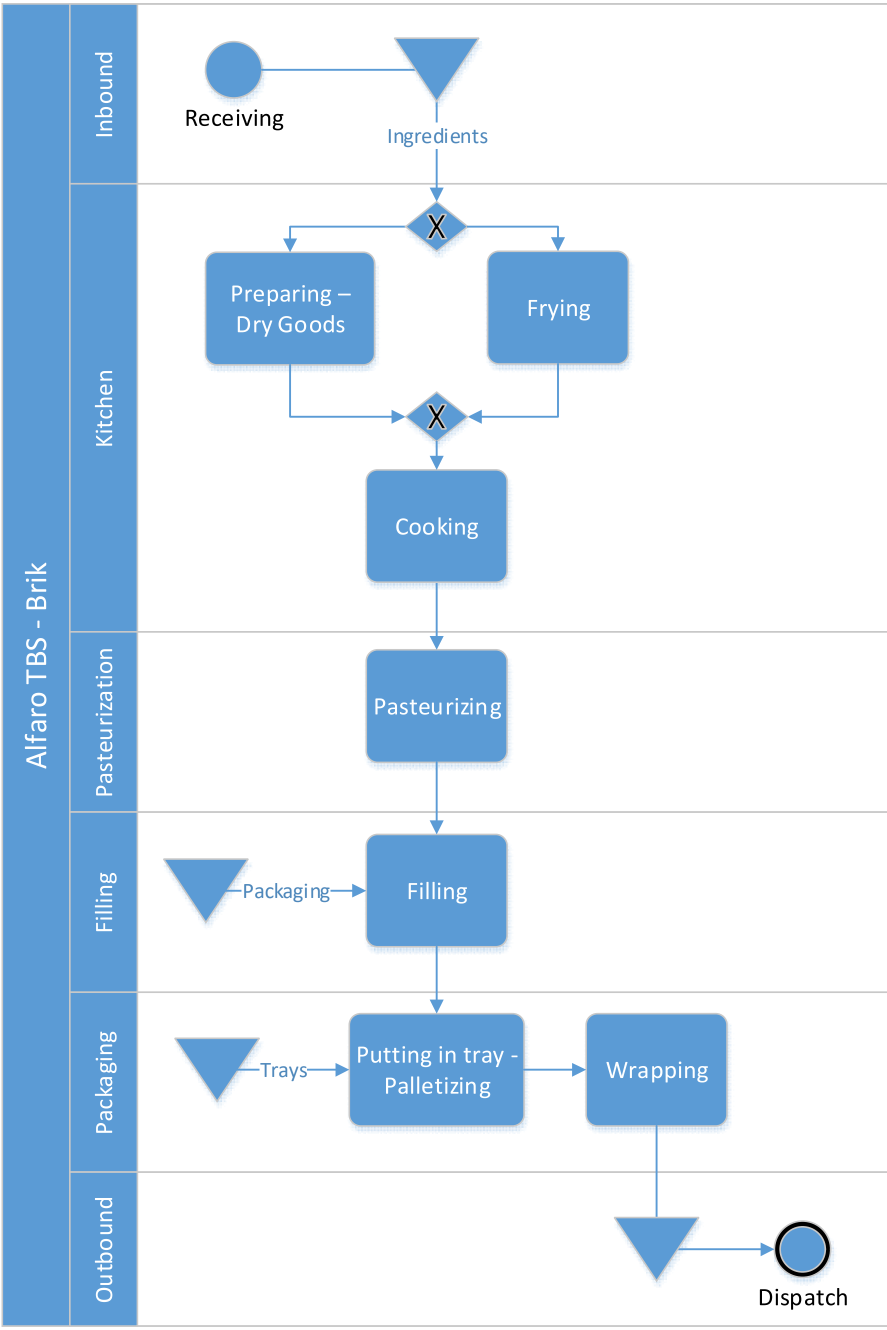

Figure 32: Flowchart of Alfaro TBS Brik line

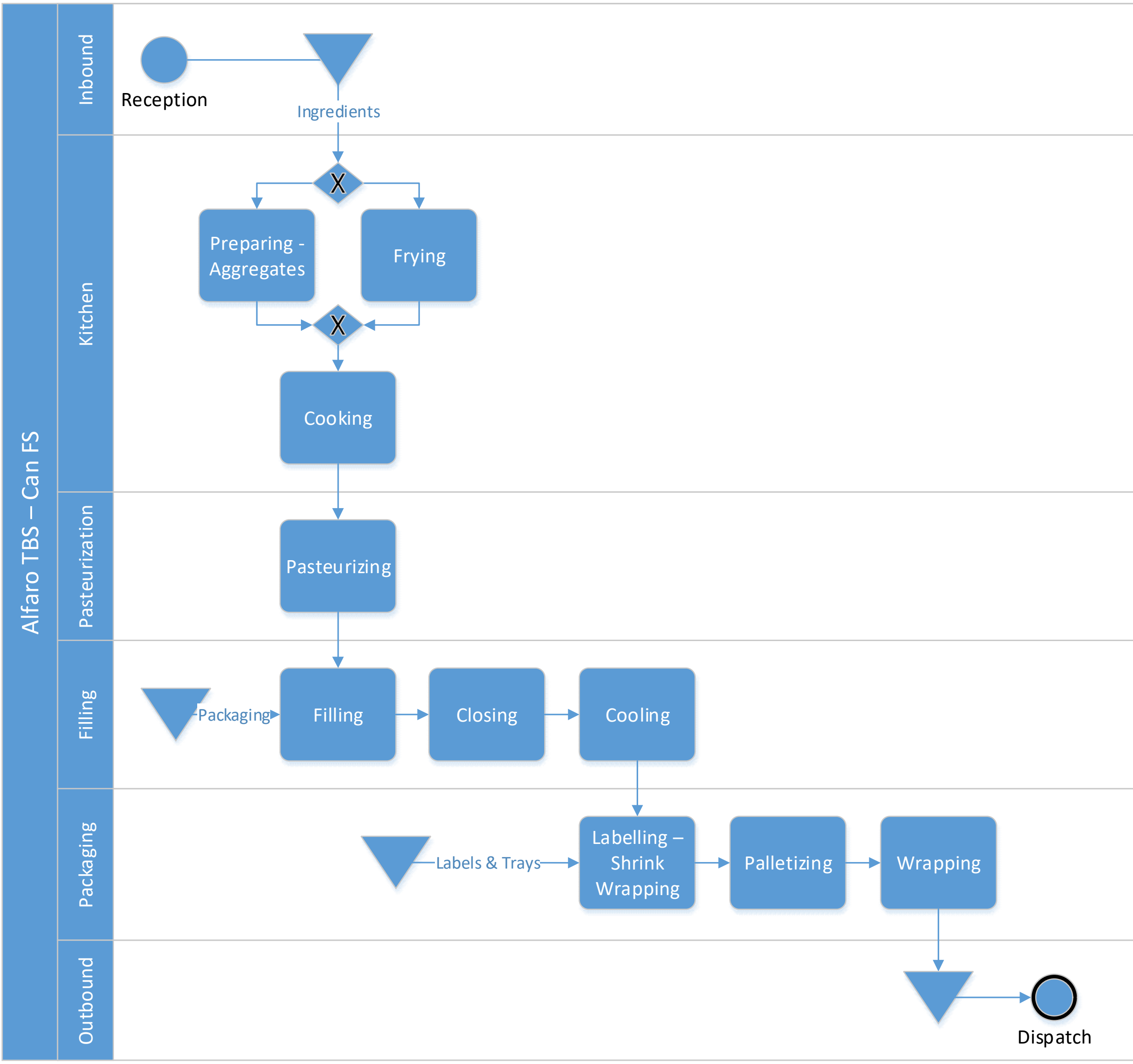

Figure 33: Flowchart of Alfaro Can Line

In general, after receiving all the raw materials and storing them in the inbound warehouse, materials are pulled from the warehouse and combined in a kitchen after preparations. After a pasteurization step, the recipe/product is put in its packaging (glass, can or plastic) on a filling line. Subsequently, a label is attached and the item is put in a tray. The bottleneck is often created by the filling and packaging lines rather than the kitchens.

For both Tomato Based Sauces and Other Sauces no production cycles have been set up, but for most products either minimum production quantities (MPQ's) or minimum are present.

Appendix O. Service Related Key Performance Indices

