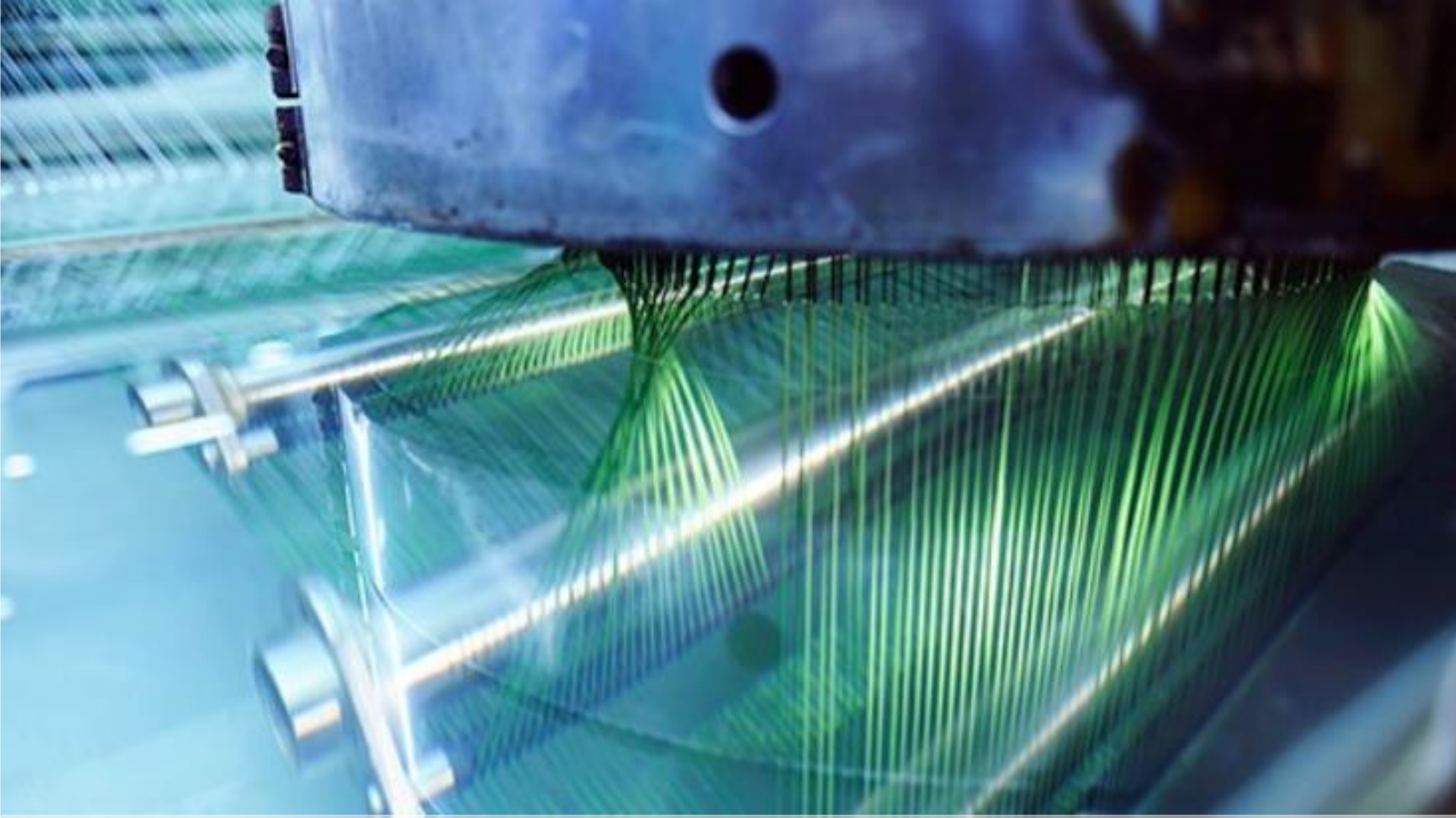

Improving the inventory control policy of TenCate Grass

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Abbreviations

Abbreviation	Full
General	
MTO	Make-To-Order
MTS	Make-To-Stock
CSL	Cycle service level
fr	Product fill rate
FCFS	First Come First Served
Shapes of the injection holes	
The shapes of the products are left out because of confidentiality reasons	
Colours of the products	
The colours of the products are left out because of confidentiality reasons	
Abbreviations linked to the inventory control policy	
Q	Economic order quantity
K	The setup or ordering cost, which is fixed per order
D	Demand rate per unit time, mostly the demand of one year
h	Holding costs, expressed as % of the cost per unit
C	Cost price per unit
TC	Total costs
D_L	Demand during lead time
σ_L	Standard deviation of demand during lead time
s	Reorder point
S	Order-up-to-level
SS	Safety stock
$\hat{x}_L$	Expected demand during lead time
z	Safety factor
ρ	Discount rate
q	Obsolescence rate
sv	Salvage value
F_t	Seasonal index of period *t*
CMA_t	Centred moving average of period *t*
I_m	Normalized seasonal index for month *m*
X_c^2	Chi-square value for the goodness of fit test
Abbreviations linked to the Monte Carlo simulation	
R(t)	Order receipt schedule in period *t*
I(t)	The available inventory in period *t*
B(t)	Backlog, the number of stockouts in period *t*

O(t)	The on-hand inventory at the end of period t
o	Decision to order; 1 if the product is ordered, 0 otherwise
c_h	Holding costs
c_s	Stockout costs
γ	Relative error, which is used to determine the number of replications

Preface

Dear reader,

In front of you lies my thesis that has been written to finish my master Industrial Engineering and Management with the specialisation Production and Logistics Management. After a studentship of five years, which consists of three years bachelor and two years master, it has come to an end. I would like to use this preface as an opportunity to thank all the people who made the realisation of this thesis possible.

First of all, I want to thank all my colleagues at TenCate Grass. They have welcomed we warmly and they always have the door open for a chat even though they are extremely busy at some times. I enjoyed every minute of working with them.

A special thanks to the employees of the production facility who helped me gaining relevant data and showing me how all production processes work in practice. But even more important, I want to thank my supervisor of the company, who was up for some substantive discussions from time to time and provided me with helpful feedback.

Finally, I want to thank my supervisors of the University. Even though they were quite busy with doing some studies on their own, teaching students during courses and supervising a lot of other students, they were still able to make time to guide me through my thesis. I learned a lot during the sessions we had and I find the feedback really helpful. With their help, my thesis was continuously improved.

Enjoy reading this thesis!

Annemijn Tijhuis

Management summary

This study is conducted at TenCate Grass, which is a global leader in development, production and marketing of synthetic turf components. For this study, there is a focus on the production of yarns. The company already implemented an inventory control policy, however, this policy lacks in support of the parameters and is mostly based on common sense. For example, for the order costs, which are based on the changeover costs, there is no reliable data available. With the use of the policy, the company strives to meet a certain target level against minimum costs. Furthermore, there is a challenge in implementing the policy into the ERP system of the company. Therefore, a research question has been developed which is answered during this study:

How to improve the current inventory control policy considering the trade-off between meeting a target cycle service level and reducing inventory costs along with the mapping of changeover costs and how to implement it into the current ERP system?

To answer this main question, several sub questions have been developed which are handled during the different chapters.

First of all, *Chapter 2. Current situation* is dedicated to mapping the current situation. The inventory control policy as already developed by the company is described, followed by an overview of the current inventory level and the ratio between MTO and MTS products in inventory. Besides, the chapter describes how the company currently deals with changeovers and which products can be produced on which production line. The chapter concludes with the probabilities of having a certain changeover, which are used to determine the actual order costs.

Secondly, *Chapter 3. Literature review* searches for theory which can be used to develop the inventory control policy. Different methods to classify products have been investigated, concluding that the ABC-XYZ classification is a good method to classify the products as either MTO or MTS. Furthermore, the chapter includes a search for different methods that can be used to develop the inventory control policy. It appears that there are many methods available in case a Normal distribution for demand can be assumed. The relation between the safety stock and the costs or the cycle service level have been investigated. Besides, there has been a search for the different methods available to improve the changeover time or the costs related to changeovers. Even though improving the changeovers is not part of this study, a plan to improve the changeovers is handy to have on hand and can be used in future studies. Lastly, an overview of the Monte Carlo simulation and a description on how the simulation can be developed is given. The purpose of the Monte Carlo simulation is to compare the current model with the proposed model in terms of costs.

Chapter 4. Solution Design includes the actual development of the proposed inventory control policy. First, it has been checked whether there are some restrictions or requirements that should be taken into account while developing the policy. It appeared that there are four factors influencing the model, namely: obsolescence, different selling prices, seasonality and outliers. Thereafter, the data is pre-processed, such that it can be used to determine the control parameters of the inventory control policy. Within the pre-processing of the data, the classification of the products as MTS or MTO has been executed, following from a determination of the most important products based on their demand value, the determination of intermediate products that are sold in at least six months and an ABC-XYZ classification. As a result, 44 MTS products are found. Thereafter, the outliers are determined based on boxplots, the inclusion of obsolescence is guaranteed with the use of a new EOQ formula and the probability theory to reduce the safety stock and it is determined whether seasonality actually plays a role. General patterns and products that had demand in a period for each of the last three years are determined. Thereafter, is has been checked whether there is actually seasonality involved with the use of seasonal subseries plots and a Chi-Square test. It appeared that for 8 MTS products, seasonality should be taken into account, which is implemented in the model with the use of seasonal indices.

The last part of pre-processing the data is the determination of the demand distribution. It can be assumed that it is allowed to assume that a product is Normal distributed if the mean demand during lead time exceeds 10 (Heijden & Diks, 2018), which holds for all of the MTS products.

Besides the control parameters, also the input parameters are required to determine the policy parameters. The input parameters are represented by the lead time, the holding costs and the order costs. The lead time for manufactured products consists of the manufacturing lead time, the procurement lead time (for raw materials, components and subassemblies) and the shipping lead time (Snapp, 2017). By combining these values we see that the lead time is fixed and equal to L weeks. The holding costs are found to be 22% of the cost price per annum, however, it should be noted that this value may be lower in practice. However, this cannot be determined with certainty as a result of missing data. The last input parameter that is determined are the order costs. These costs purely consist of changeover data, which depends on die changes and colour- or material changes. The die changes consist of the stop time, FTE operators, waste, mechanics and cleaning and is found to be 1,653,657.25 euro. The costs of a colour and material change consist of waste and FTE operators, since there is no need to stop the production line to change the colour or material. The costs for a colour and material change combined is found to be 160,465.71 euro, where a colour change represents 70% of the cost price and a material change represents 30% of the cost price. The data for the order costs are based on observations and measured in the production facility.

With the use of the input- and control parameters, the policy parameters are determined, which consist of the safety stock, the reorder point and economic order quantity. The formulas to determine these parameters are based on a (s, nQ)-policy with the assumption that the demand of the products is Normal distributed.

The last aspect of *Chapter 4* is entering the parameters of the proposed model in the ERP system. The parameters are included in the ERP system with the use of configuration packages.

Chapter 5. Analysis of results consists of the development of the Monte Carlo simulation and the determination of the number of replications required to get reliable results. The Monte Carlo simulation gives insight on the impact of using the proposed inventory control policy instead of the current inventory control policy and it appeared that using the proposed model will reduce the costs with more than 28% without affecting the cycle service level, which has even improved from 0.89 to 0.94. However, it should be noted that there is more spread in the results of the cycle service level in the proposed model compared to the current model, therefore, the increase in cycle service level may not be maintained in practice. Thereafter, the Monte Carlo simulation is verified and validated, showing that the Monte Carlo simulation meets its intended goals and the cost values based on the actual demand of 2018 fall within the ranges found by the Monte Carlo simulation. Furthermore, it is checked whether the parameters of the current policy are used in practice, which appears not to be the case. As a result, the overall costs and in particular the order costs can be reduced when one of both policies is actually used in practice. This assumption has been checked by determining the course of the inventory if the proposed policy was used in practice compared to how it actually went in practice. It appeared that the company was not always able to have some inventory of products on hand, and therefore, it may be the case that they were not always able to deliver MTS products directly. Even though it seems that the total costs are reduced, when someone keeps going on like it is in practice, there is a chance of facing stockouts which can be avoided by using the proposed policy. Therefore, it can be assumed that honouring the proposed policy is advisable.

Now that the policy is developed and the results of the proposed model sound promising, a conclusion could be drawn and the main research question can be answered. *Chapter 6. Conclusions and recommendations* summarizes the results and answers the main research question; To improve the current policy, a proposed inventory control policy is made and it will be implemented in the current ERP system with the use of configuration packages.

To summarize the improvements that can be made compared to the current inventory control policy, the main contributions of this study are mentioned below:

- This study shows the influence of using parameters of an inventory control policy in practice and it shows the company how they score in practice.
- This study compares the proposed model with the current model as already developed by the company with the use of a Monte Carlo simulation.
- This study adds configuration packages to the inventory control policy that are automatically updated. Thereafter, these files only have to be uploaded in the ERP system to have all relevant parameters in the ERP system.
- This study gives the company some insights into their demand with the use of extensive analyses.
- This study measures all relevant data, when not available within the company. For example, the order costs based on changeovers are measured with observations.
- This study takes obsolescence into account, to avoid that the company has to sell products against relatively low prices.
- This study determines one selling price per product, that is used for the calculations to classify the different products.
- This study uses seasonality factors, that are determined based on actual demand and can be updated when new demand arrives. Furthermore, an additional check has been added to see whether seasonality should actually be taken into account for specific products.
- This study determines outliers that may have a negative impact on the outcomes of the inventory control policy and excludes these outliers while calculating parameters.
- This study extends the classification of the products by also taking the cost price and selling price into account. Besides, the classification is also based on the number of months at which a product is demanded.
- This study does not base target cycle service levels on common sense, but underpins the target cycle service levels with theory. Products that are considered to be less important can have lower targeted cycle service levels to reduce the costs.

Lastly, this study recommends some activities divided upon three categories: recommendations that can be put into practice by the company immediately, recommendations that can be applied in the future by the company and recommendations for future research on the same topic. The different recommendations are mentioned below.

Recommendations that can be put into practice by the company immediately:

- Use the proposed inventory control policy in practice
- Ensure that there is inventory available for intermediate products that are not classified as MTS
- Enter the parameters of the inventory control policy in the ERP system

Recommendations that can be applied in the future by the company:

- Collect the data to calculate the cycle service level
- Determine whether obsolescence has to play a role
- Determine whether the lead time is fixed and not subject to change
- Determine the reduction of the order costs when dies are cleaned inhouse
- Determine the influence of lower holding costs
- Reclassify products as MTS or MTO
- Update the probabilities

Recommendations for further research on the same topic:

- Determine the implications of classifying the products in practice
- Check the assumptions made within this study

- Determine whether it is possible to automatically update the probabilities
- Determine how the policy can be used when a different ERP system is used
- Determine how the number of die changes can be reduced
- Investigate whether the time spend on changeovers can be reduced
- Improve the forecasting method

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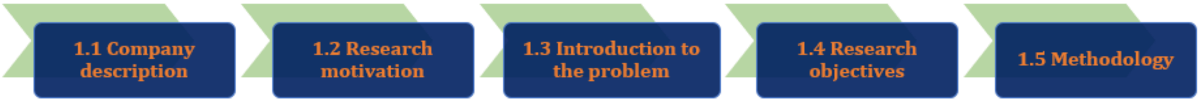
1. Introduction

This chapter represents an introduction to the aim of the study. First, the company for which the study is executed will be introduced, followed by a motivation of research. Thirdly, the problem will be introduced for which research questions are developed in section *1.4 Research objectives.* Lastly, the methods used to answer the different research questions and to fulfil this study will be mentioned in section *1.5 Methodology*. The following flow chart represents an overview of the order in which the subjects will be handled.



1.1 Company description

TenCate Grass is the global leader in development, production and marketing of synthetic turf components. The company has production facilities in different continents all around the world, for example in North America, Europe, Asia-Pacific and the Middle East. *Figure 1* represents the different places where the company is located. The products produced at the company are synthetic turf yarns, backings, woven technology, base layers and systems. They provide artificial turf fields for all kinds of sport or recreation areas.

There are many departments part of the company, for example, sales and marketing department, purchasing department, expanse management, warehouse, manufacturing, resource planning, service and human resources. This study is executed at Yarns, a part of the company which is fully focused on synthetic turf yarns.

Figure 1: *The different places at which the company is located*

1.2 Research motivation

The mission of the company is to deliver good-quality grass fields to customers. The products sold at the company are quite expensive in comparison to the competition in the market, as a result, it is essential that they comply with agreements and deliver products that are of high quality. Furthermore, it is important that they are able to meet certain cycle service levels, the production lines can run constantly, that they deliver high quality components and avoid breakdowns as much as possible. Besides, the inventory level of the company should not be extremely high, however, it should be able to come through the high season or survive critical moments. Currently, all planners use Excel to determine the production planning and fill in their obtained information into the ERP system. However, an assumption has been made that there is much to be gained by using the ERP system for all aspects involved in the company and, thus, the planning. Using software to make a planning will probably ease the way planners have to work and reduces mistakes prone to human error. For example, by filling in the ERP system manually, a spelling mistake can easily be made. The company delivers yarns to their customers, which are companies that turf or weave the field (final product) themselves. One disadvantage of this business is that it is highly seasonal. For example, the field can only be placed when there is no rain or snow and is restricted to seasonal stops (in case of a sport field), which is mainly the case from May to August. Thus, the high season finds place during this period. In order to survive the high season or to meet unexpected demand it is important to have an efficient inventory control policy. However, the contrary of having a lot of stock in advance to survive the high-season is the fact that having inventory also involves costs. Therefore, a trade-off exists between the costs of having inventory versus the downsides of not being able to fulfil all demand within a given timeframe.

At the moment of writing, an inventory control policy has been implemented. However, this inventory control policy lacks in substantiation of the parameters involved and is not yet part of the ERP system. Additionally, the inventory control policy still has to be updated manually and the planners do not use the ERP system to make the final production planning. As a result, there should be a focus on optimizing this inventory control policy and automate this policy within the ERP system. Another result of not having all data in the ERP system, is that the purchasers may not have ordered enough raw material to let the production run. In addition, the planning is not updated when a production line was not able to run as a result of not having enough raw material.

The company uses the ERP system called Microsoft Dynamics Navision (2017). Even though the ERP system is available, the system is not used most efficiently, which is something that has to be improved. The system can be used to communicate through the whole organization and make adjustments in one department visible for all departments that have to deal with this adjustment.

The company combines both a Make-To-Order (MTO) as well as a Make-To-Stock (MTS) policy. In that way, products that will not be sold a lot are only produced when an order is placed. As a result, there will be (almost) no inventory for MTO products. For the MTS products, on the other hand, reorder points and safety stock have to be determined, which is nowadays based on the demand of the previous year.

1.3 Introduction to the problem

As the company is a global leader for the production of synthetic turf components, it is essential to have the production facility in order. A main component of controlling the production facility is having an inventory control policy that keeps track of the inventory level. Some years ago, the company produced products based on the expected sales and agreements with customers, however, these agreements were not always complied with, leaving the company with unnecessary inventory leftovers. As a result, some produced products were not touched for years or sold against very low prices. Approximately two years ago, they sold a lot of inventory against low prices and implemented a basic inventory control policy. However, this implemented inventory control policy is not optimal and lacks in support for the different features of the inventory control policy. Some features were filled up based on common sense, which makes it subject to human error.

Another factor influencing the current inventory control policy is the classification of the products as either MTS or MTO products. However, there is some doubt whether the current classification model is reliable enough to make such important decisions, since it is not based on theory and a classification as MTO product means that there will be no inventory of the product.

Within this study, there is also a focus on mapping the costs of changeovers and improve the changeover times when possible, since the changeover times are linked to the ordering costs and, therefore, the order quantity. If we are able to reduce the time required to fulfil a changeover, the total costs per changeover also changes, leading to lower ordering cost. As a result, the order quantity will be lower, meaning that also the inventory level will be lower and the company is still able to fulfil all demand.