The target for customer service level is mainly grasped in a Key Performance Index for each region called OTIF Delivery, referring to a delivery that is on time and completed in full (On Time In Full). This KPI is the multiplication of Case Fill Rate and Requested Delivery Date. In addition, forecast accuracy and forecast bias are key performance indices related to service. The KPI's have been specified for Kraft Heinz Europe per calendar year, see Table 20.

Table 20: Global KPI's related to customer service.

KPI	Definition	Measurement
Case Fill Rate (CFR)	**(41)** $CFR = \frac{Total\ Delivered\ Quantity\ (cs)}{Total\ Ordersed\ Quantity\ (cs)} * 100\%$	Year to Date
Requested Delivery Date (RDD) Rate	**(42)** $RDD = \frac{\#\ orders\ delivered\ on\ time}{\#\ total\ number\ of\ orders} * 100\%$	Year to Date
On Time in Full (OTIF)Delivery	**(43)** $OTIF\ = CFR\ x\ RDD\ (\%)$	Year to Date
Forecast Accuracy (CPC level)	**(44)** $FA = \left(1 - \frac{\sum_{CPC} abs[FCST - ACT]}{\sum_{CPC}[ACT]}\right) * 100\%$	Year to Date
Forecast BIAS (country level)	**(45)** $BIAS = \frac{\sum FCST\ -\ \sum ACT}{\sum ACT} * 100\%$	Monthly

Forecast BIAS has a lower (LCL) and upper (UCL) limit. Six months per year the indicator should have a BIAS within that interval to reach the target.

$$\boldsymbol{cs\ =\ Cases}$$
$$\boldsymbol{FCST\ =\ Forecasted\ Demand}$$
$$\boldsymbol{ACT\ =\ Actual\ Demand}$$
$$\boldsymbol{EPN\ =\ European\ Product\ Number}$$
$$\boldsymbol{CPC\ =\ Case\ Number, i.e. EPN\ for\ demand\ department}$$

Appendix P. Production Related Key Performance Indices

The performance of manufacturing sites is measured with several KPI's, among others Safety Indices, Quality Indices and Operational Cost. The three main KPI's for production are PTP, CTP and OEE.

PTP and CTP

Performance-to-plan (PTP) measures how much of the planned production quantity is produced. If the plan is to produce 10 tons of a certain product and the factory produces more than the plan, the PTP can even be higher than 100%. Overproduction can be beneficial when building stock for a certain season, however it happens that factories produce more than the plan to reduce their costs per ton.

The conform-to-plan (CTP) index, measures if the actual product produced is conform to the plan. A PTP can be 100% if the right amount is produced, but a wrong flavour. In case of the production of a 'wrong' product the CTP indicator will be influenced.

OEE

The Overall Equipment Efficiency is a measurement for identifying and understanding the equipment /process losses within Kraft Heinz. The theoretical maximum capacity of the equipment is 100% Overall Equipment Efficiency. Losses can occur in:

- **Availability** (1) Breakdowns
  (2) Waiting time because of setup/cleaning
- **Performance** (3) Minor stoppages, reduced production speed
- **Quality** (4) Scrap, rework

Equation (46) shows the formula for Overall Equipment Efficiency is and the parameters are described in Table 21.

$$OEE = \frac{B}{A} * \frac{D}{C} * \frac{E}{D} \tag{46}$$

Table 21: Parameters used in Overall Equipment Efficiency equation.

Parameter	Description
$\boldsymbol{TP}$	Total Production Time is the total planned production time
$\boldsymbol{A}$	Potential Production Time; $A = \ Total\ Production\ Time\ (TP) - \ Unscheduled\ Unavailability\ (1)$
$\boldsymbol{B}$	Actual production time; $B = Potential\ Production\ Time\ (A) - Waiting\ Time\ (2)$
$\boldsymbol{C}$	Theoretical output within the actual production time (B)
$\boldsymbol{D}$	Actual Output; $D = Theoretical\ Output\ (C) - Performance\ losses\ (3)$
$\boldsymbol{E}$	Good Product; $E = Actual\ Output\ (D) - Quality\ losses\ (4)$

Some of the availability losses are already planned like changeover, cleaning and maintenance. However, performance and quality issues are unplanned losses and arise from breakdowns, slow running lines, short stops and rejects.

Appendix Q. Model Assumptions

Certain model assumptions are discussed in more detail below.

Perishability of goods

Perishability of goods is not directly considered. This has been done as the main influencer when perishability is a problem is the size of the replenishment versus the demand. Therefore, the suggestion is to reduce the size of the lots when perishability problems are occurring. Indeed a trade-off could be present as well in which the cost related to obsolete stock is considered, however this would distract from the main focus of this research. The solution of any perishability problems should be found in a different parameter.

Service level raw materials

It has been assumed that the service level of raw materials (98,5%) does not influence the service level for finished goods. As large MPQ's are often present, a lack of raw materials might mainly affect the timing (or quantity) of the next production and not directly the product availability for the customers. However, this influence has not been considered in the model.

Forecast Error

First, the lead time of the raw materials is used to determine the forecast error for raw materials. It has been assumed that the forecast error is evenly distributed over the lead time. That is, if the lead time is 3 weeks, it has been assumed that the error in week 2 and week 3 are the same size. However, in general a forecast is less accurate over a longer period then over a short period. Given a lead time of 4 weeks, and comparing the situation of, $FH = 1$ to the situation of $FH = 2$, the error just outside the frozen horizon in week 2 is probably less than the error in week 3. However, this is not taken into account.

In the case of finished goods, it has been decided to determine the forecast error based on a lag of 1 for all finished goods. This has been done as currently most plans are based on that forecast. Given the current FH of 3 weeks, the plans made in the first week of the month could be updated according to newly released forecast (and therefore a lag of 0), the other weeks however, the plan is based on a forecast released in the previous month. With a Frozen Horizon between 2 and 6 weeks the majority of the plans are based on a forecast of lag 1.

Second, it has been assumed that for raw materials there exists no error within the frozen horizon. The frozen horizon should firm a plan and therefore eliminate the uncertainty for raw materials. However, other factors play a role as well. For example, it could be decided to increase a production because certain materials are available in cycle stock. The forecast then has an error but it does not affect our safety stock requirements.