To introduce the problem, a problem cluster has been made, which can be found in *Figure 2*. Based on the problem cluster, we can conclude that there is a need to improve the current inventory policy and come up with a new and well-underpinned inventory control policy including the classification of the products as either MTO or MTS. The inventory control depends on several factors, for example, changeover times as a result of changing the dies and cleaning the lines, the holding costs and the cycle service level. When the inventory control policy is developed, we want to compare it to the current inventory control policy with the use of a Monte Carlo simulation.

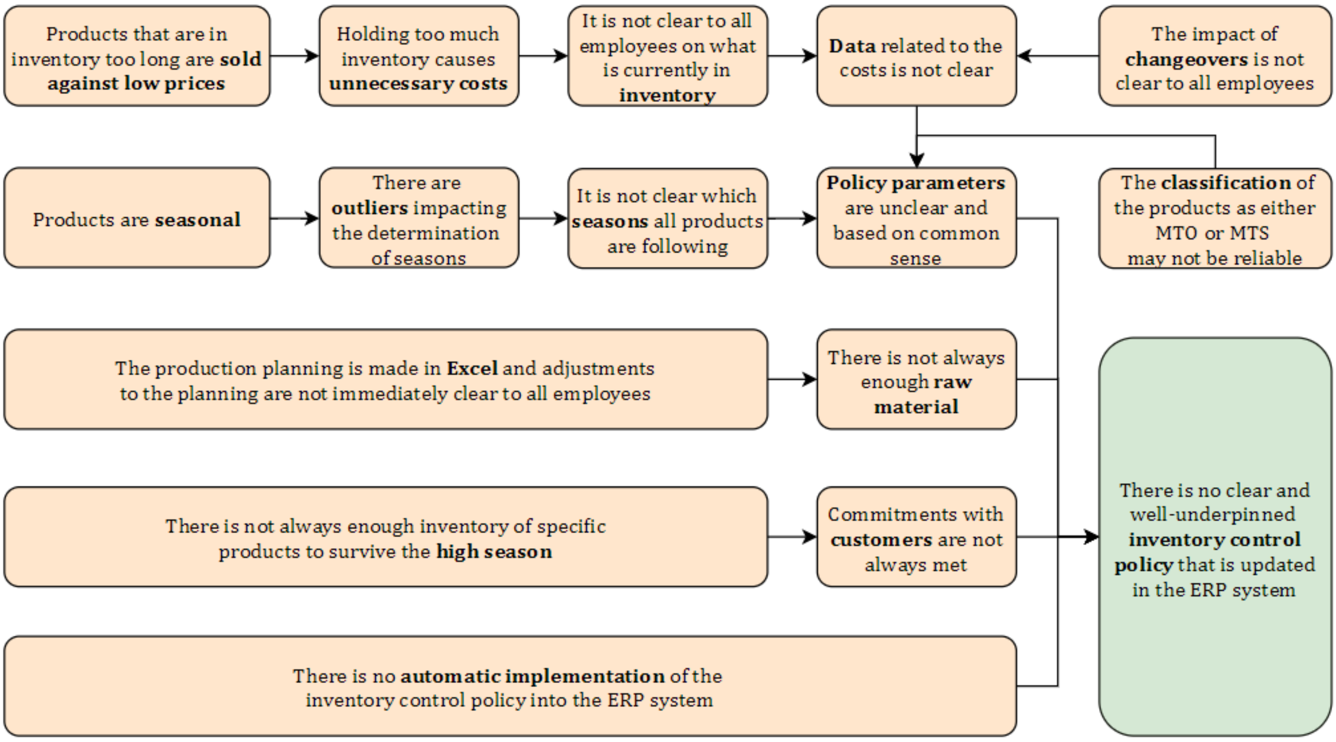


Figure 2: *Problem cluster*

1.4 Research objective

This research is introduced in order to improve the current inventory control policy and ease the way of planning by using an ERP system more effectively. In that way, the main research question that is answered during this study is:

- *How to improve the current inventory control policy considering the trade-off between meeting a target cycle service level and reducing inventory costs along with the mapping of changeover costs and how to implement it into the current ERP system?*

Additionally, other important research questions that should be answered during the study are:

- *What safety stocks should be taken for the different products and how will they be updated within the ERP system?*
- *Is there seasonality or obsolescence that should be taken into account? If so, how should they be taken into account?*
- *What distributions do the different demands follow?*
- *How should the different products be classified and how should each class be treated?*

The five questions as mentioned above represent the research objective of this study. To answer these questions, there are sub-questions divided per chapter to answer the main questions. These sub-questions are elaborated below.

1. *What is the current inventory control policy (e.g. classification, determination of parameters, inclusion of seasonality and obsolescence) and at what costs?*
2. *How does the company deal with changeovers?*

3. *What methods are available in literature to classify the different products?*
4. *Which methods are available in literature to implement an efficient inventory control policy of production systems?*
   a. *How to determine the parameters involved?*
   b. *What is the relation between the safety stock and costs?*
   c. *What is the relation between the safety stock and a desired customer service level?*
5. *Which methods are available in literature to improve changeovers?*
6. *What is the purpose of a Monte Carlo simulation and how can it be used?*

7. *Are there requirements or restrictions involved to implement an inventory control policy?*
8. *How can we use existing data to develop the inventory control policy?*
   a. *How should the different products be classified as MTO or MTS and how should they be treated based on this classification?*
   b. *How should seasonality or obsolescence when applicable be taken into account?*
   c. *What are the different distributions that the demand of the products follow?*
9. *What should the values of the input parameters be?*
   a. *What lead time should be taken into account?*
   b. *What value represents the holding costs?*
   c. *What are the costs of the changeovers?*
10. *What should the policy parameters per product be?*
    a. *What should the value of the safety stock be for each of the products?*
    b. *What should the value of the reorder point be for each of the products?*
    c. *What should the value of the EOQ be for each of the products?*
11. *How can the found inventory control policy be entered in current ERP system?*

12. *What is the impact of implementing the proposed inventory control policy based on a simulation model?*
13. *What is the effect of the parameters of the inventory control policy?*

The relation between the different research questions can be found in *Figure 3.* The first two questions will be addressed in *Chapter 2 – Current situation.* The third upon the sixth question will be handled in *Chapter 3 – Literature review*. Thereafter, question seven until question eleven will be discussed in *Chapter 4 - Solution design* and question twelve and thirteen will be handled in *Chapter 5 – Analysis of results*. Furthermore, *Chapter 6 – Conclusions and recommendations* will not answer any further questions, but it will conclude the found results and combine these results into a recommendation for the company.

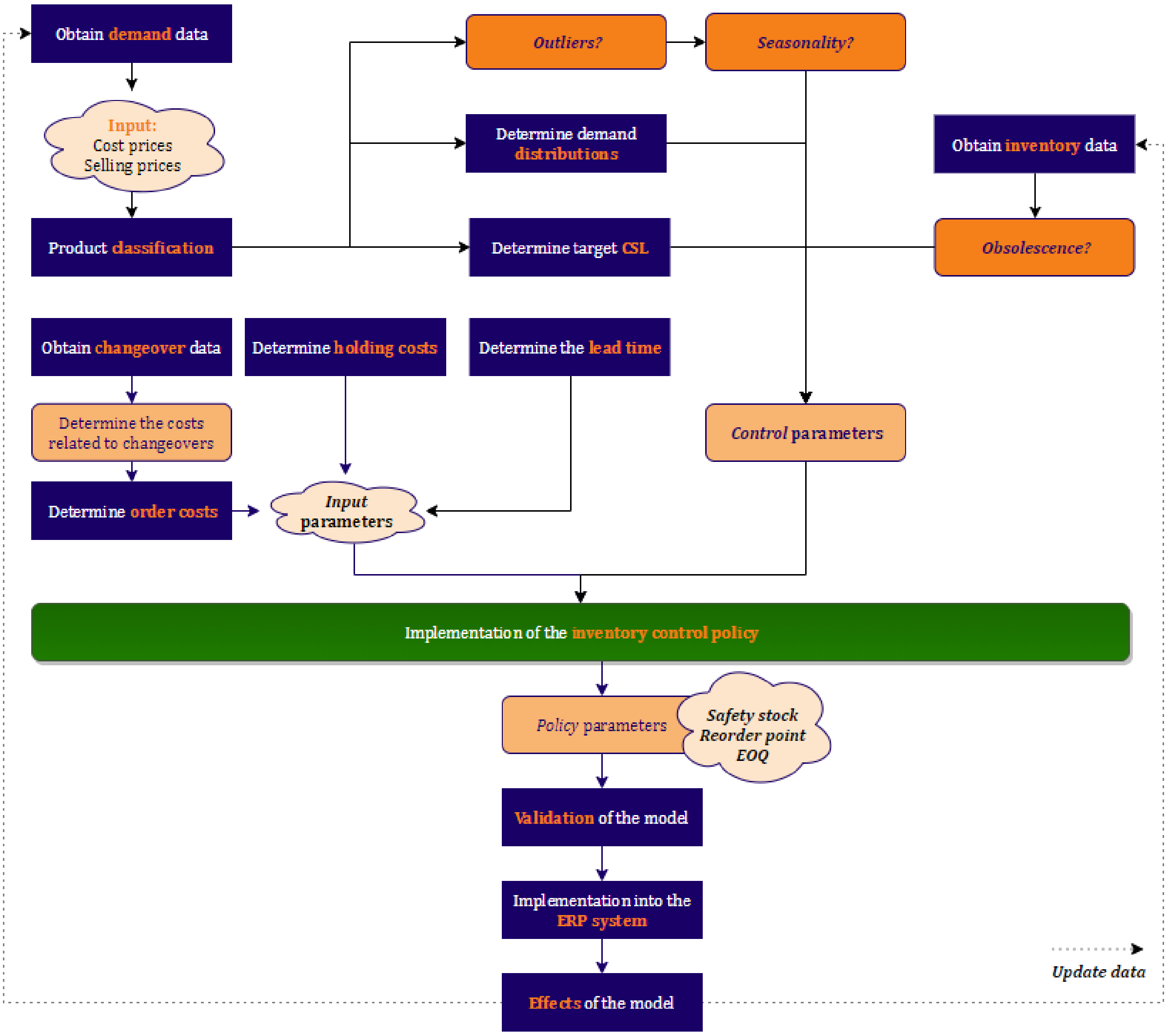


Figure 3: *Relationship between all research questions*

1.5 Methodology

This study will be conducted within a timeframe of six months, therefore, it is necessary to think of the methodologies used to answer the sub-questions to be able to perform the study within the given timeframe. This section mentions all methods used to answers each research question.

2.1 What is the current inventory control policy (e.g. classification, determination of parameters, inclusion of seasonality and obsolescence) and at what costs?
The resource planning department is responsible for the inventory control policy. To gain insight in the current inventory control policy used, some conversations will be held with employees of the resource planning department. We will determine how the products are currently classified and how they determine the different parameters involved in the inventory control policy. Moreover, we will check whether the percentage of products belonging to a classification is in line with the theory behind the inventory control policy. Besides, we will look at the current inventory level based on historical data and the corresponding costs.

2.2 How does the company deal with changeovers?
This question focuses on changeovers, however, the main aspect of changeovers are die changes. Interviews will be held with employees that have to deal with die changes in practice and with employees that have to deal with die changes in the production planning. Besides, historical data of the production planning will be studied to determine the number of die changes scheduled.

Additionally, changeovers consist of small changeovers when only the material or colour need to be changed, these kind of changeovers will only have a small impact on the total changeover cost. To determine these costs, historical data will be studied to determine the average number of times colour or material changes happen and at what costs.

3.1 What methods are available in literature to classify the different products?
The most common ways of inventory classification will be summarized and mentioned with their characteristics. This way, probably the most promising way to classify products at the company will be used in practice.

3.2 Which methods are available in literature to implement an efficient inventory control policy of production systems?
We will look at policies that are similar to the current methodology used by the company as well as policies that might seem out-of-the-box. The methods will be compared based on advantages and disadvantages in line with the desires of the company. For the determination of all parameters involved, we will look at the most common methods again. Besides, we will look for literature that takes the costs into account while approaching inventory and we will look for literature that takes the desired customer service level into account to determine the safety stock. By combining this literature, we hope to find the perfect balance between costs and customer satisfaction.

3.3 Which methods are available in literature to improve changeovers?
For this question, we will look into existing literature whether information can be found over changeovers, and how companies deal with changeover in general. As a result, we may find interesting ways to deal with changeovers that may also be used in the company.

3.4 What is the purpose of a Monte Carlo simulation and how can it be used?
This question will be answered with the use of theory. The goal of the Monte Carlo simulation is to compare the proposed with the current model. For that purpose, it is required to think of how to set up a Monte Carlo simulation and how it can be used.

4.1 Are there requirements or restrictions involved to implement an inventory control policy?
In the literature section, we already searched for inventory control policies that are most promising for the company. This question will search whether all data to determine the parameters is available and whether there are some other restrictions that should be taken into account before actually being able to implement the model.

4.2 How can we use existing data to develop the inventory control policy?
This question focuses on pre-processing the data that will be used as input for the inventory control policy. It will already start working on the development of the proposed inventory control policy, by determining how the products should be classified as either MTO or MTS and how seasonality or obsolescence should be taken into account when they appear to have an influence on the inventory control policy. Finally, it will be determined which distribution the demand of MTS products follow.

4.3 What should the values of the input parameters be?
This part focuses on getting the right data representing the lead time, the holding costs and the costs of changeovers. The holding costs will be based on literature when data is not available, but obtaining the data for the changeover costs will be done by measuring the time spend on changeovers in practice and gaining the costs of those activities related to time. Only when there is time left and the found literature of changeovers seems to be promising, we will look at whether the gained insights can be implemented at the company.

4.4 What should the policy parameters per product be?
The literature found to determine the parameters will be used to actually determine the parameters. This part focuses on determining the safety stock, the reorder point and the economic order quantity.

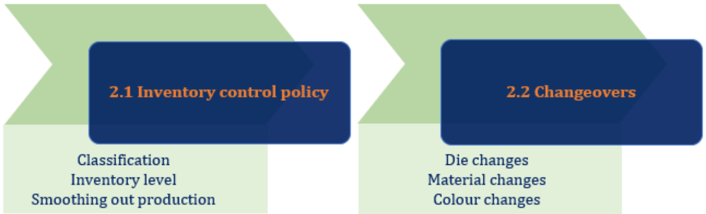
4.5 How can the found inventory control policy be entered in current ERP system?
In previous questions, we already determined whether implementing the inventory control is possible. However, there may be some other restrictions when it comes to implementing the policy into the ERP system. Therefore, this section will elaborate on the possibilities of making the ERP system dynamic and implementing the inventory control policy into the ERP system.

5.1 What is the impact of implementing the proposed inventory control policy based on a simulation model?
For this purpose, we will use the Monte Carlo simulation. As a result, the impacts of implementing the proposed inventory control policy become clear. That way, we could see whether it is a good choice to implement the proposed inventory control policy or not.

5.2 *What is the effect of the parameters of the inventory control policy?*
This question focuses on the influence of using the inventory control policy. As we have said, there is already a policy available, however, we want to see whether this policy is actually used. If this is not the case, we want to see the effect of not honouring the policy. Thereafter, the same method is used to determine the effects of the proposed policy compared to the current policy. Thus, by answering this research question, we know whether using the policy is beneficial and whether the current or the proposed policy should be used.

2. Current Situation

This chapter will elaborate on the current methodology used to determine the required inventory level and how the company deals with changeovers. The current inventory control policy is based on a classification method, the determination of the inventory level and smoothing of production as a result of facing a high season, which will all be explained during the first section of this chapter. Furthermore, the section related to changeovers will gain insight on the different changeovers available at the company and how the corresponding costs are currently treated.



2.1 Inventory control policy

This section answers sub-question 1: *What is the current inventory control policy (e.g. classification, determination of parameters, inclusion of seasonality and obsolescence) and at what costs?* The purpose of answering this question is to get a global overview on how the company nowadays deals with the production and storage of products.

In 2016, the company implemented a new inventory control policy based on a continuous review and a fixed lot size. Within this policy a distinction has been made between MTO and MTS products and it was introduced to decrease the total inventory level. MTO products will only be produced when an actual order arrives and have a promised lead time of four weeks, which means that the company has four weeks to produce and make the order ready-to-ship. The MTS products will be produced throughout the whole year, based on the implemented inventory control policy. All aspects related to the current inventory control policy will be explained below.

ABC classification

The company has a total of *X* products which are taken into account for developing a method for the inventory control policy. To see how critical a product is under consideration to the firm, the ABC classification has been used, which is based on the Pareto principle (Flores & Whybark, 1987). This method classifies the products into three different segments (A, B and C) based on the sales volume. The sales volume is determined by multiplying the volume with the annual usage. A rule of thumb included in the method is that A items make up roughly 20% of the total number of items, but represent 80% of the sales volume (Silver et al, 2017). This also holds in case of the company, since *X* products cause almost 80% of the sales volume, which is equal to 19.8% of the products. Products classified in segment A are considered to be most important and are produced as MTS. Products classified in either segment B or C are considered to be less important and are produced as MTO. As explained above, there is chosen only to produce MTO products when there is actually an order, which means that there is no inventory of MTO products in general. However, they could treat a product classified as MTO as MTS, when there is a commitment between the company and a customer for a longer period.

Modifications to the ABC classification

When the products are classified into the three different segments, modifications to the classifications may happen. For example, products that are very expensive and not sold many times may still be classified as A, while it is unnecessary to have a lot of inventory during the entire year. Therefore, it will be checked in which months the products are sold. If the products are sold during the entire year, then, the products will be produced as MTS, even though it was considered to be classified in either segment B or C. The other way around, products classified in segment A that are only sold in a limited amount of months, will be produced as MTO.

Determination of the inventory level

The required inventory level is based on two terms, namely: the reorder point and the economic order quantity. s indicates when a product should be produced and Q is equal to the quantity of products that should be produced. However, the values for each of these two parameters will only be determined for MTS products, since it is assumed that there will be no inventory of the MTO products.

The Q formula as used within the company is similar to that of Winston (2004) and can be written as:

$$Q = \left(\frac{2KD}{h}\right)^{\frac{1}{2}} \qquad [2.1]$$

Where K represents the setup or ordering cost, D represents the demand rate per unit time and h represents the cost of holding one unit in inventory for one unit of time. The order costs are nowadays based on the costs of adjusting the machines and changing the die to be able to produce the required product and the holding costs are assumed to be 15% of the cost price of an product. However, the determination of these costs are accompanied by a lot of assumptions.

The reorder point is determined as the sum of the safety stock and the demand during lead time. The value of the safety stock is the amount in excess of expected lead time demand that is ordered to protect against the occurrence of stockouts during the lead time. It is determined as the safety factor times the standard deviation during lead time. The safety factor is equal to the inverse of the standard normal cumulative distribution of the cycle service level, where the cycle service level is set as 98% for each of the MTS products. Additionally, the standard deviation during lead time is calculated as the standard deviation of the demand of last year times the square root of the lead time. The lead time is equal to four weeks and the demand during lead time is equal to the expected demand during the next four weeks. D_L is determined as the average demand of a week based on the historic demand of last year times the lead time. Concluding, the following formulas have been used to determine the inventory control policy:

$$s = SS + D_L \qquad [2.2]$$

$$SS = z * \sigma_L \qquad [2.3]$$

$$z = \phi^{-1}(CSL) \qquad [2.4]$$

$$\sigma_L = \sigma_D * \sqrt{L * \left(\frac{12}{52}\right)} \qquad [2.5]$$

The values found for Q and s are implemented in the ERP system manually. A product should be produced with the size of an economic order quantity when the current inventory level is below the reorder point, otherwise the product will not be produced.

Smoothing out the production

The company strives to deliver MTS products immediately (the customer orders today, the product will be picked out of inventory tomorrow, and delivered the day after tomorrow) and MTO products within X weeks to the customers. Therefore, a distinction could be made between the production lead time versus the promised lead time. In case of MTO the promised lead time is equal to X weeks, where CSL is equal to zero, since the MTO products will never be delivered directly from stock. When there is an order, they have X weeks to plan the MTO order within the existing planning and make the order ready-to-ship. In case of MTS products, there is a production lead time involved of X weeks. Most of the time the company can deliver the products directly from stock, however, if there is not enough in stock to fulfil the order, they have to produce the products and deliver it to the customer as soon as possible. Besides, the company decided that they have to take seasonality into account. If the yarns are used to make (sport) fields, they cannot be placed throughout the entire year, since the placement of fields depend on the weather and seasonal stops in case of sports, there are only a couple of months at which fields can be placed and so on more yarns will be sold during that period. This period equals the high season period. However, less products will be sold in other months and, therefore, this period is considered to be the low season. Since MTO products are only produced in case an order is placed, it may be beneficial to produce MTS products ahead. In the high season, it may be hard to fulfil all demand, therefore, the company tries to smoothen out the production to the low seasons in order to lower the workload in the high season. As a result, they adjust the parameters during the year based on the season, where a higher reorder point requires that a product should be produced earlier.

Some products will be sold equivalent throughout the year, therefore, the parameters, such as Q and s, will remain the same over the year. However, some other products are strongly dependent on the season, therefore, the parameters involved are also based on the high season as well as the low season. For example, in the low season, the order quantity appears to be lower than within the high season. Therefore, a distinction has been made between high and low season while implementing the current inventory control policy.

Changes in inventory as a result of the implemented inventory control policy in 2016

Figure 4 represents the inventory level of Yarns over the last 2 years

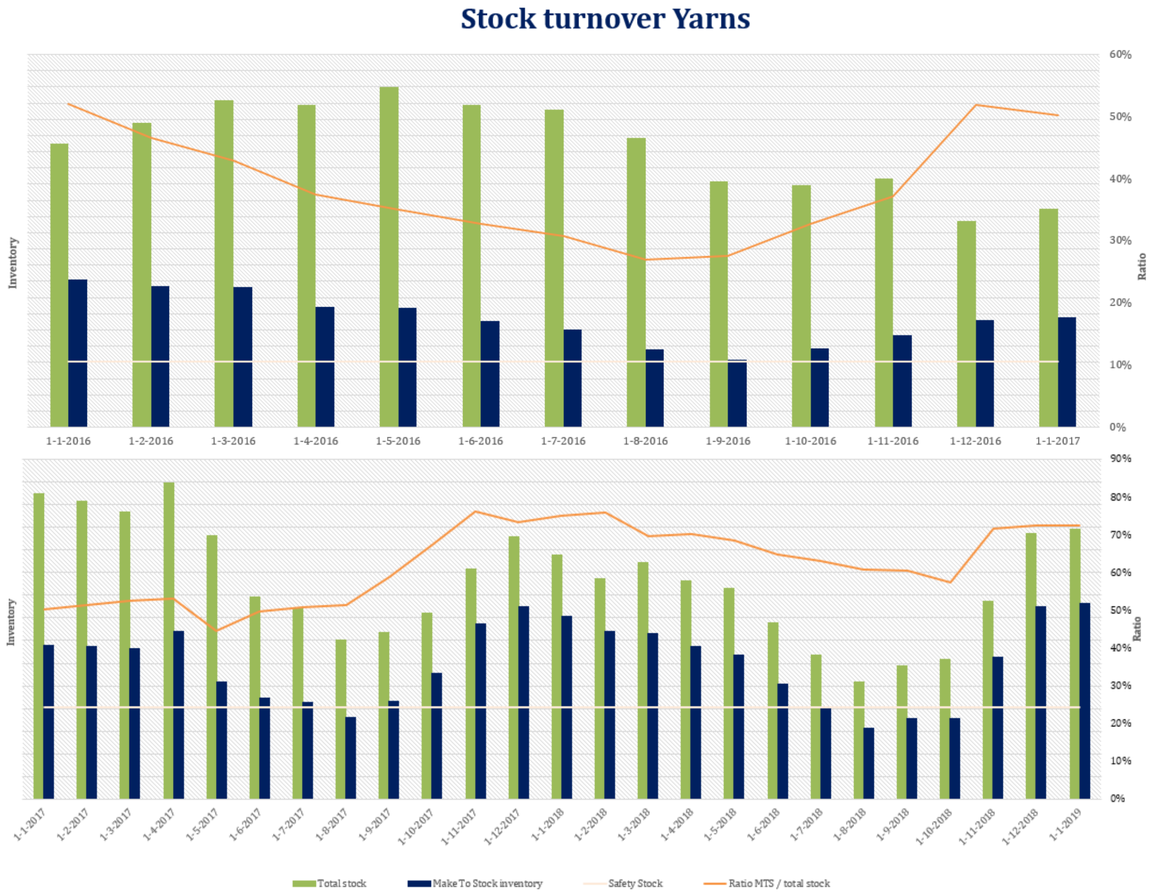


***Figure 4:** The inventory level in comparison to the MTS inventory level*

As we can see, the total stock was really high at the start of 2016, where a large number of the stock were products that were found to be MTO products. It should be noted, that during that period, the company also temporarily took over the inventory of a smaller company that is part of TenCate Grass, which resulted in a higher inventory level. Thus, the inventory level in early 2016 was higher than it would normally have been.

In the middle of 2016, the inventory control policy as it is nowadays was introduced. The goal of the implemented inventory control policy was to have MTS inventory close to the total inventory, which seemed to work according to *Figure 4.* In 2016, around 50% of the stock was related to the MTS products, while the ratio is around 70% nowadays. Additionally, we see that the inventory arises at the beginning of each year (end of the previous year), which is reasonable, since they already produce products to survive the high season. On the other hand, they should take into consideration that not too many products are produced, while still being able to have enough safety stock at all times. The safety stock is purely based on MTS products, therefore, we see that the company was not able to have enough safety stock during three months in 2018. Sequential, they were overtaken by events with a lot of unavoidable and costly changeovers as result. Finally, we should note that the inventory level depends on the sales, which are quite unpredictable. A clear picture of the sales will only be gained while the high season has already started.

Costs of the current inventory level

Normally, in the low season, the inventory level is around *X* million kilo. Assuming that the holding costs for each product are equal to 15% of the cost price and the average cost price is equal to €*X*, the total yearly holding cost of inventory is around *X* million euros. For February 18th, explicit numbers can be found in *Appendix A*. For confidentiality reasons, explicit numbers are left out in this public version.

2.2 Changeovers

This section answers sub-question *2*: *How does the company deal with changeovers?* First, the die changes will be discussed among the different shapes available for the dies and their number of occurrence. Secondly, the costs related to those die changes will be given, based on the data already available at the service cost centre of the company. Thereafter, the different types of die changes will be mentioned followed by the different materials and products that can be produced on the different lines. Finally, other changeovers linked to a material or colour change will be discussed.

Die changes in the production planning

First of all, it is important to gain insight on the different die changes that occur within the company together with the related costs of such a die change. The purpose of these insights is to see the influence of die changes on the costs and which factors should be focused on in order to reduce these costs.

There are two ways to see which die changes have occurred in the past. First of all, the technical service is present during the die changes and translates all relevant data into an Excel sheet. Secondly, the production planning of the past mentions which die changes were scheduled during the year and includes unexpected or preventive die changes afterwards. The latter is used to get an overview of the different die changes.

Figure 5 represent the anonymized die changes (changeovers) for the last three years, based on the production schedule of extrusion and knitting.

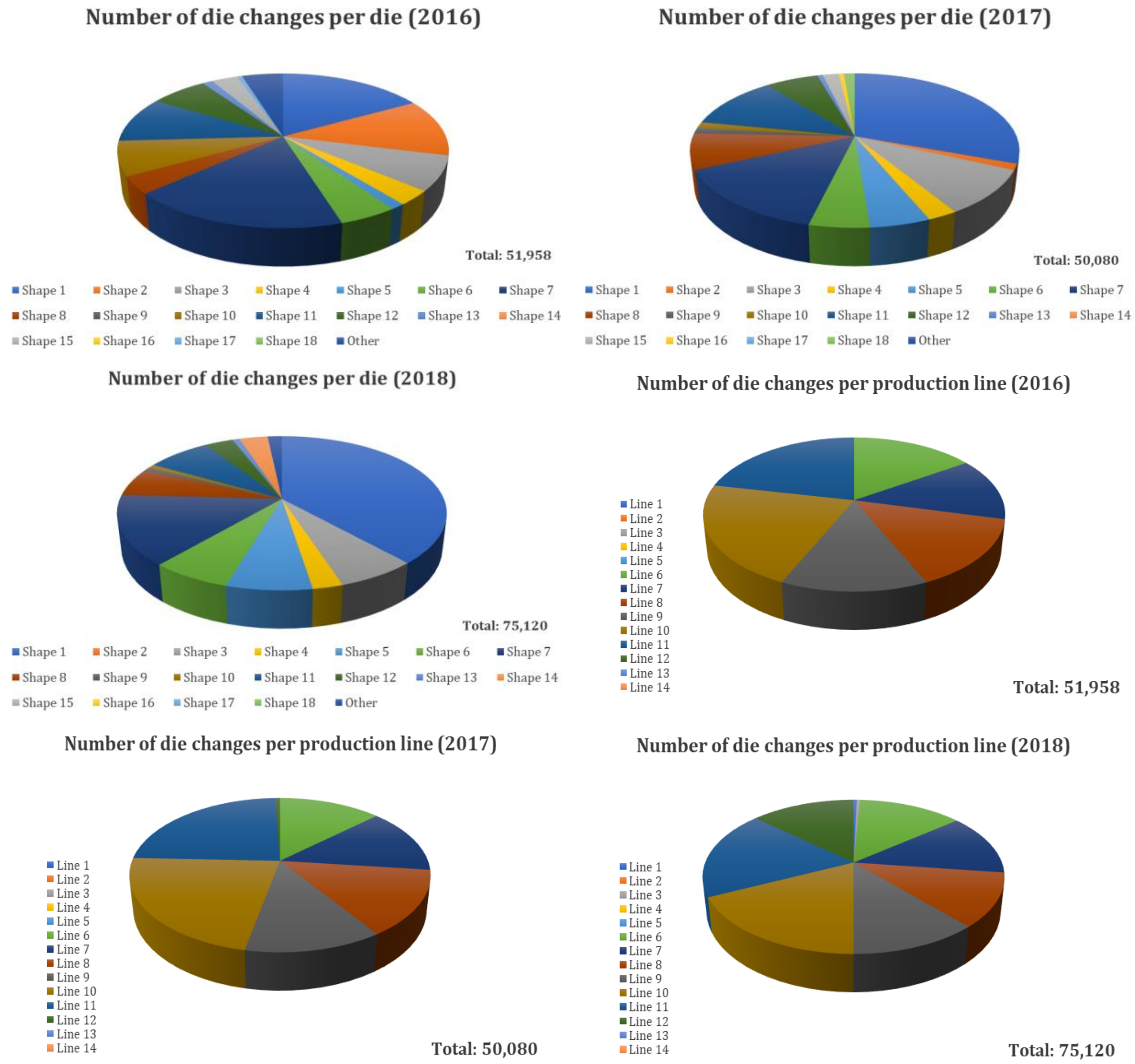


Figure 5: *Number of die changes per shape and per line for the last three years*

The type of die represent the injection holes that are used to produce a certain shape of yarns. These shapes will be applied to the machine together with the die. For some of the shapes, there are more ways to attach the shape to the die, based on the production process that is required. In that way, different products can be produced with the same shape. Therefore, the figures only represent a global overview of the number of die changes per shape. The actual shapes are left out because of confidentiality reasons.

As one can see in *Figure 5*, production Line 12 has one die change during the first two years. The reason is that the machine was only tested during 2017 and actually used from 2018. Besides, we see that some shapes do not have any die change during a year. The reason is that the R&D department always searches for new shapes to introduce to the market and that, on the other hand, some shapes will be removed from production to be able to fit all processes in a schedule and to have a reasonable amount of products to be sold.

Secondly, Shape 1 and Shape 7 are by far the most changed shapes. Therefore, it may be interesting to see what happens when the run length of products related to those sizes will be extended. Currently, there is no focus on adjusting the run lengths, however, this may be an interesting aspect for future research. Based on this remark, *Figure 6* represents the pareto charts of the different die changes linked to a production line or shape to see which shapes or lines do require the most die changeovers based on the data of 2016 to 2018.

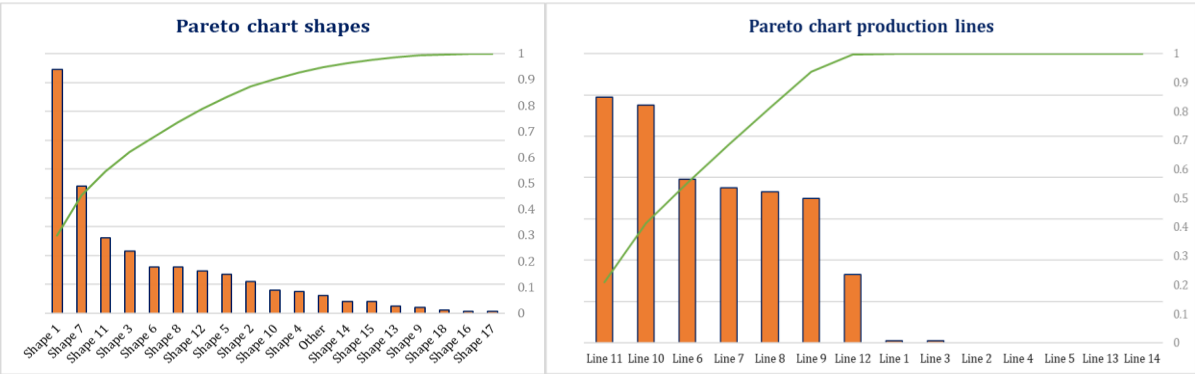


Figure 6: *Pareto chart per shape or production line*

Based on *Figure 6,* we can conclude that the Shape 1 and Shape 7 are indeed the most occurring die changes, making up for at least 50% of all die changes. Additionally, most of the die changes occur on Line 11 and Line 10. Therefore, these lines are also interesting to take into account when someone wants to improve the number of die changes and the costs involved. Additionally, Line 6 also has a lot of die changes compared to the other production lines. A die change that occurs on Line 6 is often accompanied by a die change on Line 7. Therefore, production Line 6 and Line 7 may also be interesting to consider.

Finally, we see that the number of die changes is increasing during the past couple of years. Since a die change is not for free, it is essential to ensure that the number of die changes will not grow further during the following years in order to limit the costs. It is important to get a solution between the trade-off of minimizing costs by reducing the number of die changes versus being able to offer different products that can be delivered within a reasonable time frame.

Costs related to the die changes

There are two types of die changes, namely a combi die change or a mono die change. The difference between the types depends on the final product. For a mono die change, only one line is required and the final product consists of only one colour and one type of material. For the combi die change, there are two lines required, each producing its own colour and using its own material, these two lines will be combined in the end such that the final product consists of two colours or materials. The costs corresponding to the die change depends to the type. Each die change is scheduled for 2 shifts. *Table 1* summarizes all costs multiplied by a random factor for confidentiality reasons involved for a die change, based on the data available at the service cost centre of the company.

Table 1: *All costs involved for a die change*

	Combi die change	Mono die change
Stop time (including waste)	€788,760	€338,040
Waste	€492,975	€219,100
FTE operators	€219,100	€93,900
Mechanics	€169,802.50	€95,856.25
Cleaning	€339,733.33	€169,868.23
Total	**€2,010,370.83**	**€916,764.48**

The costs are based on characteristics that are left out due to confidentiality reasons.

The costs of cleaning one die is equal to €169,868.23, based on the costs of cleaning supplies, transportation costs and the actual cleaning. Additionally, the company tries to implement the SMED methodology (Single-Minute Exchange or Die), which strives to reduce the stop time to *X* hours for the combi die change and to reduce the stop time to *X* hours for the mono die change. Besides, the FTE operators per line will reduce, which will automatically reduce the costs. If the company is able to apply the SMED methodology correctly, the costs of a combi die change will reduce with 14% and the costs of a mono die change will reduce with 15.71% according to their own measurements.

To summarize all findings above, the die changing costs of the previous years and their related range of stop time based on the anonymized costs is summarized in *Table 2*.

***Table 2:** Overview of the number of die changes and their costs*

	Number of die changes (year)	Range of production time lost	Range of costs
2016	51,958	311,748 – 727,412	153,370,000 – 334,910,000
2017	50,080	300,480 – 701,120	147,110,000 – 322,390,000
2018	75,120	450,720 – 1,051,680	219,100,000 – 482,020,000

Since the costs of die changes are possibly higher than four hundred eighty million euros, it shows the importance of correctly mapping the costs involved. It also shows the opportunity of cost reduction as a result of reducing the number of die changes, which is interesting for future studies or even this study.

Different types of die changes

Now that the die changes related to changing the shape are clear, it is also important to see which other changeovers are possible. These different types of die changes are mentioned below.

A die change may happen for several reasons, which can be divided in the following categories:

1. Regular die changes, which happen when procedural run time is reached.
2. Die changes as a result of a technical issue which is machine related.
3. Die changes as a result of a quality issue.
4. Die changes as a result of a new customer / production order. This happens when the production target is reached before the regular die change.
5. Die changes as a result of a colour change.
6. Die changes as a result of a customer adjusting his/her order.
7. Die changes as a result of an urgent customer order.
8. Die changes as a result of an trial for the R&D department.
9. Other, for all die changes that do not fit in any of the above categories.

Looking at the die changes of the past, the most common die change is that of a colour change. For example, in 2018, there were 171,524 colour changes. Besides, die changes as a result of a new customer / production order and regular die changes occur a lot. The number of regular die changes is already given and the number of die changes as a result of a new customer or production order are somewhat below the number of the die regular die changes. Even though this kind of changeovers are interesting, they are impossible to avoid. All other categories of die changes only happen now and then.

Which materials and type of product can be produced on which production line?

When someone searches for opportunities to extend the run time to reduce changeovers or when someone wants to adjust the planning, it is important to know which products can be produced on which production lines together with the materials that can be produced on a production line. Therefore, *Table 3* represents the different types of materials and on which production line they can be produced and *Table 4* represents the different types of products and the corresponding production lines on which they can be produced. For confidentiality reasons, actual names are hidden.

Table 3: *The production lines where the different materials can be produced*

Line	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	Line 9	Line 10	Line 11	Line 12	Line 13	Line 14
Material 1	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓	✓	✓	✓
Material 2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	✓	✓
Material 3	X	X	✓	✓	✓	X	X	X	X	X	X	X	✓	✓
Material 4	X	X	X	X	X	✓	✓	✓	✓	✓	✓	X	X	X
Material 5	X	X	X	X	X	✓	✓	✓	✓	✓	✓	X	X	X
Material 6	X	X	X	X	X	X	X	✓	✓	✓	✓	✓	X	X

Table 4: *The production lines where the final product type can be produced*

Line	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	Line 9	Line 10	Line 11	Line 12	Line 13	Line 14
Product type 1	✓	✓	✓	✓	✓	X	X	X	X	X	X	X	✓	✓
Product type 2	X	X	X	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓
Product type 3	X	X	X	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓

Material 2, Material 3, Material 4 and Material 5 are different types of one material and Material 6 does not necessarily represent material, but the processing method of a product which leads to the desired final product. Therefore, there are only two types of materials that are used to produce yarns. Besides, the blue checks within *Table 3* indicate that the materials can be theoretically handled by the machine, however, these materials are not used on that specific line in practice or only in case of dire need. Additionally, the combination of Material 2 with Material can also be produced on Line 12.

As a result of this analysis, we know which products can be produced on which production line, which will become handy in case the planning regarding the changeovers will be adjusted.

Costs of only changing the material or colour

Finally, we are interested in all changeovers other than the die changes related to the shape. The different types are already mentioned showing that the colour change is the most occurring changeover. Furthermore, all other die changes that are not considered to be colour changes, are considered to be material changes. Therefore, our goal here is to gain insight on the occurrence of those two changeovers and the costs involved. *Figure 7* gives an overview of the ratio between changing the colour and changing the materials based on the production planning of 2018. Additionally, the division of colour changes as well as material changes per production line can be seen in *Figure 8*.