Third, in gathering the inputs for the model it is assumed that the forecast error includes all errors, negative and positive. Any bias has not been considered. In the case that a forecast is consistently higher than the actual demand, there would be no need for safety stock to cover any forecast errors. The literature does not directly mention the effect of forecast bias on the safety stock requirements. The management within Kraft Heinz suggested not to include the bias. One of the main targets of the demand planners, the ones responsible for generating the forecast, is reducing the bias. Although there might be a ‘preference’ in terms of over- or under forecasting at this moment, it was not considered in this model.

Finally, the forecast error is assumed to be normally distributed. Although the largest part of the finished goods seems to have a forecast error that is normally distributed, the C items of raw materials (according to the ABC analysis) lean more towards non-normal distribution. To be able to generalize, the normal distribution has been chosen. However, this does not correspond with all forecast error analysis results.

Capacity constraints

Production capacity constraints influence average lead times of the finished goods, thus increasing the need for safety stocks. In addition, storage constraints affect the possibility to hold additional stock. However, to clarify the direct relation between the frozen horizon and the safety stocks, it has been decided that for this purpose the capacity constraints are left out of the model.

In the case of Alfaro higher utilization happens in the summer period because of the harvesting of tomatoes. Additional stock cover plans are running parallel to the safety stock requirements aimed at the uncertainty throughout the year. In addition, noticeable storage constraints are present for certain ingredients, like oil. It would therefore require investments if the oil storage capacity needs to be increased. Suggesting much higher safety stocks might prove difficult for these ingredient.

Uncertainties

In this scoping it has been stated that only uncertainties arising from the demand and the transportation times are included. However, a real-life environment is subject to more uncertainties.

For raw materials, safety stocks could be increased to account for supply uncertainties, like: disruption (the supply of goods is interrupted due to e.g. bad weather, strikes, suppliers going bankrupt), yield uncertainty (the quantity supplied falls short of the amount ordered) or lead time uncertainty (uncertainty in the lead time due to e.g. stockouts at the supplier or transit delays) (Atan, 2015).

For finished goods, safety stocks could be increased to account for inefficiencies the internal process. Although there is a measurement for the production performance of a factory, it is not clear where errors in the performance are arising from. Performance-to-plan (PTP) measures how much of the planned production quantity is produced, while the conform-to-plan (CTP) index measures if the actual product produced is conform to the plan. A PTP can be 100% if the right amount of the ‘wrong’ product is produced. A CTP score can be low per day, without affecting the inventory positions on a weekly level. In addition, a PTP score can be affected by raw material availability. Increasing the finished goods safety stock based on this score might not be the right choice.

Appendix R. Normal Distribution & Loss function

The normal distribution follows a bell-shaped curve (see Figure 35). The standard normal distribution is a special case of the normal distribution in which the mean is 0 and the standard deviation is 1. $\Phi(x)$ the cumulative distribution function of the standard normal distribution is the probability that a variable from the standard normal distribution will be less than or equal to X. The $\Phi(x)$ values are shown in Table 22.