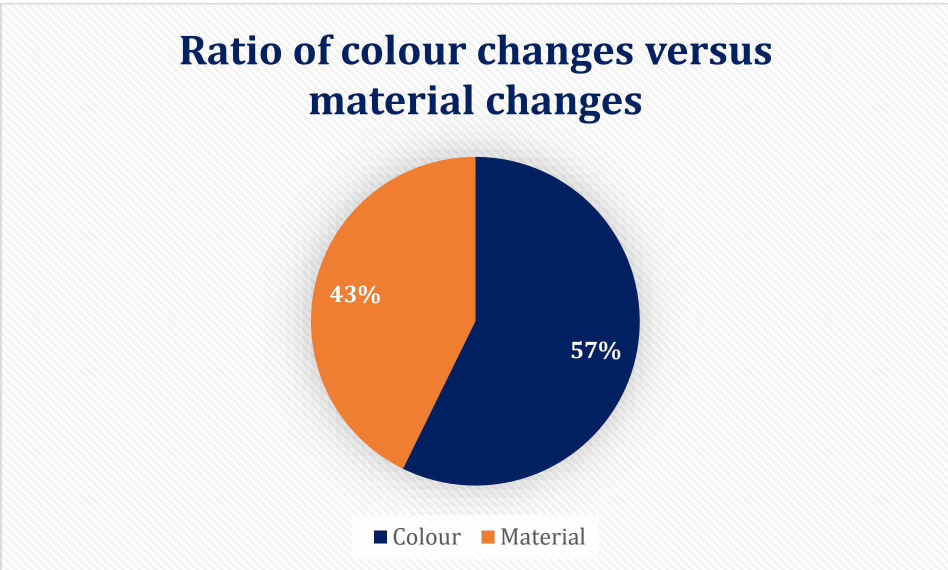


Figure 7: *The ratio between changeovers due to materials versus changeovers due to colour changes*

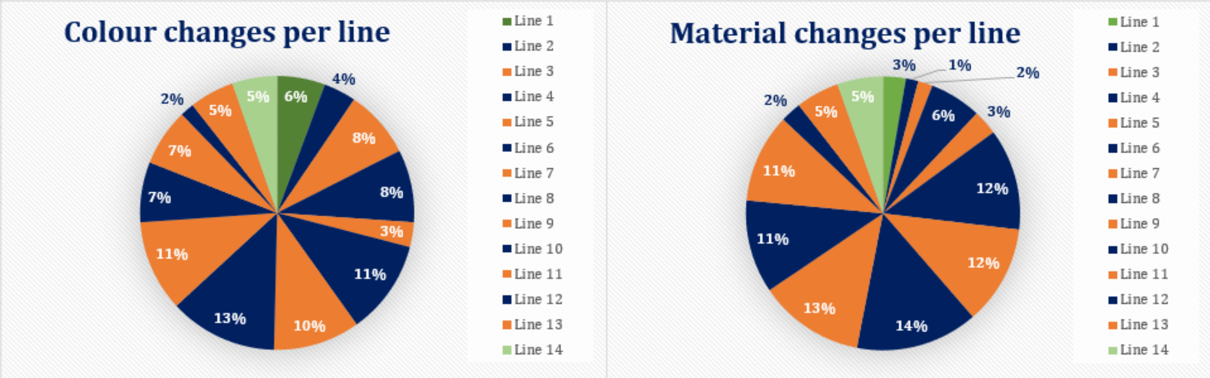


Figure 8: *The division of colour changes as well as material changes among the production lines*

Next up, we have to determine how the different changeovers affect the order costs. For that purpose, the probability that a certain changeover occurs given a shape is determined based on the data of 2018. The probability is determined by defining the number of orders produced during one die and the ratio of colour and material changes related to the found number. By taking the average of all results related to a shape, we found the probabilities as given in *Table 5*. For example, if we have a product that is of a Shape 1, we will take 55% of the cost of a die change, 95% of the cost of a colour change and 94% of the cost of a material change and sum these values up. The value that is found represents the order costs. However, we should note that the die changes are only taken into account for Type 2 products. For some shapes, there was no data available to determine the probability, since the shape was not used in 2018. Therefore, we take the average probabilities to determine the costs related to those shapes.

Table 5: *Probabilities that a certain changeover occurs given the shape*

	Probability die change	Probability colour change	Probability material change
Shape 1	0.55	0.95	0.94
Shape 3	0.50	0.97	0.76
Shape 4	0.63	1.00	0.80
Shape 5	0.67	1.00	0.81
Shape 6	0.35	0.90	0.63
Shape 7	0.21	0.85	0.75
Shape 8	0.78	1.00	0.93
Shape 9	1.00	1.00	1.00
Shape 10	1.00	1.00	1.00
Shape 11	0.80	1.00	0.92
Shape 12	0.50	0.92	1.00
Shape 13	1.00	1.00	1.00
Shape 14	0.67	0.92	0.92
Average	**0.66**	**0.96**	**0.88**

One aspect that determines the costs of a changeover is the waste that is released. In 2018, there is data concerning the waste resulting from production changes, which is left out due to confidentiality reasons. However, we should keep in mind that there were a lot of changeovers in 2018 compared to the previous years, due to the shortage in inventory in the high season, which means that the data may not be representative for a future situation. Within the data, each component of this waste is explicitly linked to an order. As a result, the average waste per product could be determined. The costs of the waste and the waste corresponding to a die changes, however, are not clear. There is no explicit data mentioning the costs involved. Therefore, to determine these costs, we have to measure the data ourselves. Data measurement will be one of the topics discussed in *Chapter 4.*

2.3 Conclusion

This chapter focuses on answering sub-questions *1* and *2*. The first question indicates what the current inventory control policy looks like and the second question shows how the company deals with changeovers.

The first question that is answered during this chapter is: *What is the current inventory control policy (e.g. classification, determination of parameters, inclusion of seasonality and obsolescence) and at what costs?* In 2016, the company developed a continuous inventory control policy with a fixed lot size, otherwise known as the (s,Q)-policy. They started with the classification of products as either MTS or MTO, based on the ABC-classification (Flores & Whybark, 1987). Thereafter, they change the classification if a product is either frequently demanded against low volumes or when the volumes are high but the product is only demanded in a short period. Based on the formulas for an (s,Q)-policy, the company calculates the reorder points and safety stocks for all MTS products. Q is calculated with the use of a formula of Winston (2004). Finally, the company strives to smoothen the production, such that MTS products are mostly produced during the low season, giving more flexibility to produce MTO products in the high season. For that purpose, the company takes seasonality into account, by determining which months should have higher parameters. By comparing the inventory level before and after the development of the current inventory control policy, we do see that the overall inventory level has decreased and that the ratio of MTS products in inventory has increased.

The second question handled during this chapter is: *How does the company deal with changeovers?* The company has three different kind of changeovers, namely: die changes, colour changes and material changes. The most costly changeover is that of a die change, which occurs quite frequently. In 2018, the number of die changes has increased a lot in comparison to the previous years. The goal of the company is to decrease this number to the level of 2017 again. There are two shapes for which a die change occurs a lot, namely Shape 1 and Shape 7. Besides, most of the die changes occur on production lines 11 and 10. However, production lines 6 and 7 also face a lot of changeovers. Therefore, it is interesting to see whether the number of die changes on these production lines can be reduced. According to the service cost centre of the company, the cost of a combi die change are equal to a bit more than 2 million euro. Besides, it has been checked which products can be produced on which production line. Thereafter, there has been a focus on the colour and material changes. The ratio between the different changeovers are determined and we see ratio of changeovers on certain production lines. Lastly, the probabilities of facing a certain changeover are determined based on the data of 2018. Based on these probabilities, the order costs for the inventory control policy will be determined.

3. Literature review

This chapter will elaborate on the different research questions that should be answered based on theory. First, we will look at different methods available to classify the products, which will be helpful in determining the strategy on how to handle products. Secondly, we will search for theory that helps to determine the parameters related to the inventory control policy, with an additional focus on the relation between the cycle service level and the inventory control policy and the relation between the costs and the inventory control policy. Thirdly, we will search for methods available to improve the changeover time, which will cause a cost reduction in the order costs. Lastly, we will search for the purpose of the Monte Carlo simulation and how the simulation can be developed. Altogether, when all theory related research questions are answered, we should be able to set up the inventory control policy and compare the proposed model with the current model. The following flow chart shows the order in which the different subjects are treated.

3.1 Classifying products

This section will search for the answer of sub-question *3: What methods are available in literature to classify the different products?* Currently, the company is already using the ABC analysis as described by Flores & Whybark (1987), however, this section will give insight in what extensions of the classification method are possible. Besides, this section will give insight if there are even totally different methods available to classify products.

First of all, there exists a XYZ-classification model that will be combined with the ABC-classification model. Where the ABC-classification depends on the annual usage, the classification into X, Y or Z depends on the frequency that inventory items move and, thus, the demand rate. As a rule of thumb materials that had demand in at least 10 of the past 12 months will be classified as X, product that had demand between 4 and 9 of the past 12 months will be classified as Y and products with demand in less than 3 months during the last 12 months will be classified as Z (Jones, 2017). Thereafter, based on the combination of the ABC- and XYZ-classification the targeted cycle service level could be determined based on the following table (Heijden, 2018):

Table 6: *Service level target per ABC-XYZ classification*

Service level target		Sales variability		
		X	**Y**	**Z**
Sales volume	**A**	0.97	0.95	0.93
	B	0.95	0.93	0.90
	C	0.93	0.90	0.90

Secondly, a study by Kampen et al (2012) represents a literature review on some of the different methods available to classify different products. *Table 7* will summarize the different methods found.

As one can see, the Bi-criteria ABC is an extension for the ABC-classification. For example, unit cost, demand volume, product lead time, product criticality could be taken into account and compared using weighted linear programming (Ramanathan, 2006). And even this method could be extended by comparing the most favourable and least favourable scores of an product (Zhou and Fan, 2007).

***Table 7:** Different methods available to classify products*

Technique	Knowledge source	Short description
VED	Judgmental	Determine criticality of a product
AHP	Judgmental	Rank based on pairwise comparison
TOPSIS	Judgmental	Order preference by similarity to ideal solution
Distance modelling	Judgmental	Calculate a product's distance to a predefined reference point
Traditional ABC / Pareto analysis	Statistical	Sort products based on a single characteristic (demand value)
FSN/FNS	Statistical	Sort products based on a single characteristic (demand volume)
Bi-criteria ABC	Statistical	Use more than one characteristic to sort products
Graphical/2x2 matrix	Statistical	Plot products on a graph with mean weekly demand versus the associated variance. For each quadrant, a production strategy is determined.
Decision tree	Statistical	Classification is performed stepwise, with one characteristic at a time. For each combination, a specific inventory management procedure is developed
Other	Statistical	Typical profiles, cluster analysis, optimisation techniques, neural networks or genetic algorithm

The classification depends on four factors: Characteristics, Aim, Technique and Context. Where each factor has its own aspects. *Figure 9* gives a clear overview of the relation of important aspects of the classification (Kampen et al, 2012).

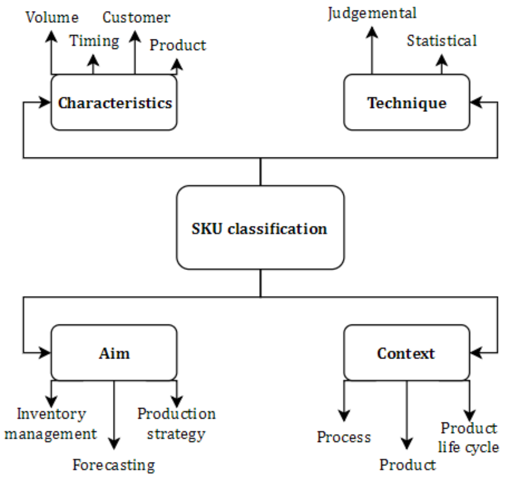


***Figure 9**: The relation of important aspects of product classification*

By combining all four factors, we are able to come up with a model to classify products. The different aspects of the factors represent the different options on which the factors are based. For example, to classify based on the characteristics, there are four characteristics that could be taken into account, namely, the volume of products sold, the timing at which products are sold, the number of customers for a product or the product type. The technique could be either judgemental or statistical, dependent on the influence of the decision maker on the decision. If the decision to classify is based on facts and calculations, the technique is statistical. If the decision maker has any influence on the outcome based on what he or she thinks are the most important aspects, then the technique is judgemental. Furthermore, the figure states which aims insist on classifying products. For this study, the aim is a combination of inventory management and a production strategy. Lastly, the context plays a role for the classification of products, since one can either classify processes, products and product life cycles. For this study, we are limited to the classification of products. If we choose at least one aspect for each of the factors, we are able to come up with a classification model that fits the aim of the classification.

Thus, the aim of our product classification is inventory management and a little bit of production strategy and the technique used will be statistical. The reason is that we do not want to have a strong opinion who decides the product classification, but we want to underpin the decisions based on historic data. Finally, the context of our product classification will be product and the characteristics have yet to be determined.

3.2 Inventory control policy

This section will elaborate on sub-question *4: Which methods are available in literature to implement an efficient inventory control policy of production systems?* It will also provide insight on how to determine the parameters involved and the relation between certain parameters, for example the relation between the safety stock and the costs or CSL.

Inventory control policy

Currently, the company already uses the economic ordering quantity formula described by Winston (2014) in order to determine how many products should be produced when the inventory level comes below a certain reorder point.

The total costs corresponding to a fixed Q can be calculated by:

$$TC = \frac{K*D}{Q} + \frac{h*Q}{2} + C*D \qquad [3.1]$$

Where Q represents the ordering quantity and C the cost price per unit.

However, it may also be possible to have a variable lot size, according to Silver et al (2017). In that case, we will not order a fixed economic order quantity, but we will produce the number that is required to reach a fixed amount of inventory (the order-up-to level). In both ways, we can either review the inventory status continuously or periodically. *Table 8* summarizes the possible options for implementing an inventory control policy (Heijden & Diks, 2018).

Table 8: *Different options for implementing an inventory control policy*

	Continuous review	Periodic review
Fixed lot size	(s,Q) or (s,nQ)	(R,s,Q) or (R,s,nQ)
Variable lot size	(s,S)	(R,S) or (R,s,S)

Under a continuous review, less safety stock is needed, however, multi-item coordination is not possible. Additionally, within a continuous review, the size of the order does not change but the time between orders may fluctuate. For a periodic review, the time between orders is fixed, but the size of the order can fluctuate given variable demand (Chopra & Meindl, 2013). It is assumed that a continuous review can also be seen as a periodic review when the review period is equal to one day.

Safety stock

The safety stock (SS) could be defined as the average inventory level just before a replenishment order arrives. It serves as a buffer to overcome situations such as a higher demand as expected or problems in the production facility due to uncertainties in demand or the supply chain. The safety stock should be enough to cover demand until the next replenishment order arrives. For a periodic review, the time between two replenishment orders is equal to the review period combined with the replenishment lead time. If we determine to include a continuous review, the period is equal to only the replenishment lead time, which will result in a lower safety stock.

Figure 10 provides a complete overview of the different formulas involved to determine the safety stock based on the chosen inventory control policy. This figure is obtained through the course Supply Chain Management (2014) and is adjusted to represent the formulas of Silver et al (2017).

Reorder point and order lot size

Since the planners will look on a daily basis whether a product has to be produced according to the inventory control policy, we assume that we have to deal with a continuous review for the remainder of the study.

In case of a continuous review and a variable lot size, the order-up-to-level (S) is the value to which the inventory should be increased in case the inventory drops below reorder-point s. The order-up-to level could be determined with the following formula (Silver et al, 2017):

$$S = \hat{x}_L + SS \qquad [3.2]$$

Where $\hat{x}_L$ represents the expected demand during the lead time. The order size in this case is equal to the S – the current inventory level. However, in case of a fixed lot size, the order size should be equal to Q.

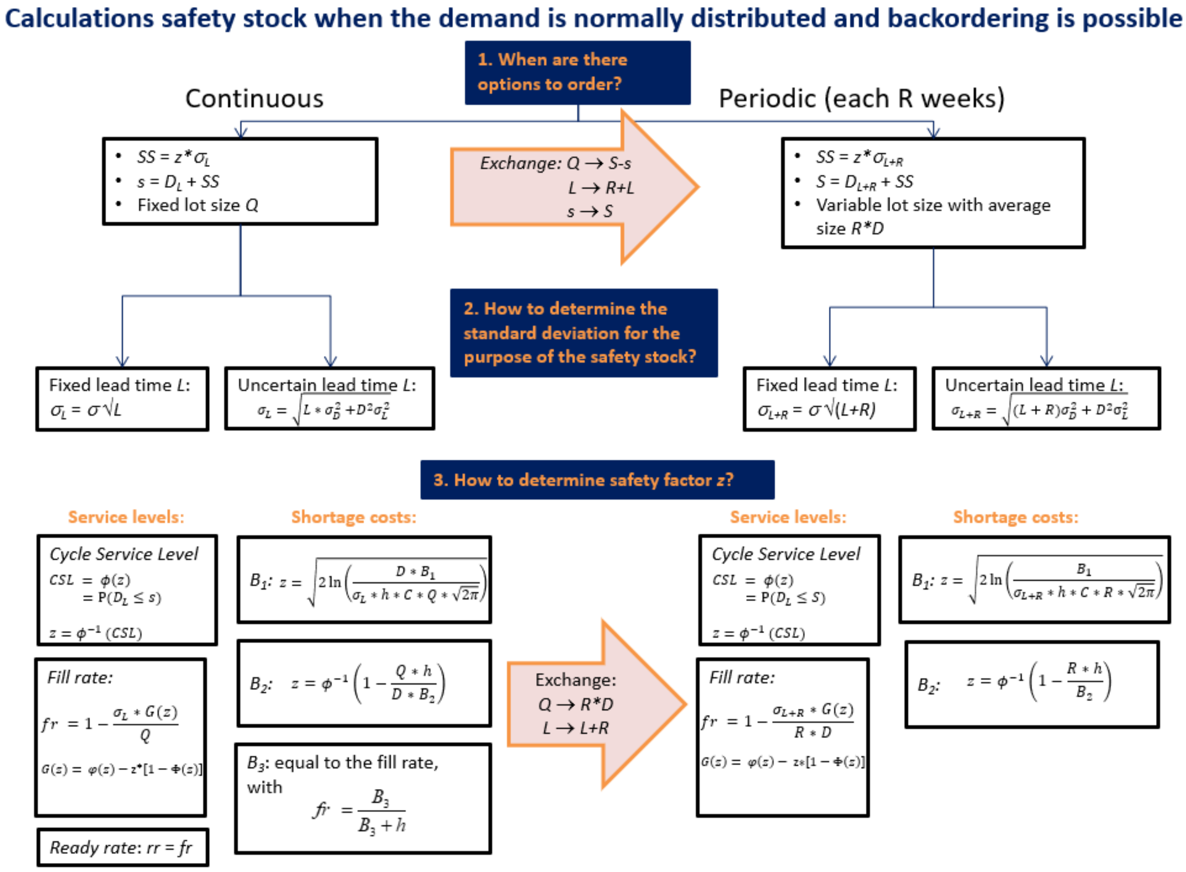


Figure 10: *An overview on how to determine the safety stock*

As one can see, some factors influencing the safety stock are the service target level and the shortage costs. Therefore, we are interested in the relation between the service level, shortage costs and the safety stock.

Relation between safety stock and costs

Figure 11 represents the relationship between the holding costs, order costs and total costs related to the order quantity as described by Chopra & Meindl (2013). This relationship only holds when the cost price of one single unit remains the same, independent of the order quantity.

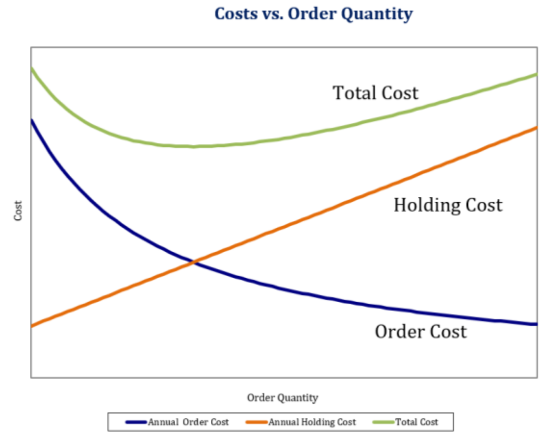


Figure 11: *The relation between the costs and the order quantity when there is no quantity discount*

In some cases, quantity discount happen when the supplier lowers the price if a certain amount is ordered. If this is the case, the relation between the total cost and the order quantity will change, which can be seen in *Figure 12.*

Figure 12: *The relation between the costs and the order quantity when there is quantity discount*

A lot of factors are representing the inventory holding costs, for example, rental of the warehouse, personnel costs, inventory handling and losses for handling one unit for a defined period and even more. Therefore, the higher the number of inventory, the higher the costs.