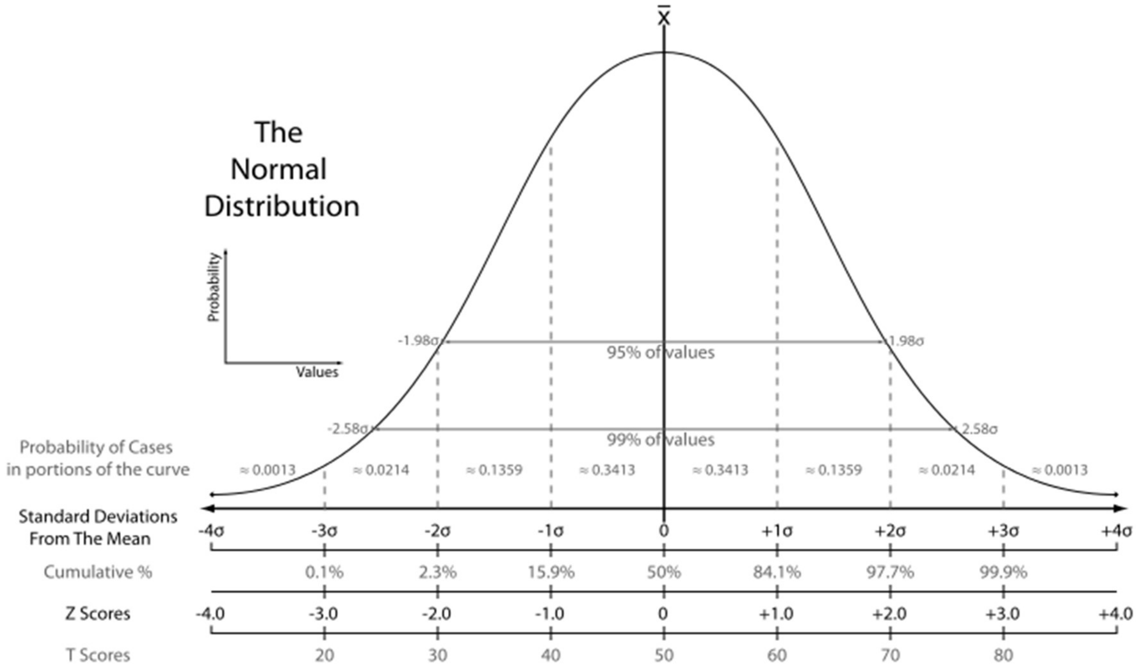

Figure 35: The normal distribution curve

The loss function $G(k)$ is depicted in Figure 36. Looking up a k-value corresponding to a $G(k)$ value can also be done in Table 23.Figure 37: Both k and Safety Factor plotted against the Loss Function.

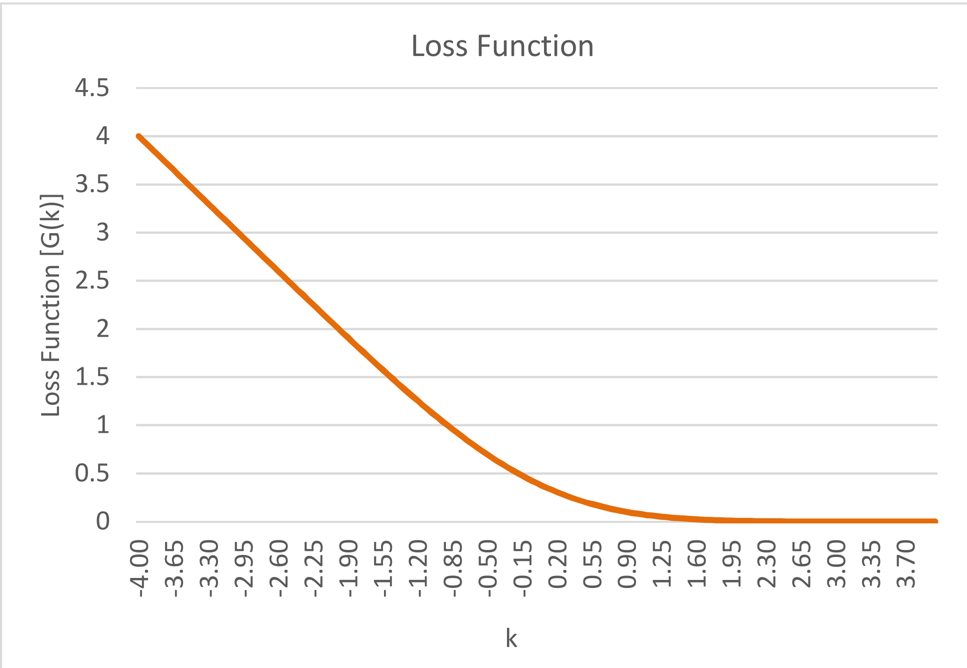

Figure 36: Loss Function $G(k)$

Table 22: x-values with corresponding $\Phi(x)$ values for the standard normal distribution