It might seem obvious to reduce the inventory as much as possible. However, if there is not enough inventory, the chance of shortages arises, which also leads to costs. Thus, taking the costs of stockout into account is important to determine the safety stock from a financial perspective. Chopra & Meindl (2013) discussed that the cost of overstocking by one unit and the lost current and future profit margin from understocking one unit are the two major factors that affect the optimal level of product availability.

As seen in *Figure 10*, the shortage costs may influence the safety stock. The different shortage costs are divided into three categories: *B1*, *B2* and *B3*. *B1* represent the shortage costs per stockout occasion, *B2* represents the shortage costs per unit short and *B3* represents the shortage costs per unit short per unit time. The shortage costs per unit short per unit time are related to the fill rate, using the following formula:

$$B_3 = \frac{fr*h}{(1-fr)} \quad [3.3]$$

Shortage costs happen when demand is larger than the supply on hand. The shortage costs consist of opportunity costs of lost customers due to loss of goodwill (Demirtas & Schuur, 2018).

One way to determine the stockout costs is to implement a decision tree, representing the different roads a customer could take when a product is out of stock. For example, the buyer could either cancel, accept or ask for a better date. The probability that the buyer is taking a certain road together with the costs of taking that road have to be determined. By using backward induction, the expected costs for stockout could be determined (Oral et al, 1972).

Another method to determine the stockout costs is to let the costs be equal to the purchase price difference, if one is forced to buy materials if a shortage happens (Sarjono, 2014). However, most of the time the stockout costs are equal to a predetermined stockout penalty.

Relation between the safety stock and CSL

Product availability reflects a firm's ability to fill a customer order out of available inventory and, thus, it represents the customer level achieved. A stockout happens if a customer order arrives when the product is not available (Chopra & Meindl, 2013). Some ways to measure the product availability are:

- *Product fill rate (fr)* = the fraction of product demand that is satisfied from product inventory. It should be measured over a specified amount of demand rather than time.
- *Order fill rate* = the fraction of orders that are filled from available inventory. It should be measured over a specified number of orders, rather than time.
- *Cycle service level (CSL)* = the fraction of replenishment cycles that end with all the customer demand being met. A replenishment cycle is the interval between two successive replenishment deliveries. It should be measured over a specified number of replenishment cycles.

The relationship between the cycle service level (CSL) and the safety stock can be seen in *Figure 13*. As one can see, the higher the required cycle service level, the higher the amount of safety stock.

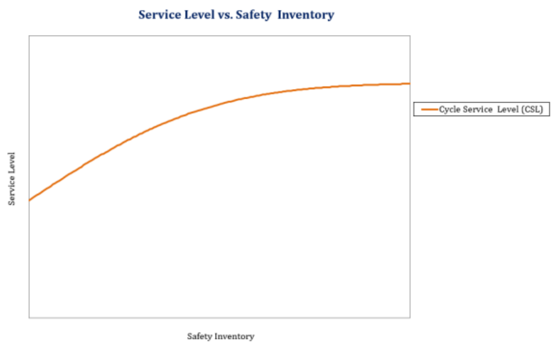


Figure 13: *The relation between CSL and SS*

The measurements are taken into account to determine the safety stock and reorder point based on the customer level. For that purpose, we use P_1, P_2 or P_3 as described by Silver et al (2017), where P_1 represents the Cycle Service Level (CSL), P_2 represents the volume fill rate and P_3 represent the ready rate. The ready rate describes the fraction of time during which net stock is positive.

The formulas for the different customer levels are already part of *Figure 10* of *Section 3.2.* However, if the ABC-XYZ classification is used, there is already an targeted CSL. Therefore, the CSL could be used as input to determine the safety factor. Furthermore, under Normal demand, it is assumed that the decision rules for P_3 and P_2 are equivalent (Heijden, 2018).

3.3 Improving changeovers

This section elaborates on sub-question *5: Which methods are available in literature to improve changeovers / die changes?* We search for different methods available to improve the changeover time, which will lead to a reduction in changeover costs.

Single Minute Exchange of Dies (SMED)

As mentioned before, the company already tries to implement SMED. Therefore, we will first give an overview of this methodology.

The principle of the SMED methodology is to reduce change-over time from hours to minutes and minimize machine down time despite the complexity and weight of tools. It suggests that everything that can be done outside machine downtime must be done before or after (Symbol, 2018).

The SMED methodology consists of several steps:

1. Observe and measure
2. Analyse external activities and interruptions
   - All external activities should take place during preparation or after a changeover
   - Methods should be identified to eliminate interruptions
3. Analyse internal activities
   - Possible ways to change internal activities in external activities and into needed measures should be investigated.
   - Remaining internal measures should be streamlined; simplify, reduce or eliminate movements and walk times
4. Eliminate adjustment activities
   - Optimal process settings (temperature, pressure, speed) should be used and changed to fixed settings
   - Use "*error proofing*" to determine which adjustment activities can be done efficiently

Figure 14 represents an example of the implementation of the steps involved (Symbol, 2018).

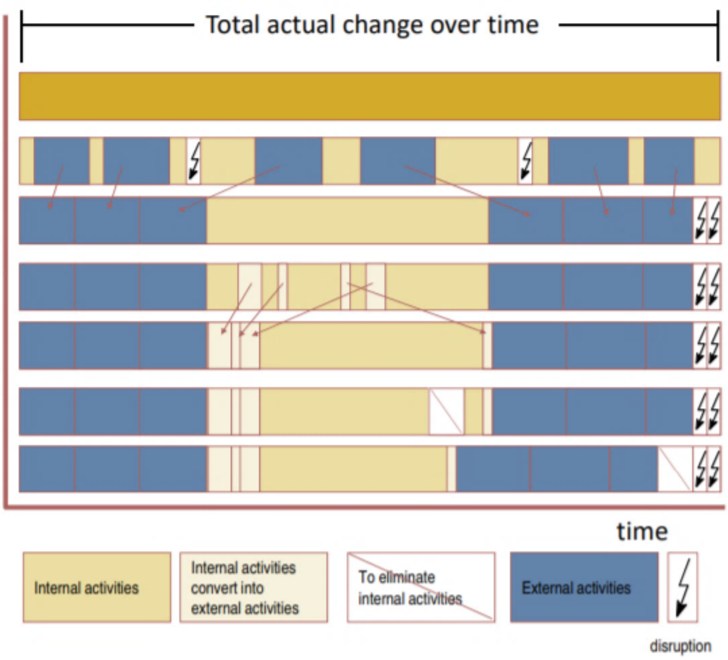


Figure 14: *Implementation of the steps of SMED*

Optimisation of these steps can be achieved by a Plan-Do-Check-Act list. Within the 'planning' phase, the project should be defined and the baseline performance should be determined. Additionally, the internal and external activities should be defined. Within the 'do' phase, the internal activities that could be external activities should be altered and the process should be streamlined. In the 'check' phase the proposed changes should be tested and the results verified. If the tests have proven that the changes are promising, the improvements should be implemented in the 'act' phase.

As one can see in *Figure 14*, the total time changeover time required has reduced with the time of the internal activities that have been eliminated and the time of disruptions. By reducing the time of one single changeover, also the total cost will decrease even though the number of die changes did not change. Therefore, it may be interesting to see whether there are other methods to reduce the changeover time.

Schedule jobs in pairs

Another method that could be implemented is to schedule jobs in pairs (Duncan, 2011). Within this method, components will be set up together with components that belong to the same product. That way, to produce a product there is no need to wait for components that belong to other products, and the changeover time of a product will be reduced. However, the total changeover time will not be reduced using this methodology, but it will reduce the lead times, since less time will be spent on changeovers for a particular product. For example, 4 different machines will produce 4 components of one single product and 4 components of another product. By letting machine 1 and 2 produce the components of product A and letting machine 3 and 4 produce components of product B, the number of changeover times will be reduced from 4 to 2. If there are products with more than two parts, the other parts will be produced on the same machine when the preceding pair has been produced.

Schedule jobs using group technology

The third methodology that could be used is scheduling jobs using group technology (Duncan, 2011). This methodology is based on the rank order clustering algorithm to combine jobs that share the same fixtures and tools. By combining all jobs that have the same tools, only small adjustments instead of changeovers are required to produce the different products.

Make changeover time visual

This methodology focuses on operators, which may not be aware whether they are on pace for a given changeover. Therefore, a real-time plant floor indication should be provided to show how long changeovers are taking compared to the target time. There is a scoreboard on the work floor that shows the target time and the remaining time for the changeover, when the changeover time is beyond the budgeted time, the scoreboard flashes red. This way, operators should be motivated to execute the changeover within the target time. This method could be combined with SMED, where the changeover has a visual timer for each step of the SMED (Vorne, 2019).

3.4 Monte Carlo simulation

This section answers sub-question *6: What is the purpose of a Monte Carlo simulation and how can it be used?* Since it is decided to use a Monte Carlo simulation to compare the proposed model with the current model, we want to see how the model can be used and how the model can be developed based on theory.

Purpose of the Monte Carlo simulation

Within the inventory control policy, the input parameters are quite fixed and not subject to change, however, the demand data fluctuates a lot. Therefore, we propose a Monte Carlo simulation to compare different outcomes in terms of money and the corresponding inventory level based on different demand data. It is a technique that is used to understand the impact of risk and uncertainties (RiskAMP, 2019). Since we cannot explicitly forecast the demand as a result of having a lot of fluctuations, this model will help us to understand the impact of facing different demand levels. The simulation model will be executed on both the current as well as the proposed model. By comparing the results, we can see whether the proposed model has a positive influence on the costs compared to the current model. If the results of both the models lie close to each other, the differences may also be a result of the random demand data. Therefore, only conclusions could be made when the outcomes of the different models differ quite a lot.

To serve the goal of comparing the different models, we will build a Monte Carlo simulation that determines the attained cycle service level and the total costs which is based on the holding costs and the order costs. Within the model, the lead time, the reorder point, the economic order quantity and safety stock are fixed, based on the results of the inventory control policy. The beginning inventory is based on the inventory level at the date at which the simulation model is executed. The demand data will change within a given range causing different outcomes. By using this model, we will simulate the demand data for a year, where each run represents L weeks. By taking the sum of the total costs of all runs, we will have the most likely total costs of a year. By finding the number of replications required and taking the average of all replications, we will find the likely total costs. The same model will be used based on the data of the current inventory control policy. By comparing the found results, we can see whether the total costs have lowered and, thus, whether the proposed inventory control policy seems promising.

Developing the Monte Carlo simulation

The purpose of the Monte Carlo simulation is to get insight on what the total costs of the inventory control policy probably will be. The total cost consists of holding costs, stockout costs and order costs. To determine these costs, we will first determine how other important parameters of the Monte Carlo simulation can be determined.

The one parameter that is uncertain and which will be used as variable input parameter for the original Monte Carlo simulation is the demand. There are two ways to include the demand, namely by determining the probabilities of having demand in a certain range or by taking a random number between the minimum and maximum of the historic demand. The first option is more reliable, since a higher probability of being in a certain range will cause more random demand data to be in that range. The probabilities are based on a histogram of the existing demand data. To determine the probabilities, the following formula is used:

$$p_i = \frac{x_i}{\sum x_i} \qquad \text{for } \forall i \qquad [3.4]$$

Where x_i represents the frequency of historic demand falling within demand range i, and $\sum x_i$ represents the total frequency of historic demand available. These probabilities of demand can be seen as an uniform distribution. Thereafter, upper and lower limits of the probabilities are determined. As a result, the first demand range has a lower limit of zero and an upper limit of the found probability, the second demand range has a lower limit of the upper limit of the previous demand range and an upper limit of the sum of the found lower limit and the found probability, and so on. Thereafter, a random number between zero and one is generated, representing the probability, which indicates the value the random demand should be.

All other parameters are based on fixed input parameters and could be determined. To set up a Monte Carlo simulation, the formulas as described by Pujawan et al (2010) will be used. First of all, we have the begin inventory. For the first period, this inventory is based on the data of the current inventory level. In any next period, the begin period is equal to the end inventory of previous period.

Secondly, we have the order receipt schedule *R(t)*, which is determined by using the formula:

$$R(t+L) = Q \tag{3.5}$$

This formula suggests that if the decision is made to place an order, the order receipt schedule is equal to order quantity Q in the period at which the order arrives, thus, after lead time L if the order is placed at time *t*.

Thirdly, we determine the available inventory after a period, which is determined using the following formula:

$$I(t) = I(t-1) + R(t) - D(t) - B(t) \tag{3.6}$$

Where *I(t-1)* represents the already found beginning inventory and *D(t)* represents the random demand. It may be the case that there is not enough inventory to fulfil all demand. In that case, we have to deal with backlog *B(t),* also known as stockouts. The on-hand inventory in that case is determined by:

$$O(t) = \max(0, I(t)) \tag{3.7}$$

Additionally, the backlog in period *t* can be determined using following formula:

$$B(t) = \max(0, -I(t)) \tag{3.8}$$

The decision on whether or not to order a product is based on the on-hand inventory after a period. If the inventory position of the on-hand inventory at the end of a period is below reorder point, n times Q will be ordered, otherwise, nothing will be ordered. The number of times Q is ordered is equal to the number of orders within a period and depends on the number of products that is required to have an inventory level above reorder point again. Additionally, if there is backlog in a period, the value of the backlog will be added to the demand of the next period to ensure that the demand is still satisfied.

In the current model, the reorder points and order quantities are already determined and could, therefore, easily be entered in the Monte Carlo simulation. We make a distinction between the different months, meaning that all months could have a different reorder point as well as a different order quantity based on the determined season. With the proposed model, the reorder points and order quantities are also determined leading to different values as a result of taking obsolescence into account and another way of implementing seasonality. Therefore, the input of the reorder points and order quantities are already determined and could easily be entered in the Monte Carlo simulation.

Since all relevant parameters of the Monte Carlo simulation are determined, the next step is to calculate the costs involved. As already said, the total cost consists of holding costs, stockout costs and order costs. The different costs are determined per period and added up to get the costs per year. The holding costs are determined using the following formula:

$$holding\ costs = O(t) * c_h \tag{3.9}$$

Where *O(t)* represents the on-hand inventory at the end of a period and c_h represents the holding costs.

The stockout costs are more difficult to obtain, because you cannot easily attach a fixed value to the lost profit margin and additional costs. Therefore, assumptions have to be made to come up with the costs of having backlog. Similar to the holding costs, the stockout costs are expressed as percentage of the cost per unit, resulting in the following formula:

$$stockout\ costs = B(t) * c_s \tag{3.10}$$

Where $B(t)$ represents the backlog in period t and c_s represents the stockout costs.

Thereafter, the order costs have to be determined, which is simply the multiplication of the decision to order with the order costs. Which can be expressed in the following formula:

$$order\ costs = K * o * n \qquad [3.11]$$

Where K represents the order costs and o represents the decision to order, with a value of one if there is chosen to place an order and a value of zero if there is chosen not to place an order and n represents the number of orders per time unit. By combining all costs, the total cost could be determined using the following formula:

$$total\ costs = holding\ costs + stockout\ costs + order\ costs \qquad [3.12]$$

If the model is replicated for a to be determined number of times and the average of all those outcomes is taken, it is possible to run the model for both inventory control policies and compare the models based on costs. The replications are based on a data table, which automatically calculates the results for the required number of replications. Besides, graphs and histograms could be made for each replication to draw conclusions from the Monte Carlo simulation.

One of the graphs that is helpful to compare the results of the different models is the use of a graph that sets the cycle service level against the total costs. The cycle service level could be determined by one minus the fraction of stockouts compared to the total demand. The cycle service level is placed on the horizontal axis and the total costs are placed on the vertical axis. That way, a data point in the graph is received for any of the options.

When this graph is made, the best option is the one in the lower right corner, which means that this option has a better cycle service level in combination with lower costs. However, when one option appears to have lower costs and another option appears to have a higher cycle service level a trade-off has to be made. When the increase in cycle service level outweighs the increase in costs the option with the highest cycle service level may be considered to be the best option.

Another graph that is helpful to see the results of the Monte Carlo simulation is a histogram of the results of all replications. For that purpose, the minimum value, the maximum value, the number of bins and the bin width have to be determined. The minimum value is the lowest value of all replications and the maximum value is the highest value of all replications. The number of bins is equal to the rounded up value of the square root of the number of replications and the bin width is determined using the following formula:

$$bin\ width = \frac{maximum\ value - minimum\ value}{number\ of\ bins} \qquad [3.13]$$

The first step in setting up the histogram is the determination of the upper bound for any of the bins. For the first bin, the upper bound is equal to the minimum value plus the bin width. For the remainder of the bins, the upper bound is equal to the upper bound of the previous bin plus the bin width.

The second step is to calculate the cumulative frequency. The cumulative frequency for a bin is equal to the number of replications that fall within the range of zero to the upper bound of that bin. Thereafter, the frequency is determined. For the first bin, this value is equal to the cumulative frequency. However, for the second upon the last bin, this value is determined by taking the cumulative frequency minus the cumulative frequency of the previous bin. If we sum up all frequencies, the value should be equal to the number of replications. If this appears to be the case, the histogram could be made with the frequency on the vertical-axis and the factor for which the histogram is made on the horizontal-axis.

When the histogram is made, it shows the range which has the most number of replications (frequency) and whether the results fall far apart or lie close to each other. Therefore, the histogram gives an indication of what the results of the model most probably will be.

Determining the number of replications required
Furthermore, the number of replications required to get reliable outcomes have to be determined. For that purpose, the formula as proposed by Law (2014) is used:

$$\frac{t_{n-1,1-\propto/2} * \sqrt{\frac{S^2}{n}}}{\bar{X}} < \gamma' \qquad [3.14]$$

The first part of the formula, before the less than sign, is said to be the found error. Where $\bar{X}$ represents the mean and is determined by a moving average, which is the average of all found data up to the corresponding replication number. The same way, a moving variance is determined, which represents S^2 and is required to determine the value of the enumerator. The value of the t-distribution can be determined in Excel with the following formula:

$$t_{n-1,1-\propto/2} = T.INV(probability; degrees\ of\ freedom) \qquad [3.15]$$

The degrees of freedom is equal to the corresponding replication number minus one and the probability depends on the confidence interval someone wants to include. To include a confidence interval of 95%, which is quite common, the probability and outcome of $1-\propto/2$ is equal to 0.975.

Finally, we have to determine γ', which is calculated by the following formula:

$$\gamma' = \frac{\gamma}{1+\gamma} \qquad [3.16]$$

Gamma represents the relative error allowed and is a fixed input that has to be determined upfront. In combination with a confidence interval of 95%, a quite common value for gamma is equal to 0.05.

There are enough replications if formula [3.14] constantly holds. Which means that the number of replications is the first number of replications for which the found error is below γ' ensuring that if the number of replications is increased, the found error remains below γ'.

Validation and verification of the Monte Carlo simulation
To check whether the Monte Carlo simulation provides reliable results, we either have to verify and validate the Monte Carlo simulation.

Within a verification method, it is checked whether the model satisfies the conditions imposed at the start of the development of the Monte Carlo simulation and, thus, whether the simulation is of high quality (Sharma, 2017). It does not ensure that the results of the simulation are useful, but it will show that the simulation is free of errors and carries out the intended goals.

With a validation method, it is determined whether the results of the simulation satisfies specified requirements. The validation method shows whether the results of the Monte Carle simulation are reliable and can be used to draw any conclusions.

According to Kleijnen (1995), there are 4 ways to verify a simulation model. The first is to have a procedure for general good programming practice. The second is to verify intermediate simulation output. The third option is to compare final simulation outputs with analytical results and the last option is to use animation. With the second option, analysts may calculate some simulation results manually and compare these with the results of the program.

Lastly, to validate the Monte Carlo simulation, we will perform the simulation for a time period of one year with the beginning inventory of the 1st of January in 2018. By simulating how the model would have performed if we had used the model in 2018, based on the actual demand, we can see whether the results based on actual demand are in line with the results of the Monte Carlo model. If the results appears to be in line with each other, we can conclude that the results of the Monte Carlo simulation are validated and can be used to draw any conclusions.

3.5 Conclusion

This chapter focuses answers sub-questions *3* upon *6* based on theory.

The first question that is handled is: *What methods are available in literature to classify the different products?* This chapter shows many opportunities to classify the products, which are not even all available methods. The ABC-classification is the most commonly used classification method and it is a good way to make a distinction between the different kind of products, but it is important to think of which other criteria should be taken into account to make the final classification. There is chosen that a combination of the ABC-classification and the XYZ-classification is a good way to classify the products of TenCate Grass, since it includes the demand in combination with the number of months in which the products are demanded and the profit margin of a product. Furthermore, the ABC-XYZ provides targeted cycle service levels. The ABC-XYZ classification meets all requirements of the factors chosen to decide which classification method is most promising.

The second question that is answered during this chapter is: *Which methods are available in literature to implement an efficient inventory control policy of production systems?* There are several methods available to implement an inventory control policy of production system. For that purpose, the decision has to be made whether we deal with a fixed periodic review or a continuous review. For TenCate Grass, it is decided to set-up an inventory control policy based on a continuous policy. The safety stock could be calculated using different aspects as input, for example, the cycle service level or the shortage costs. The CSL as determined by the use of classification models could, therefore, serve as input to determine all other parameters. Based on the parameter with the most priority, the safety stock could be determined. Furthermore, the formulas for the reorder points, order-up-to-level and order size are given. By using the CSL as input, the actual cycle service level will probably be enough to fulfil the expectations of actual customers. The shortage costs could serve as input factor for determining the safety stock. There are different ways to determine the shortage costs, but most of the time it is a predetermined penalty that the company has to pay when they are not able to deliver a product on time. However, customers may cancel their order if there is a stockout, or they could accept for a later date. For each possibility, there is a certain probability that the customer would take this action, combined with the costs of those action, the shortage costs could be determined.

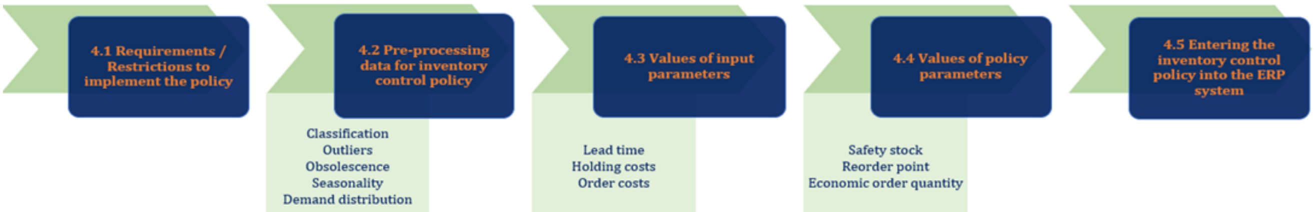
The third question handled during this chapter is: *Which methods are available in literature to improve changeovers?* First of all, we should note that improving changeovers is not one of the scopes of the project. The goal of this project is to map changeover costs rather than to improve the changeovers. Therefore, improvements on the changeovers will only be made when there appears to be enough time to dive into the scheduling of the changeovers, otherwise this aspect will be kept in mind for future studies. On that notice, it is good to know which methods are available to improve the changeovers or to improve the planning method related to changeovers.

As we can see, there are several methods available to reduce the overall changeover time. The most commonly used method is that of SMED. Even though the company already heard of the method, it is not fully implemented yet. When the SMED is implemented correctly, the changeovers may be further improved by also implementing other methods, which are more related to the planning of changeovers, rather than to reduce the time of a single changeover. Three other methods that are found during this study are: schedule jobs in pairs, schedule jobs using group technology and make changeover time visual. A combination of different methods will lead to the most optimal schedule related to changeovers.

The last question treated in this chapter is: *What is the purpose of a Monte Carlo simulation and how can it be used?* A Monte Carlo simulation model will be used to compare the proposed inventory control policy with the current inventory control policy. The Monte Carlo simulation will be developed such that it determines the total costs when the order quantity, reorder point, safety stock and lead time are fixed and based on the inventory control policy. The simulation will simulate demand data for a year, where each period represents L weeks. The simulation model will run for the number of replications found and the results originated by the proposed model will be compared to the results that belong to the current model. Based on varying demand, the model with the lowest costs is considered to be the most promising model. To verify the Monte Carlo simulation, we will compare results of the simulation with results that are calculated manually, to check whether the simulation generates results that follow from the formulas as proposed by Pujawan et al (2010). Lastly, the model will be validated by comparing the results of the simulation with the results when the model was used based on actual demand.

4. Solution design

This chapter consists of modelling the inventory control policy. First, it will be checked whether there are some requirements or restrictions that should be taken into account while developing the policy. Secondly, an overview of the formulas used to develop the model will be given, followed by a classification of the products. Thirdly, data that is required to set up the parameters of the inventory control policy will be improved by checking out whether there are some outliers, obsolescence or seasonality that should be taken into account. Furthermore, it will be checked whether a Normal distribution can be assumed for the demand for each of the products. Thereafter, the input parameters (the lead time, holding and order costs) will be determined. The 4th section of this chapter will mention how the policy parameters are gained and what should be the values for each of these parameters. By combining these four sections, the inventory control policy has been developed. Finally, it will be determined how the model, or at least the policy parameters, will be implemented in the ERP system. The following flow chart represents the order in which each of the steps will be handled.



4.1 Requirements / Restrictions to implement the policy

This section answers sub question *7*: *Are there requirements or restrictions involved to implement an inventory control policy?* To answer this question, we determine whether there are any notable aspects that should be taken into account before developing the actual policy.

With the use of the found policy within the literature, we do not take obsolescence of the products into account. Even though the quality of the product remains the same over the years, if it is not used and placed in inventory, the company still decides that the product will be sold for 50% of the total price if it is in stock for over a year and the product will be sold for 10% of the total price if it is in inventory for over two years. Therefore, obsolescence may form a restriction to implement the inventory control policy and it is important that a product will be in stock for at most one year to avoid lower selling prices. Assuming that the company uses a FCFS policy, we will only have to look whether a product is in inventory for over a year. If not, obsolescence does not have to be taken into account. *Figure 15* represents the inventory level per product over the time period from 2016 to 2018, where each line represents an individual product.

Figure 15: *Inventory per product over the time period from 2016 to 2018*

The inventory level seems to be quite high in some months, however, it does also show that there is always a month that the inventory is equal to or close to zero at its lowest level. Especially after the high season, the inventory drops to its lowest level. That way, it should be the case that there is no individual product that is in inventory for over a year and in combination with a FCFS policy, we assume that obsolescence does not play an important role to determine the inventory control policy and we do not have to take it into account. However, to underpin this assumption, we will also look at existing data, stating the amount of inventory and the period for which the products have been in inventory. Surprisingly, we find that 49 products do have products in inventory for over a year and some of them do even have products in inventory for over two years. *Appendix B* will give an overview of the products that seemed to have inventory for over a year and the number of products in inventory for over a year multiplied with a random factor for confidentiality reasons. If some of these products are classified as MTS, we have to determine how we will take obsolescence into account.

Another restriction that influences the inventory control policy is the fact that the company accepts different selling prices from customers. That way, there is no fixed income per product. Depending on the customers, the profit margin could be higher or lower. This especially influences the classification of the different products, which in turn has an influence on the target cycle service level. The higher the target cycle service level, the higher the inventory level should be. Therefore, some assumptions have to be made in order to determine the selling price of a product which are used for the classification. One way to deal with this problem, is just to take the average of all selling prices available for a certain product. Another method, is to look at the amount a customer demands compared to the total amount demanded of a product and multiply this ratio with the selling price per customer, the total sum of these values will represent the demand weighted average selling price.

The third restriction that should be taken into account is seasonality. As seen within the current situation of the company, they apply different parameters in the low season compared to the high season. This way, the parameters are only based on limited data throughout the year. Another method to handle seasonality may be to implement a seasonality factor which should be multiplied with the parameters that are based on the data of the whole year. This factor could be determined based on past data observations.

Finally, we have to take into account that there may be outliers in the demand data, that could have a big influence on the parameters and eventually on the safety stock, reorder point and order quantity. Therefore, we have to look whether we can see any patterns based on historic data and remove outliers. These outliers may also have an influence on whether you include a month in the high season or not, therefore we will have to look in depth whether a value seems to be in line with all other data.

4.2 Pre-processing data for the inventory control policy

This section focuses on sub-question *8: How can we use existing data to develop the inventory control policy?* The main improvement that could be made compared to the current inventory control policy is to have reliable data to determine the parameters. Currently, most of the parameters are based on common sense and some general data. Therefore, obtaining the cost data and analysing the existing demand data is required to gain reliable data for the inventory control policy and to process them into the required parameters. To get an overview of the data that is required to set up the inventory control policy, we will first give an overview of the formulas and data required. To pre-process the data of the inventory control policy, we will start with the classification of the products in either MTO or MTS. Secondly, we will determine whether some outliers should be removed or whether there is some obsolescence or seasonality that should be taken into account. This part will be based on historic data to see if there are any patterns or notable outliers. Finally, we will look for all MTS products whether it can be assumed that the demand of the products follow a Normal distribution or whether they follow another distribution.

4.2.1 Development of inventory control policy

Development of the model

Based on *Figure 10* in *Section 3.2*, we see that the first step in developing the inventory control policy is to determine when there are options to order to determine which formulas and data is required to set up the model. Since the inventory control will be for a production company that produces (almost) every day, we consider that we can constantly order a product. Therefore, the model will be based on a continuous review.

Using the same figure as basis in combination with having a continuous review, we know that we have to include a fixed lot size. The fixed lot size will be determined for each of the MTS products. To determine this fixed lot size, also known as the economic order quantity, we will use the following formula:

$$Q = (\frac{2KD}{h})^{\frac{1}{2}} \quad [4.1]$$

The formula depends on the order costs, demand and holding costs which are all subject to change. The order costs depend on changeovers and will be measured by observations during this study. To determine the yearly demand, historic demand is used. Since we know that outliers, seasonality and obsolescence probably form restrictions to develop the model, the demand data will be updated with inclusion of these factors. Lastly, the holding costs consist of capital costs, area costs and risk costs (Durlinger, 2013) and are company dependent. Further research will be executed to get a reliable value for the holding costs h.

The following step is to determine whether we have to deal with a fixed or uncertain lead time. In case of a fixed lead time, the following formula will be used to determine the standard deviation of the lead time:

$$\sigma_L = \sigma * \sqrt{L} \quad [4.2]$$

However, it may also be the case that the lead time is uncertain. If that is the case, the following formula will be used to determine the standard deviation of the lead time:

$$\sigma_L = \sqrt{L * \sigma_D{}^2 + D^2 * \sigma_L{}^2} \quad [4.3]$$

The value of the standard deviation of the lead time is required to determine the safety stock as well as the reorder point, which is based on the safety stock. As a result, the following formulas are used to determine these values and to set up the inventory control policy:

$$SS = z * \sigma_L \quad [4.4]$$

$$s = D_L + SS \quad [4.5]$$

It is already possible to determine the demand during lead time and the standard deviation of the lead time, however, we do not have a formula for the safety factor yet. Note that the demand during lead time changes when seasonality, obsolescence and outliers are taken into account.

According to *Figure 10* of *Section 3.2*, the determination of the safety factors depends on either the shortage costs or the service level. We do consider the service level to be more important than the shortage costs, therefore, we have three options to include the service level to determine the safety factor, namely by introducing the cycle service level, the fill rate or the ready rate. Since we are only interested whether all demand is met after a predetermined period, it is already sufficient to include the cycle service level. Besides, the cycle service level is one of the outputs of the ABC-XYZ classification which will be used to classify the products, therefore, we let the safety factor depend on the cycle service level. The safety factor could be determined using the following formula:

$$z = \phi^{-1}(CSL) \quad [4.6]$$

If the inventory level becomes below reorder point and the production of the economic order quantity is not enough to pass the reorder point, one can also decide to produce *n* times the order quantity to get above the reorder point. Therefore, if the model is developed using the formulas as mentioned above, we use a (s, *n*Q) policy.

Differences between the current policy and the to-be developed policy
As one can see, the formulas are quite similar to the formulas of the current inventory control policy. Therefore, we will highlight the differences between current model and the to-be-developed model. The following differences take place between the models:

- The data that is used as input to fill in the formulas in the current inventory control policy are based on common sense and generalized data. In the proposed model, data will be measured and each data aspect that plays a role in the development of the inventory control policy will be underpinned.
- In the proposed model, the cycle service level will be based on the classification of products and not based on a random self-chosen number.
- The current model does not take outliers and obsolescence into account.
- Seasonality is included in the current model based on common sense and not based on formulas. Furthermore, if seasons change, they have to be adjusted manually in the current model.
- The classification of products in the proposed model also takes the cost price and selling price of products into account instead of only taking the historic demand into account. Besides, in the proposed model also the number of months at which the products are sold are taken into account and updated automatically.

4.2.2 Classification

Determination of important products before the actual classification
Before the products will be classified, we want to determine which products are important purely based on the volume of the demand data. We will make an assumption that for each of these products, they have to be treated as MTS. The determination of the important products can be found in *Appendix C*. A product is considered to be important when the demand volume of the product is relatively high for the data of 2012 to 2018 compared to all other products as well as for the data of 2018 alone. Besides, the product must have had demand in a relatively high number of months in at least 2018. Based on this analysis, the products that should be classified as MTS are: 100004, 100007, 100021, 100022, 100024, 100027, 110007, 110009, 110011, 110018, 110020, 110028, 110117, 110224 and 110239.

Furthermore, we should note that there are products that are used as intermediate products for other production processes. Some of them do not even have a selling price, which can be seen in *Appendix E* in the non-public version, since they are not for sale and only used as intermediate product. As a result we have to find which products only serve as intermediate product and in how many months they are used. That way, we will classify intermediate products that are used in at least six months in the previous twelve months as MTS. These six months do not have to be subsequent. There is chosen to have a restriction of six months, because the company refuses to classify a product as MTS if it is sold in less than six months, which makes sense, since you only want inventory of products that are sold or used frequently. The products that are used as intermediate products for other articles, can be found in *Table 9*. For each of the intermediate products, we will include a target cycle service level of 97%, which is the highest CSL of *Table 6,* which can be found in *Section 3.1*.

Table 9: *Intermediate products that should be classified as MTS*

Item	Number of months with demand in 2018
100104	12
110047	8
110176	8
110208	6
110211	7
110242	7
110244	10
110245	8
110326	7

Now that it is clear which products should be classified as MTS with certainty, the remainder of the products will be classified.

Development of the classification

To classify the different products, the ABC-XYZ classification is used. The classification can be separated in to two different classifications, namely the ABC-classification and the XYZ-classification.

The ABC-classification is based on the sales volume. As a result, both the cost price as well as the selling price are required to determine the profit margin. The cost price is fixed data which is already available within the company. The selling price, however, is more difficult to obtain. The company sells products for different prices dependent on the negotiation with customers. The different ways to obtain the selling price of a product will be mentioned below.

One of the methods to obtain selling prices is to look at historic data and determine the ratio that a customer demands a certain product compared to other customers. By multiplying this ratio with the customer specific selling price and summing up all these values related to a certain product, we get the demand weighted average selling price. Another method is to take the average of all selling prices available per product. If those two methods still do not provide a selling price, the price could be gained by taking the budgeted price as determined by the company. However, we should note that the last option is less reliable. When all three methods are used an there is still no selling price found, it can be assumed that the product is either not sold or an intermediate product.

When the cost price and the selling price are determined and the selling price is greater than zero, the profit margin can be determined using the following formula:

$$profit\ margin = selling\ price - cost\ price \qquad [4.7]$$

Thereafter, the sales volume per product could be determined by multiplying the historic demand over a pre-determined period with the profit margin. The sales are normalized to see which product contributes most to the overall sale. The products that make up to 80% of the total sales will be classified as A. The products that contribute to the next 11% (up to 91% of the total sales) will be classified as B and the remainder of the products will be classified as C.

Thereafter, the XYZ-classification should be determined. Based on the theory, we will classify products that had demand in at least 10 of the past 12 months as X, products that had demand between 4 and 9 of the past 12 months as Y and products that had demand in less than 3 months of the past 12 months will be classified as Z. However, to implement the XYZ-classification for this specific company, adjustments in contrast to the theory given are made. For example, the company believes that a product should never be classified as MTS if the product is only demanded in less than 6 months of the past 12 months. Therefore, the subdivision between Y and Z is changed. Products that had demand in at least 10 of the 12 past months will be classified with X, products that had demand in 6 to 9 months of the past 12 months will be classified as Y and products that only had demand in less than 6 months of the past 12 months will be classified as Z.

The combination of the ABC-classification and the XYZ-classification tells us how the products should be classified in the ABC-XYZ classification. If the product falls within any of the categories AX, AY, BX, BY and CX, it will be classified as MTS. The corresponding target cycle service level is based on the values found in *Table 6* in *Section 3.1.* As a result, products classified as AX receive a target cycle service level of 0.97, products classified as AY receive a target cycle service level of 0.95, products classified as BX receive a target cycle service level of 0.95, products classified as BY receive a target cycle service level of 0.93 and products classified as CX receive a target cycle service level of 0.93. If a product falls in any of the remaining categories and is not one of the intermediate products, it will not receive a target cycle service level. The found target cycle service level is used to determine the safety factor which serves as input for the inventory control policy.

Implementation of the classification

The classification is based on the data from the last twelve months, therefore, the classification is subject to change in the future.

The first step in the classification is to determine the profit margin, which is based on the cost price and selling price. The cost price is fixed per product and already available in the ERP system. An overview of the cost prices per product as obtained in March 2019, can be found in the non-public version as *Appendix D.* To determine the selling price, we first try to determine the weighted average selling price. If there is not enough data to determine this weighted average selling price, the average of all selling prices available in the ERP system is taken. If these methods provide different results, the lowest selling price is chosen. That way, the profit margin is never overestimated. If there is still no selling price and there is also no budgeted price available, the product is omitted from the classification. The found the selling price are represented in *Appendix E* of the non-public version. With the use of the cost price and selling price, the profit margin is determined. Notable, we see that some of the products do have a negative profit margin, which is a result of selling the product for a lower price than the cost price to certain customers. This is done in practice for strategical reasons, for example to make a commitment with customers or to combine the products that are sold with a lower profit margin with products that are sold with a higher profit margin to let the overall price look attractive to customers. The profit margin is multiplied with the demand of the last twelve months to determine the sales volume in monetary terms which are used for the ABC-classification.

When we normalize the sales volume, we see that 25% of the products with sales is classified as A, 17% of the products with sales is classified as B and 58% of the products with sales is classified as C. Which is quite in line with the theory.

Now that the ABC-classification is implemented, the classification will be extended with the XYZ-classification. For that purpose we determine the number of months for which there was demand in the past twelve months. In total, there are *X* products classified with X and *X* products classified with Y, the remainder of the products is classified with Z.

After the execution of the ABC-XYZ classification, we search for the products that fall either in one of the categories of AX, AY, BX, BY and CX. Products that fall within one of these categories are classified as MTS and they are provided with the corresponding target cycle service level. Furthermore, intermediate products are manually set as MTS products with a target cycle service level of 0.97. As a result, 44 products are classified as MTS in total. Since the company only holds inventory on purpose for MTS products, we only have to determine the parameters for the inventory control policy for these products. However, we should note that with the use of proposed demand data, the classification may change leading to different MTS products.

Furthermore, since we know which products are classified as MTS and we know which products had inventory for more than a year, we can check whether obsolescence has to play a role. There are seven products which do have inventory for over a year and are considered to be MTS, therefore obsolescence has to be taken into account. We should note, however, that the number of products in inventory for over a year are relatively small compared to the total number of products in inventory for these specific products, therefore, the company may still decide not to take obsolescence into account.