x	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.50000	0.50399	0.50798	0.51197	0.51595	0.51994	0.52392	0.52790	0.53188	0.53586
0.1	0.53983	0.54380	0.54776	0.55172	0.55567	0.55962	0.56356	0.56749	0.57142	0.57535
0.2	0.57926	0.58317	0.58706	0.59095	0.59483	0.59871	0.60257	0.60642	0.61026	0.61409
0.3	0.61791	0.62172	0.62552	0.62930	0.63307	0.63683	0.64058	0.64431	0.64803	0.65173
0.4	0.65542	0.65910	0.66276	0.66640	0.67003	0.67364	0.67724	0.68082	0.68439	0.68793
0.5	0.69146	0.69497	0.69847	0.70194	0.70540	0.70884	0.71226	0.71566	0.71904	0.72240
0.6	0.72575	0.72907	0.73237	0.73565	0.73891	0.74215	0.74537	0.74857	0.75175	0.75490
0.7	0.75804	0.76115	0.76424	0.76730	0.77035	0.77337	0.77637	0.77935	0.78230	0.78524
0.8	0.78814	0.79103	0.79389	0.79673	0.79955	0.80234	0.80511	0.80785	0.81057	0.81327
0.9	0.81594	0.81859	0.82121	0.82381	0.82639	0.82894	0.83147	0.83398	0.83646	0.83891
1	0.84134	0.84375	0.84614	0.84849	0.85083	0.85314	0.85543	0.85769	0.85993	0.86214
1.1	0.86433	0.86650	0.86864	0.87076	0.87286	0.87493	0.87698	0.87900	0.88100	0.88298
1.2	0.88493	0.88686	0.88877	0.89065	0.89251	0.89435	0.89617	0.89796	0.89973	0.90147
1.3	0.90320	0.90490	0.90658	0.90824	0.90988	0.91149	0.91309	0.91466	0.91621	0.91774
1.4	0.91924	0.92073	0.92220	0.92364	0.92507	0.92647	0.92785	0.92922	0.93056	0.93189
1.5	0.93319	0.93448	0.93574	0.93699	0.93822	0.93943	0.94062	0.94179	0.94295	0.94408
1.6	0.94520	0.94630	0.94738	0.94845	0.94950	0.95053	0.95154	0.95254	0.95352	0.95449
1.7	0.95543	0.95637	0.95728	0.95818	0.95907	0.95994	0.96080	0.96164	0.96246	0.96327
1.8	0.96407	0.96485	0.96562	0.96638	0.96712	0.96784	0.96856	0.96926	0.96995	0.97062
1.9	0.97128	0.97193	0.97257	0.97320	0.97381	0.97441	0.97500	0.97558	0.97615	0.97670
2	0.97725	0.97778	0.97831	0.97882	0.97932	0.97982	0.98030	0.98077	0.98124	0.98169
2.1	0.98214	0.98257	0.98300	0.98341	0.98382	0.98422	0.98461	0.98500	0.98537	0.98574
2.2	0.98610	0.98645	0.98679	0.98713	0.98745	0.98778	0.98809	0.98840	0.98870	0.98899
2.3	0.98928	0.98956	0.98983	0.99010	0.99036	0.99061	0.99086	0.99111	0.99134	0.99158
2.4	0.99180	0.99202	0.99224	0.99245	0.99266	0.99286	0.99305	0.99324	0.99343	0.99361
2.5	0.99379	0.99396	0.99413	0.99430	0.99446	0.99461	0.99477	0.99492	0.99506	0.99520
2.6	0.99534	0.99547	0.99560	0.99573	0.99585	0.99598	0.99609	0.99621	0.99632	0.99643
2.7	0.99653	0.99664	0.99674	0.99683	0.99693	0.99702	0.99711	0.99720	0.99728	0.99736
2.8	0.99744	0.99752	0.99760	0.99767	0.99774	0.99781	0.99788	0.99795	0.99801	0.99807
2.9	0.99813	0.99819	0.99825	0.99831	0.99836	0.99841	0.99846	0.99851	0.99856	0.99861
3	0.99865	0.99869	0.99874	0.99878	0.99882	0.99886	0.99889	0.99893	0.99896	0.99900
3.1	0.99903	0.99906	0.99910	0.99913	0.99916	0.99918	0.99921	0.99924	0.99926	0.99929
3.2	0.99931	0.99934	0.99936	0.99938	0.99940	0.99942	0.99944	0.99946	0.99948	0.99950
3.3	0.99952	0.99953	0.99955	0.99957	0.99958	0.99960	0.99961	0.99962	0.99964	0.99965
3.4	0.99966	0.99968	0.99969	0.99970	0.99971	0.99972	0.99973	0.99974	0.99975	0.99976
3.5	0.99977	0.99978	0.99978	0.99979	0.99980	0.99981	0.99981	0.99982	0.99983	0.99983
3.6	0.99984	0.99985	0.99985	0.99986	0.99986	0.99987	0.99987	0.99988	0.99988	0.99989
3.7	0.99989	0.99990	0.99990	0.99990	0.99991	0.99991	0.99992	0.99992	0.99992	0.99992
3.8	0.99993	0.99993	0.99993	0.99994	0.99994	0.99994	0.99994	0.99995	0.99995	0.99995
3.9	0.99995	0.99995	0.99996	0.99996	0.99996	0.99996	0.99996	0.99996	0.99997	0.99997
4	0.99997	0.99997	0.99997	0.99997	0.99997	0.99997	0.99998	0.99998	0.99998	0.99998

Table 23: Standard Loss Function Table with corresponding k values

k	G(k)	k	G(k)	k	G(k)	k	G(k)
-4.00	4.000007	-2.00	2.008491	0.00	0.398942	2.00	0.008491
-3.95	3.950009	-1.95	1.959698	0.05	0.374441	2.05	0.007418
-3.90	3.900011	-1.90	1.911054	0.10	0.350935	2.10	0.006468
-3.85	3.850014	-1.85	1.862575	0.15	0.328422	2.15	0.005628
-3.80	3.800017	-1.80	1.814276	0.20	0.306895	2.20	0.004887
-3.75	3.750021	-1.75	1.766174	0.25	0.286345	2.25	0.004235
-3.70	3.700026	-1.70	1.718288	0.30	0.266761	2.30	0.003662
-3.65	3.650032	-1.65	1.670637	0.35	0.248131	2.35	0.003159
-3.60	3.600039	-1.60	1.623242	0.40	0.230439	2.40	0.002720
-3.55	3.550048	-1.55	1.576124	0.45	0.213667	2.45	0.002337
-3.50	3.500058	-1.50	1.529307	0.50	0.197797	2.50	0.002004
-3.45	3.450071	-1.45	1.482813	0.55	0.182806	2.55	0.001715
-3.40	3.400087	-1.40	1.436668	0.60	0.168673	2.60	0.001464
-3.35	3.350105	-1.35	1.390898	0.65	0.155372	2.65	0.001247
-3.30	3.300127	-1.30	1.345528	0.70	0.142879	2.70	0.001060
-3.25	3.250154	-1.25	1.300587	0.75	0.131167	2.75	0.000899
-3.20	3.200185	-1.20	1.256102	0.80	0.120207	2.80	0.000761
-3.15	3.150223	-1.15	1.212104	0.85	0.109972	2.85	0.000643
-3.10	3.100267	-1.10	1.168620	0.90	0.100431	2.90	0.000542
-3.05	3.050320	-1.05	1.125680	0.95	0.091556	2.95	0.000455
-3.00	3.000382	-1.00	1.083315	1.00	0.083315	3.00	0.000382
-2.95	2.950455	-0.95	1.041556	1.05	0.075680	3.05	0.000320
-2.90	2.900542	-0.90	1.000431	1.10	0.068620	3.10	0.000267
-2.85	2.850643	-0.85	0.959972	1.15	0.062104	3.15	0.000223
-2.80	2.800761	-0.80	0.920207	1.20	0.056102	3.20	0.000185
-2.75	2.750899	-0.75	0.881167	1.25	0.050587	3.25	0.000154
-2.70	2.701060	-0.70	0.842879	1.30	0.045528	3.30	0.000127
-2.65	2.651247	-0.65	0.805372	1.35	0.040898	3.35	0.000105
-2.60	2.601464	-0.60	0.768673	1.40	0.036668	3.40	0.000087
-2.55	2.551715	-0.55	0.732806	1.45	0.032813	3.45	0.000071
-2.50	2.502004	-0.50	0.697797	1.50	0.029307	3.50	0.000058
-2.45	2.452337	-0.45	0.663667	1.55	0.026124	3.55	0.000048
-2.40	2.402720	-0.40	0.630439	1.60	0.023242	3.60	0.000039
-2.35	2.353159	-0.35	0.598131	1.65	0.020637	3.65	0.000032
-2.30	2.303662	-0.30	0.566761	1.70	0.018288	3.70	0.000026
-2.25	2.254235	-0.25	0.536345	1.75	0.016174	3.75	0.000021
-2.20	2.204887	-0.20	0.506895	1.80	0.014276	3.80	0.000017
-2.15	2.155628	-0.15	0.478422	1.85	0.012575	3.85	0.000014
-2.10	2.106468	-0.10	0.450935	1.90	0.011054	3.90	0.000011
-2.05	2.057418	-0.05	0.424441	1.95	0.009698	3.95	0.000009

Appendix S. Planning Software Model - Confidential

In the Planning Software a different method is used to find the numerical k value from a $G(k)$ value. Calculating the safety factor through their approximation formula is a different method of using the Loss Function table to find the appropriate k-values. The Safety Factor is defined as follows:

[redacted]

The appropriate values for the parameters in function [redacted] are dependent on the value for $G(k)$ and are displayed in the table below

Table 24: Values for $G(k)$ [redacted]

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

If G(k) is calculated for a range of k values, the approximation of the safety factor with equation [redacted] can be plotted to determine how accurate the approximation is. This has been done in Figure 37. In addition, the plot points are tabulated in Table 25.

Figure 37: Both k and Safety Factor plotted against the Loss Function.

Table 25: Loss Function G(k) with corresponding k values, and SF according to the Planning Software based on G(k)