Conclusion

The products are classified based on the ABC-XYZ classification. However, there are some products that always will be classified as MTS as a result of being an intermediate product, namely products: 100104, 110047, 110176, 110208, 110211, 110242, 110244, 110245 and 110326. Additionally, the differentiation between Y and Z is adjusted, such that products are considered to be classified as Y if they had demand in 6 to 9 months of the past 12 months and are considered to be classified as Z if there was demand in less than 6 months of the past 12 months. Based on the ABC-XYZ classification, products that are classified as AX, AY, BX, BY and CX will be labelled as MTS and receive a target CSL corresponding to their classification. As a result, 44 products are classified as MTS. Besides, it can be concluded that obsolescence should be taken into account since there are 7 products classified as MTS having some products in inventory for over a year.

4.2.3 Determination of outliers, obsolescence and seasonality

Outliers

Determination of outliers

After the classification of products as either MTO or MTS, the following step in data pre-processing is to determine whether there are outliers which should be removed from the data to avoid having unreliable outcomes. For that purpose, boxplots are developed to see which values do not fall within the boxplot and its margin of error. The values that are assumed to be outliers will be removed from the data that is used to determine the parameters of the inventory control policy. The goal of boxplots is to ignore individual data values and show the overall pattern of all data. Next up, it is discussed how boxplots are made (MathBootCamps, 2019).

First, a summary of the data set has to be made, which consists of the minimum value, the first quartile, the median, the third quartile and the maximum value. The minimum value is equal to the lowest demand value that exists in the data, the maximum value, on the other hand, is equal to the highest demand value that exists in the data. The median is the value that separates the higher half from the lower half of data. For example, when there are 13 periods with demand data available, the seventh-highest demand value represents the median. The first- and the third quartile respectively represent the median of the lower half and the median of the higher half.

With the use of the summary, outliers can be identified. With boxplots, outliers are determined with the use of fences. Any demand value outside the fences are potential outliers and will not be included in the determination of the parameters for the inventory control policy.

The lower fence is calculated using the following formula (MathBootCamps, 2019):

$$lower\ fence = Q_1 - 1.5 * IQR \quad [4.8]$$

Where Q_1 represents the first quartile and IQR represents the interquartile range, which can be calculated using the following formula (MathBootCamps, 2019):

$$IQR = Q_3 - Q_1 \quad [4.9]$$

Where Q_3 represents the value of the third quartile.

Any demand value that is lower than the lower fence is considered to be an outlier. In contradiction to the lower fence, the upper fence is calculated using the following formula (MathBootCamps, 2019):

$$upper\ fence = Q_3 + 1.5 * IQR \quad [4.10]$$

Where each demand value higher than the upper fence is considered to be an outlier.

If all values are calculated, the actual boxplot can be made. The first step in drawing a boxplot is to draw a line from the lower fence value to the upper fence value. The remainder of the boxplot is made by drawing a box from the first- to the third quartile. In the middle of the box, there will be a line representing the median. Each demand value that does not fall within this boxplot is considered to be an outlier and will be removed from the data that is used to determine the parameters for the inventory control policy.

Implementation of the determination of outliers

One example of a boxplot can be found in *Figure 16*. Based on this example, we see that only one value is outside the fences and is considered to be an outlier, which is the demand of the sixth month in 2015. An overview of the data that are considered to be outliers and should be removed when determining the parameters of the inventory control policy can be found in *Appendix F.*

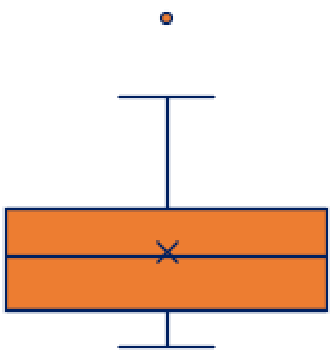


Figure 16: *Example boxplot of product 100022*

As one can see in *Appendix F,* there are 59 out of *X* products for which outliers are found. From these products, 21 products do have outliers in 2018. Since the determination of the parameters for the inventory control policy are mainly based on the data of 2018, we will check whether the outliers are still considered to be outliers when we purely look at the data of 2018. *Figure 17* gives an overview of the boxplots for the products which had outliers for 2018. Based on this method, there are 9 outliers in total for products 100002, 100028, 110010, 110019, 110021 and 110071. The values of the demand data from 2018 that should be removed to determine parameters of the inventory control policy are summarized in *Table 10*.

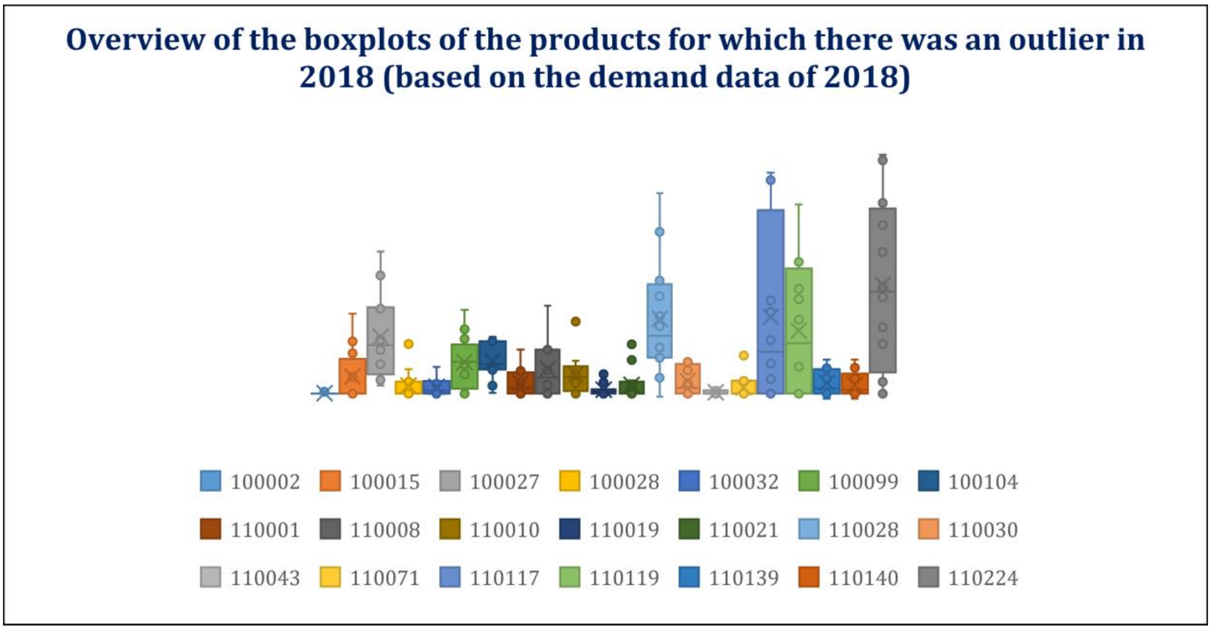


Figure 17: *Overview of the boxplots for which there was an outlier in 2018*

Table 10: *Outliers found in the demand data of 2018 that should be removed*

Product	Months for which the demand data is considered to be an outlier, based on boxplots (2018)
100002	P1-2018 – P4-2018
100028	P7-2018
110010	P4-2018
110019	P1-2018 – P4-2018
110021	P2-2018 – P9-2018
110071	P2-2018

There are only two MTS products, which have outliers in 2018, namely products 110010 and 110019. Thus, to determine the parameters of the inventory control policy, only these 3 outliers should be removed. Since demand data changes, the development of a boxplot is implemented in the model and updated when new demand is included in the model. Now that the outliers are clear, we have to determine a way on how obsolescence plays a role in the determination of the inventory control policy.

Obsolescence

Determination of inclusion of obsolescence

From the products that are found to have products in inventory for over a year, there are 7 products classified as MTS, namely: 100007, 100099, 110018, 110117, 110242, 110323 and 110324. In total, they make up for a bit more than 15,853,000 kilo that is in inventory for over a year, from which a quarter is in inventory for over two years. As we know, the company sells products that are in inventory for over a year for 50% of the total price and products that are in inventory for over two years are sold for 10% of the total price. Therefore, products that are in inventory for over a year are considered to be obsolete. Since there are MTS products who have inventory for over a year, we should take obsolescence into account. For that purpose, we have to find ways on how obsolescence could be included in the model.

One way to deal with obsolescence, based on common sense, is to ensure that the company will never produce more than the expected yearly demand of a product. As we have seen in the data, some products faced obsolescence. The main reason is that there was more produced than required in available orders. This is done with the thought that the remainder of products will be sold anyway and extending the production process is better for manufacturing purposes. However, it appeared that the remainder was not sold, leaving the company with unnecessary inventory. Besides, as a result of having fluctuating demand, products may not be demanded for years, causing obsolescence. If it is not possible to produce more than required in orders and expected demand, the product will not face obsolescence anymore.

However, the inclusion of obsolescence should not be based on common sense. Therefore, different methods have been searched on how to include obsolescence. The main decision that has to be made is whether there is deterministic or stochastic demand involved. Deterministic demand is predictable and represent a sequence of outcomes that have a causal relationship. Stochastic demand, on the other hand, depends on coincidence and is hard to predict (Renard et al, 2013).

If there is a deterministic demand and a fixed lifetime, Nahmias (1982) states that the optimal order size is equal to the minimum of Q or Dm, at which D represents the demand rate and m represents the product lifetime. If there appears to be deterministic demand, the product lifetime is said to be one year, since the selling price of a product will be lowered after a year.

However, it may also be the case that we have to deal with stochastic demand. In that case, it is more difficult to find a way on how to deal with obsolescence. Goyal and Giri (2000) made up a review of different methods that can be used to include either obsolescence or deterioration of products. It mentions that the probability theory is very useful in making decisions under the condition of risk and uncertainty. Therefore, if the demand is stochastic, obsolescence will be included in the inventory control policy by making use of the probability theory.

When the probability theory has to be included, it will have an influence on the safety stock, and thus, the reorder point. When the safety stock is determined it will be multiplied with the probability that the product is in inventory for less than a year (p_1). If there is no data available for a product being in inventory for over a year, this probability will be equal to one, meaning that the safety stock does not change. That way, the model takes the probability of being in inventory for over a year into account.

Additionally, obsolescence is also important to determine the economic order quantity. Therefore, a new formula is used to determine Q (Delft & Vial, 1996):

$$Q = \sqrt{\frac{2*K*D}{(\rho+q)*(p-sv[\left(\frac{q}{\rho}+q\right)]}} \qquad [4.11]$$

Where ρ represents the discount rate and is equal to the holding costs which are expressed as percentage of the cost per unit. The value for ρ will be determined in paragraph *4.3.2.* Additionally, q represents the obsolescence rate, which is based on the time before the product becomes obsolete. Since the real impact of obsolescence becomes clear after two years, this value is equal to q = ½ = 0.5. Lastly, *sv* represents the salvage value, otherwise known as the value that is left over when the product has become obsolete. Since there is chosen to take two years as the time in which the product becomes obsolete, this value should be equal to 0.1 percent of the selling price. With the implementation of this formula, the model takes obsolescence into account to determine the output of the model.

Implementation of inclusion of obsolescence

First, the decision has been made whether we deal with stochastic or deterministic demand. Based on the demand of the past, we see that the demand fluctuates quite a lot and that there is no causal relationship between each of the demand values. Therefore, we consider the demand to be stochastic.

As a result, the probability theory has to be included. For that purpose, probabilities of having a certain selling price are determined based on the data of *Appendix B*, where products that do not have any products in inventory for over a year, have a probability of 1 to be sold against the normal price. For the remainder of the products, the probability of a product being in inventory over a years has to be determined as well as the probability of being in inventory for over two years. The sum of all three probabilities should equal 1. The probabilities found for all products which had products in inventory for over a year can be found in *Appendix G*. When the safety stock for a product is determined, this value will be multiplied with the probability found of having inventory for less than a year.

Furthermore, the new EOQ formula *[4.11]* will be implemented to take obsolescence into account. However, this will be part of paragraph *4.4.3*.

Seasonality

Determination of seasonality

Now that the outliers are clear and it is known how to handle obsolescence, the following step is to determine whether a product is facing seasonality. It should be noted that the determination of the seasons is only part of defining the input parameters for the inventory control policy, since forecasting is part of the sales department, therefore, forecasting will not be included in this study.

To determine whether seasonality has to be taken into account, the first step is to get a global overview of the demand data. For that purpose, the demand data can be processed in graphs showing whether the product is facing a general pattern. Furthermore, it is interesting to see which products had demand in a month for each of the last three years. When there are products that appear to have demand for a specific month in each of the last three years, we can assume that the product will also be sold during the same month next year and that this month is part of a season. These two aspects combined will give a global overview of the different products and their demand.

The second step is to actually check whether seasonality has to be taken into account. For that purpose, seasonal subseries plots as founded by Cleveland (1993) are made, which is a tool that detects seasonality in a time series. One example of a seasonal subseries plot can be found in *Figure 18.*

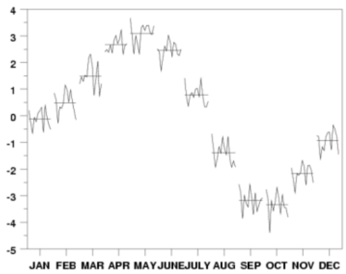


Figure 18: *An example of a seasonal subseries plot by Cleveland (1993)*

Based on this example, we see that the data is following a clear season, where April to June represent the high season and September to October represent the low season. Even though individual data points differ for the same month, the overall season is quite clear. Thus, seasonality has to be included if the seasonal subseries plot shows seasons.

If there is chosen to include seasonality in the model, the last step is to determine how seasonality can be included. Seasonality can be included with the use of seasonal indices as explained by Silver et al (2017). Mainly, seasonal indices combined with a level and trend are used to determine the forecast of a product, however, as we explained, forecasting is not part of this study. Therefore, a complete forecasting model is not included, but the normalized seasonal indices have to be determined. When the normalized seasonal indices are found, they have to be multiplied with the average demand of last year to get an indication of what the demand level that is used as input for the inventory control policy should be. According to Silver et al (2017), the estimate of the seasonal factor for any particular historical period is obtained by dividing the demand by the centred moving average. The seasonal indices will be normalized such that the estimates of the seasonal indices sum up to the total number of periods.

The moving average is determined by taking the average value of 12 data points, representing the data for one entire year. The second moving average equals the average of 12 data points, starting with one month later than the first month of the data that is used to determine the first moving average. The average of the first- and second moving average represents the centred moving average. The estimate of the seasonal index for one specific month is then determined by using the following formula:

$$F_t = \frac{D_t}{CMA_t} \quad [4.12]$$

Where D_t represents the demand of month t and CMA_t represents the centred moving average of month t. Please note that t does not represent the twelve months of a year, but all months for which there is data available. To get the seasonal index for each of the twelve months (January to December), the average of all seasonal indices representing the same month is taken.

The seasonal indices found for each of the twelve months are normalized, such that the sum of all seasonal indices is equal to twelve. Therefore, the normalized seasonal indices are determined using the following formula:

$$I_m = \frac{S_i}{\sum S_i} * 12 \quad [4.13]$$

Where I_m represents the normalized seasonal index for month m (m = Jan, Feb, …, Dec) and S_i represents the estimate of the seasonal index for month i (i = Jan, Feb, …, Dec). The values that are found using this formula are the seasonal indices that are used to determine the parameters of the inventory control policy.

However, if the seasonal subseries plots do not show a clear season, it is still uncertain whether the seasonal indices should be used to determine the policy parameters. Therefore, a statistical test will be introduced to check whether seasonality should actually be taken into account. For that purpose, a Chi-Square test (goodness of fit test) will be carried out. The goal of the test is to check whether a null hypothesis can be rejected. The null hypothesis that will be tested is equal to:

H_0: Seasonal indices are evenly distributed over the year, meaning that there is no (strong) season involved.

The Chi-Square is calculated using the following formula (StatisticsHowTo, 2019):

$$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad [4.14]$$

Where O_i represents the i-th observation and E_i represents the expected value of i. In our specific case, i represents a month. The expected value is equal to the average value of all seasonal indices, since we have normalized the seasonal indices, this value is equal to one for all months. The higher the difference between the expected and observed value, the higher the change that the null-hypothesis will be rejected. The outcome of the formula will be used to search for the corresponding *p*-value in Chi-square table. However, since we have access to Excel, the following formula can be used to determine the *p-value*:

$$p - value = CHISQ.TEST(observed\ values; expected\ values)$$

If the *p-value* is smaller than 0.1, the null hypothesis will be rejected (StatisticsHowTo, 2019). The higher the p-value, the lower the significance level that the null hypothesis should be rejected. If it appears that the null hypothesis cannot be rejected, we can assume that the seasonal indices lie close to each other and that seasonality does not have to be taken into account. In that case, all seasonal indices are set to one. However, if it appears that the null hypothesis must be rejected, then we should take the actual seasonal indices into account.

Implementation of seasonality

To get a global overview of the products, we will start with determining whether the products seem to have a pattern based on the demand data. *Appendix H* summarizes the products for which a general pattern is found. This holds for products 100004, 100007, 100014, 100021, 100022, 100024, 110007, 110011, 110036, 110071, 110117, 110225 and 110231. Even though a global pattern is found for these products, there are still some fluctuations making it hard to conclude that there is a fixed season. Furthermore, *Figure 19* represents an overview of the total demand over the years.

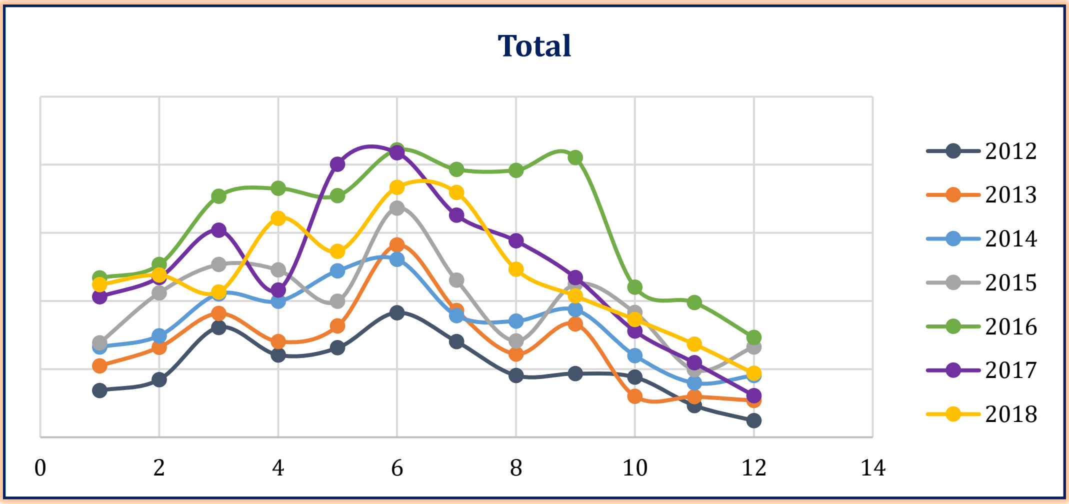


Figure 19: *Total demand over the years 2012 to 2018*

Based on *Figure 19*, we see that the value of the total demand changes over the years, but that there is quite a clear pattern. The demand is rising during the first six months and, thereafter, drops again to its lowest value in December. Based on this figure, the high season is found to be in March until September.

Even though some products seem to have a general pattern, it is also handy to see which products did have demand in a month for each of the last three years (2016-2018) and to see whether these months are part of a season. If there is demand in a month for each of the last three years, we assume that this month will probably be part of a season. It should be noted, however, that if there is demand in each of the last three years, it does not mean that the demand level is relatively high, thus, it does not necessarily mean that this month should be part of a high season. The determination of products having demand in a month for each of the last three years can be found in *Appendix I*.

To summarize, there are 10 products for which there was demand in each of the last three years in at least 9 months. These products can be found in *Table 11*. For the time being, we consider these months to be part of the season that the product is following.