k	G(k)	SF	k	G(k)	SF	k	G(k)	SF	k	G(k)	SF
-4.00	4.000007	[redacted]	-2.00	2.008491	[redacted]	0.00	0.398942	[redacted]	2.00	0.008491	[redacted]
-3.95	3.950009	[redacted]	-1.95	1.959698	[redacted]	0.05	0.374441	[redacted]	2.05	0.007418	[redacted]
-3.90	3.900011	[redacted]	-1.90	1.911054	[redacted]	0.10	0.350935	[redacted]	2.10	0.006468	[redacted]
-3.85	3.850014	[redacted]	-1.85	1.862575	[redacted]	0.15	0.328422	[redacted]	2.15	0.005628	[redacted]
-3.80	3.800017	[redacted]	-1.80	1.814276	[redacted]	0.20	0.306895	[redacted]	2.20	0.004887	[redacted]
-3.75	3.750021	[redacted]	-1.75	1.766174	[redacted]	0.25	0.286345	[redacted]	2.25	0.004235	[redacted]
-3.70	3.700026	[redacted]	-1.70	1.718288	[redacted]	0.30	0.266761	[redacted]	2.30	0.003662	[redacted]
-3.65	3.650032	[redacted]	-1.65	1.670637	[redacted]	0.35	0.248131	[redacted]	2.35	0.003159	[redacted]
-3.60	3.600039	[redacted]	-1.60	1.623242	[redacted]	0.40	0.230439	[redacted]	2.40	0.002720	[redacted]
-3.55	3.550048	[redacted]	-1.55	1.576124	[redacted]	0.45	0.213667	[redacted]	2.45	0.002337	[redacted]
-3.50	3.500058	[redacted]	-1.50	1.529307	[redacted]	0.50	0.197797	[redacted]	2.50	0.002004	[redacted]
-3.45	3.450071	[redacted]	-1.45	1.482813	[redacted]	0.55	0.182806	[redacted]	2.55	0.001715	[redacted]
-3.40	3.400087	[redacted]	-1.40	1.436668	[redacted]	0.60	0.168673	[redacted]	2.60	0.001464	[redacted]
-3.35	3.350105	[redacted]	-1.35	1.390898	[redacted]	0.65	0.155372	[redacted]	2.65	0.001247	[redacted]
-3.30	3.300127	[redacted]	-1.30	1.345528	[redacted]	0.70	0.142879	[redacted]	2.70	0.001060	[redacted]
-3.25	3.250154	[redacted]	-1.25	1.300587	[redacted]	0.75	0.131167	[redacted]	2.75	0.000899	[redacted]
-3.20	3.200185	[redacted]	-1.20	1.256102	[redacted]	0.80	0.120207	[redacted]	2.80	0.000761	[redacted]
-3.15	3.150223	[redacted]	-1.15	1.212104	[redacted]	0.85	0.109972	[redacted]	2.85	0.000643	[redacted]
-3.10	3.100267	[redacted]	-1.10	1.168620	[redacted]	0.90	0.100431	[redacted]	2.90	0.000542	[redacted]
-3.05	3.050320	[redacted]	-1.05	1.125680	[redacted]	0.95	0.091556	[redacted]	2.95	0.000455	[redacted]
-3.00	3.000382	[redacted]	-1.00	1.083315	[redacted]	1.00	0.083315	[redacted]	3.00	0.000382	[redacted]
-2.95	2.950455	[redacted]	-0.95	1.041556	[redacted]	1.05	0.075680	[redacted]	3.05	0.000320	[redacted]
-2.90	2.900542	[redacted]	-0.90	1.000431	[redacted]	1.10	0.068620	[redacted]	3.10	0.000267	[redacted]
-2.85	2.850643	[redacted]	-0.85	0.959972	[redacted]	1.15	0.062104	[redacted]	3.15	0.000223	[redacted]
-2.80	2.800761	[redacted]	-0.80	0.920207	[redacted]	1.20	0.056102	[redacted]	3.20	0.000185	[redacted]
-2.75	2.750899	[redacted]	-0.75	0.881167	[redacted]	1.25	0.050587	[redacted]	3.25	0.000154	[redacted]
-2.70	2.701060	[redacted]	-0.70	0.842879	[redacted]	1.30	0.045528	[redacted]	3.30	0.000127	[redacted]
-2.65	2.651247	[redacted]	-0.65	0.805372	[redacted]	1.35	0.040898	[redacted]	3.35	0.000105	[redacted]
-2.60	2.601464	[redacted]	-0.60	0.768673	[redacted]	1.40	0.036668	[redacted]	3.40	0.000087	[redacted]
-2.55	2.551715	[redacted]	-0.55	0.732806	[redacted]	1.45	0.032813	[redacted]	3.45	0.000071	[redacted]
-2.50	2.502004	[redacted]	-0.50	0.697797	[redacted]	1.50	0.029307	[redacted]	3.50	0.000058	[redacted]
-2.45	2.452337	[redacted]	-0.45	0.663667	[redacted]	1.55	0.026124	[redacted]	3.55	0.000048	[redacted]
-2.40	2.402720	[redacted]	-0.40	0.630439	[redacted]	1.60	0.023242	[redacted]	3.60	0.000039	[redacted]
-2.35	2.353159	[redacted]	-0.35	0.598131	[redacted]	1.65	0.020637	[redacted]	3.65	0.000032	[redacted]
-2.30	2.303662	[redacted]	-0.30	0.566761	[redacted]	1.70	0.018288	[redacted]	3.70	0.000026	[redacted]
-2.25	2.254235	[redacted]	-0.25	0.536345	[redacted]	1.75	0.016174	[redacted]	3.75	0.000021	[redacted]
-2.20	2.204887	[redacted]	-0.20	0.506895	[redacted]	1.80	0.014276	[redacted]	3.80	0.000017	[redacted]
-2.15	2.155628	[redacted]	-0.15	0.478422	[redacted]	1.85	0.012575	[redacted]	3.85	0.000014	[redacted]
-2.10	2.106468	[redacted]	-0.10	0.450935	[redacted]	1.90	0.011054	[redacted]	3.90	0.000011	[redacted]
-2.05	2.057418	[redacted]	-0.05	0.424441	[redacted]	1.95	0.009698	[redacted]	3.95	0.000009	[redacted]