Table 11: *Products which had demand in each of the last three years for at least 9 months*

Product	Months for which there is demand in each of the last three years
100004	P2 – P3 – P4 – P5 – P6 – P9 – P10 – P11 – P12
100007	P2 – P3 – P4 – P5 – P6 – P7 – P8 – P9 – P11
100021	P1 – P2 – P3 – P4 – P5 – P6 – P7 – P8 – P9 – P10 – P11 – P12
100022	P1 – P2 – P3 – P4 – P5 – P6 – P7 – P8 – P9 – P10 – P11 – P12
100027	P1 – P2 – P3 – P4 – P5 – P6 – P7 – P8 – P9 – P10 – P11
110007	P1 – P2 – P3 – P4 – P5 – P6 – P8 – P9 – P10 – P11 – P12
110011	P1 – P2 – P3 – P4 – P5 – P6 – P7 – P9 – P10
110018	P1 – P2 – P3 – P4 – P5 – P7 – P8 – P9 – P10
110028	P2 – P4 – P5 – P6 – P7 – P8 – P9 – P10 – P11
110239	P1 – P2 – P3 – P4 – P5 – P6 – P7 – P8 – P9 – P10 – P11

To check whether there is actually seasonality involved for products, seasonal subseries plots are made. For the products for which a general pattern was found and the classification turned out to be MTS, we will use this method to determine whether there was a season that should be taken into account. This holds for products 100004, 100007, 100021, 100022, 100024, 110007, 110011, 110036, 110117 and 110225. Additionally, it has been checked whether seasonality should be part of the determination of the inventory control policy for all other MTS products. The results of the seasonal subseries plots for these products individually can be found in *Appendix J*. As a result we find that based on the seasonal subseries plots, seasonality should play a role in the determination of the inventory control policy and have to be taken into account.

To include seasonality in the inventory control policy, seasonal indices are determined. After the determination of the seasonal indices, a Chi-Square test is executed to check whether seasonality should actually be taken into account. If the found *p-value* is below 0.1, the null hypothesis should be rejected and the actual seasonal indices are taken into account. However, if the *p-value* appears to be above 0.1, seasonal indices of 1 for all months are taken into account. One example of the Chi-Square test can be found in *Figure 20.*

	Chi-square test													
Observed	0.45	3.38	0.76	3.91	0.00	0.12	0.09	1.10	1.64	0.52	0.02	0.00		If p value > .10 → "not significant that the null hypothesis should be rejected"
Expected	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		If p value ≤ .10 → "marginally significant that the null hypothesis should be rejected"
Residual (Obs-Exp)	-0.55	2.38	-0.24	2.91	-1.00	-0.88	-0.91	0.10	0.64	-0.48	-0.98	-1.00		If p value ≤ .05 → "significant that the null hypothesis should be rejected"
(Obs-Exp)^2	0.31	5.66	0.06	8.48	1.00	0.78	0.82	0.01	0.41	0.23	0.97	0.99		If p value ≤ .01 → "highly significant that the null hypothesis should be rejected."
Component = (Obs-Exp)^2 / Exp	0.31	5.66	0.06	8.48	1.00	0.78	0.82	0.01	0.41	0.23	0.97	0.99	19.72	
												p-value	0.0493	
If not rejected take expected value, otherwise, take observed value.												Reject?	Yes	
												H0: Seasonal indices are evenly distributed over the year, meaning that there is no strong season involved.		

Figure 20: *Example of the Chi-Square test for product X*

In this specific example, it can be concluded that it is significant to reject the null hypothesis. Therefore, seasonality plays a role for this product and the observed seasonal indices should be taken into account. From all MTS products, it appeared that only for 8 MTS products, seasonality has to be included.

The found seasonal indices are multiplied with the average demand of last year, to get an indication of what the demand in that specific month will be. This value is used as input to determine the parameters of the inventory control policy. If it appeared that seasonality does not have to play a role, this value is similar for all months.

In the model, the user of the model has to insert the month for which the parameters are required, for this month the seasonal indices are determined and included to have the demand that is used as input to determine the parameters. For example, if one wants to find parameters for the month January, the seasonal index of January is multiplied with the average demand of the last twelve months and rewritten as the demand during lead time or yearly demand to determine the parameters.

4.2.4 Determination of the demand distributions

Determination of the demand distribution

For all MTS products, it should be checked whether a Normal distribution can be assumed for the demand. It can be assumed that the demand of a product follows a Normal distribution in case the mean demand during lead time of a product exceeds 10 (Heijden & Diks, 2018). Additionally, a Normal approximation works well in case of high backorder costs or a high cycle service level (Axsäter, 2013). Therefore, the first step in determining the demand distribution is to determine the mean demand during lead time.

The mean demand during lead time can be determined by taking the average demand per month based on all data available and take the average of all twelve months. This value should be rewritten such that is represents the demand for a time period equal to the lead time. If this value exceeds 10, it can already be assumed that the products follows a Normal distribution. Otherwise, it should be checked whether there is a high cycle service level or high backorder costs involved. If no statements could be made based on this data, the last option to determine the distribution is to use a fitting method based on the QQ-plot and the goodness-of-fit test.

Implementation of the determination of the demand distribution

Each of the 44 products that are classified as MTS do have a mean demand during lead time that exceeds 10, therefore, we conclude that a Normal distribution can be assumed. Additionally, for all MTS products, the target cycle service level is above 90 percent, which is another indication that a Normal distribution can be assumed. Based on these assumptions, we can use the formulas for the inventory control policy found in literature, which are based on a Normal distribution.

Conclusion

Based on the rule-of-thumb that a product follows a Normal distribution in case the mean demand during lead time exceeds 10, it can be assumed that the demand of each of the MTS products follow a Normal distribution. As a result, we can use the inventory control policy found in literature.

4.3 Values of the input parameters

This section focuses on sub-question *9: What should the values of the input parameters be?* The lead time, holding and order costs are assumed to represent the input parameters of the inventory control policy and will, therefore, be determined in this section. It should be noted that the order costs purely consists of the changeover costs.

4.3.1 Lead time

Determination of lead time

One of the input parameters that has to be determined is the lead time. According to *Figure 10* of *Section 3.2*, there are two ways to take the lead time into account. One way is to assume that the lead time is fixed and another way is to assume that the lead time is uncertain. The lead time is used to determine the safety stock.

According to Snapp (2017), the lead time for manufactured products consists of the manufacturing lead time, the procurement lead time (for raw materials, components and subassemblies) and the shipping lead time. By finding the values for each of the three lead times, the total lead time can be found.

The determination on whether the lead time is fixed or uncertain depends on whether the lead time depends on the quantity of the order and whether the lead time tends to vary. If the lead time remains the same irrelevant of the quantity of the order, it can be assumed that the lead time is fixed. If the lead time fluctuates a lot, it can be assumed that the lead time is uncertain.

If the lead time is fixed, the formula that is used to determine the safety stock is equal to:

$$SS = z * (\sigma * \sqrt{L}) \quad [4.15]$$

Otherwise, when the lead time is uncertain, the formula that is used to determine the safety stock is equal to:

$$SS = z * \sqrt{L * {\sigma_D}^2 + D^2 * {\sigma_L}^2} \quad [4.16]$$

Implementation of the determination of lead time

First, the manufacturing lead time is determined. The company restricts itself to produce orders within *X* weeks, therefore, the manufacturing lead time is said to be *X* weeks. In case of MTS products, it may be the case that an order can be delivered directly from stock, however, if the stock level is not high enough to fulfil an order entirely, they also have *X* weeks to produce the (remainder of the) order. Altogether, we assume that the manufacturing lead time is fixed and equal to *X* weeks.

Secondly, to find the procurement lead time, we assume that there is always enough raw material to produce the required amount of products or that it is delivered within the manufacturing lead time. As a result, we do not have to include the procurement lead time, since it does not influence the inventory control policy.

Lastly, the shipping lead time is determined. The shipping of products is an ongoing process. However, the sales department only makes agreements with customers in terms of ready-to-ship-products. Thus, a company agrees with a customer that an order is ready for a customer after *X* weeks (the earliest if not in inventory already), which is the agreed manufacturing lead time and does not take the shipping lead time into account. It is communicated with customers that the delivery time of a product is not included in the date agreed with the customer and, therefore, the shipping date should be added to get the actual date of delivery. Therefore, the cycle service level is purely based on the time when a product is ready for shipment and the shipping lead time will not be influencing the inventory control policy.

By combining the different lead times, we do see that only the manufacturing lead time plays a role in the determination of the inventory control policy. Therefore, it can be concluded that the lead time is fixed and equal to *L* weeks. As a result, formula *[4.15]* is used to determine the safety stock, with *L* representing a period of *X* weeks, which can be expressed in any time unit. For confidentiality reasons, the actual number of weeks is left out.

4.3.2 Holding costs

Determination of the holding costs

Holding costs are the costs a company makes to hold inventory. These costs consists of three aspects, namely interest, area costs and risk costs (Martin, 2012).

The interest consists of the costs that arise as a result of having assets tied up in inventory. The area costs arise from the need of having a location to store the products. These costs consists of either the rental of the warehouse, maintenance costs, depreciation of scaffolding and means of transport and energy costs. Finally, the risk costs are costs that occur when keeping products in inventory causes risks that cost money. For example, these costs arise when products become less worthy in inventory. Some example of risk costs are a reduction in the selling price of a product, a reduction in demand of a product and reduction of quality when products are too long in inventory.

If we are able to find the costs for each of the three aspects, the holding costs are found. However, when there is not enough data available to determine the holding costs, theory is used to determine the holding costs.

A percentage of 25 percent of the cost price per annum is commonly used in theory to describe the holding costs and it is already seen as rule of thumb to describe the holding costs when the data is not clear. This number is also the average of the holding cost observed in the industry which ranges from 5 to 45 percent (Durlinger, 2012). This percentage is probably based on the article of Harris (1913), which was the first person to introduce an economic order quantity. Harris mentions that it is assumed that a charge of ten percent on stock is a fair one to cover both interest and depreciation and that it is even probable that a double of this number would be fairer in many instances. According to Durlinger (2013) the holding costs consist of capital costs, area costs and risk costs. The average holding cost that is found by Durlingen (2013) during a research within fifty companies is equal to 22 percent, which is the percentage that is taken into account when the data is not clear. It should be noted, however, that the holding costs may be lower in practice.

Implementation of the determination of holding costs

In the current situation, it is assumed that the holding costs are equal to fifteen percent of the cost price. To actually determine the holding costs, we will look whether we can find a value for the interest, area costs and risk costs.

First, the interest costs consist of the interest rate and the premium rate. The values for both the interest rate as well as the premium rate are left out because of confidentiality reasons. Together, the interest makes up for a percentage equal to the sum of the interest rate and premium rate of the total costs.

Secondly, the area costs are determined. When looking at historical data, the company pays a fixed price for the locations at which the company stores their inventory. First of all, they have two warehouses located on the terrain of the company itself. The size of the warehouses is left out due to confidentiality. Furthermore, they have a contract with a warehouse in Almelo, where they store the remainder of the inventory. For the warehouse next to the production facility, they pay a fixed price per year and for the warehouse in Almelo, they pay a fixed price per pallet that they will store combined with a price for handling the pallet into the warehouse or a price for letting the pallet leave the warehouse. Taking into account the transportation costs, the material handling costs and all other costs involved to store a pallet, the company assumes that *X* euros per pallet stored per is a reasonable price for the holding costs, assuming that a pallet is on average *X* days in inventory. At each pallet, around *X* kilo can be stored, dependent on the product that is placed on the pallet. However, most of these numbers are still subject to change, therefore, we cannot find an explicit number that represents the area costs.

Lastly, the risk costs have to be determined. There are risks of facing a lower selling price or a reduction in demand. However, it is too complicated to assign a fixed value to the increase of costs due to risks. Therefore, we assume that it is impossible to correctly determine the holding costs, which means that the holding costs as found in theory are taken into account, which is equal to 22% of the cost price per annum. Even though there is chosen to take a holding cost of 22% of the cost price per annum into account, we should keep in mind that the actual value is possibly lower.

4.3.3 Order costs

The final input parameter that has to be determined is that of the order costs. The order costs mainly depend on the changeovers and have to be measured since there is no explicit data available. There are three different aspects involved in changeovers, namely: colour change, material change and a die change. Since the gathering of data consists of observations, there is no specific methodology involved to determine the order costs. The data will be gathered for each of the different changeovers involved separately.

Die change

The die changes are responsible for the largest part of the order costs and have to be observed and measured in order to gain reliable data. The costs of a die change depends on several factors, namely: stop time, waste, FTE operators, mechanics and cleaning of the die. It should be noted that Type 1 products do not require die changes, thus, the costs of a die change will only be determined for Type 2 products. The data for the stop time, FTE operators and waste is fully based on observations and is not dependent on a methodology to determine the values. For that purpose, a measurement plan is introduced in the production facility. The measurement plan can be found in *Appendix K.* Within the plan, there is room for the operators to take notes if there are activities which results in additional time compared to regular die changes. By gaining data of several die changes, an average could be determined which will be used to determine the stop time, the number of FTE operators involved and the waste.

Stop time and FTE operators

One example of data, gained on April 5th, 2019, can be found in *Table 12*. If the number of operators states M, this means that the task is executed by mechanics. Each row represents a specific task that has to be executed to fulfil the die change.

Table 12: *Example of obtained data by observing a die change*

5-4-2019 Line 12	Start time	End time	Total time	# Operators
Task 1	12:00	12:30	00:30	2
Task 2	12:45	13:30	00:45	1
Task 3	13:45	15:30	01:45	M
Task 4	14:15	14:45	00:30	1
Task 5	15:00	15:15	00:15	1
Task 6	15:15	15:30	00:15	1
Task 7	15:30	15:40	00:10	1
Task 8	15:40	16:00	00:20	1
Task 9	16:00	16:20	00:20	1
Task 10	16:20	16:50	00:30	1
Task 11	17:00	18:30	01:30	2
Task 12	18:30	18:40	00:10	2
Task 13	18:40	19:00	00:20	2
Task 14	20:00	20:10	00:10	1
Task 15	19:00	20:00	01:00	2
Total	12:00	20:10	**08:10**	**10:55**

During this die change, there was one additional task, which costs 40 minutes. Since this task was executed simultaneously with other tasks and it does not represent a standard situation, we do not take this additional 40 minutes into account. Therefore, we can conclude that for this specific die change, the stop time of the production line was equal to 8 hours and 10 minutes and that there was 10 hours and 55 minutes of FTE operators involved. As we have seen in *Chapter 2*, the price of one hour of stop time is equal to 56,340 euro and the price of one FTE hour is equal to 7,825 euro. Thus, based on this example, the cost price of the stop time and FTE operators is around 545,559 euro.

When we look at all the data gained to determine the stop time and the number of FTE operators, we see that on average the stop time is equal to 7 hours and 7 minutes with 11 hours and 51 minutes of FTE operators involved. Therefore, by taking into account the cost of 56,340 euro for one hour stop time and the cost of 7,825 euro for one hour operator, the cost price for both the stop time and FTE operators is considered to be 493,679.25 euro.

Waste

Another factor that plays a role in the cost price of a die change is the waste that is released during a die change. From the service cost centre, we received the cost price per kilo waste, of which the values multiplied by a random factor can be found in *Table 13*.

Table 13: *Cost price for waste*

Row Labels	Cost price / kilo	Material	Variable costs	Fixed costs
Compound	€ 563.40	€ 547.75	€ 12.52	€ 3.13
Type 2	€ 998.47	€ 726.16	€ 212.84	€ 59.47
Type 1	€ 954.65	€ 694.86	€ 219.10	€ 40.69

The found waste during a die change relates to the compound, therefore, we do take a cost price of 563.40 euro per kilo into account.

The waste that is released during a die change can be divided upon three categories:
- Waste from the extractions
- Waste from emptying the bunker and big pieces of material
- Start-up cutting waste

However, this data is not explicitly gained by the company. The waste that is daily gained by the company is divided upon different categories. One main disadvantage of the data available is that it is not explicitly linked to die changes, which makes it hard to conclude the amount of waste that is released during die changes. Therefore, the determination of waste is one of the aspects of the measurement plan.

Some measurements do involve the waste explicitly linked to the changeover. As a result, it is found that on average 771 kilo of waste originates from extractions, 79 kilo of waste originates from emptying the bunker and big pieces of material and 216 kilo originates from start-up cutting waste, thus, in total there is 1066 kilo of waste related to a die change. By multiplying this value with 563.40 (the cost price of waste) we find that the total costs of waste related to a die change is equal to almost 600,585 euro.

Mechanics

Determination of the mechanics involved in a die change

In contradiction to the stop time, the number of FTE operators and the waste, the time that mechanics spend on a die change is not explicitly part of the measurement plan. The reason is that preparation of the dies and disassembling the dies are extern activities that do not fall within the stop time of a production line but have to be executed in order to fulfil a die change. Therefore, we have to find a way on how we find the time that mechanics spend on a die change in total.

Data related to the number of mechanics and the time used by mechanics to fulfil die changes are part of the data system of the technical service. As a result, the average time that is spend on either the preparation of the die or the actual die change and the average number of mechanics that play a role in these activities can be determined.

Additionally, there are more activities that the mechanics should perform in order to complete a die change, such as: installing the die on the preheater, administration activities related to cleaning, making the die transport-ready, receiving a cleaned die, administration related to receiving of a cleaned die, control of the injection holes in the warehouse and lastly, the administration and control of invoices. To determine the time that is spend on all of these activities, the average time that is spend on the activities is determined, which is again based on the data of the system of the technical service.

Implementation of the determination of the mechanics

The data system was implemented in March 2018, which is the first month for which there is data available in the system. To base the averages on a full year, we will take the data from 27-3-2018 until 26-3-2019. Per shape for which there is data available, the average time spend on either the preparation or change of a die is determined. The average number of mechanics required to fulfil an activity is also determined an rounded up to have an integer number of mechanics. The results found can be seen in *Table 14*.

Table 14: *The average time and number of mechanics spend on a changeover*

	Preparation		Change		Total time
	Hours	# Mechanics	Hours	# Mechanics	Hours
Shape 1	2.38	2	5.10	3	7.48
Shape 3	2.55	2	4.03	3	6.58
Shape 4	2.25	2	3.41	3	5.66
Shape 5	2.28	2	4.05	3	6.33
Shape 6	2.25	2	4.13	3	6.38
Shape 7	2.27	2	3.79	4	6.06
Shape 8	2.43	2	3.60	3	6.03
Shape 11	1.84	2	3.92	3	5.76
Shape 12	1.88	1	3.29	3	5.17
Shape 14	2.50	2	3.57	3	6.07
Shape 18	1.75	1	3.25	3	5.00
Other	1.75	1	3.25	4	5.00
Average	2.24	2	3.81	3	6.05

The time given in the table represents the number of hours that is spend on an activity by all involved operators. For example, 3.81 hours that is spend on average on a die changes is a combination of all hours spend by the three involved operators.

It should be noted that the table mentions the average time mechanics spend on the combination of the preparation and the execution of the die change. As we know, there are more activities that the mechanics should perform in order to complete a die change. Based on the data system of the technical service, we could say that these activities combined make up for about 4 hours per combi die change. Therefore, by summing up the total time determined in *Table 14* with 4, we get the total number of hours the mechanics spent on average on a die change. By multiplying this value with the wage of the mechanics, which is equal to 12,520 euro per hour per mechanic, we get the cost related to mechanics. The hours spend on a die change in *Table 14* are based on a mono die change, since the dies in a combi die change are similar, the total time found should be multiplied with 2 and added to the 4 hours of additional tasks. As a result, on average, the mechanics make up for around 201,572 euro of the cost price.

We should note that we do not have data for some of the shapes. The reason is that there was not a single die change for each of these shapes during the time period from 27-3-2018 to 26-3-2019. Therefore, we will take the average number of hours and mechanics of all shapes to represent the data for these shapes.

Cleaning

The final costs related to a die change that have to be measured are that of the cleaning of the dies. Even though the costs of cleaning are not part of the measurement plan, these costs have been observed and do not require a methodology. The costs are based on the data available by the technical service. The costs are multiplied with a random factor for confidentiality reasons.

Currently, cleaning of the die and injection hole, together with the cleaning of the outer ring when required is outsourced for a bit more than 123,635 euro per die. The costs to ship the dies to the company that cleans the die costs around 12,520 euro. Therefore, cleaning the die costs 136,155 euro in total. Additionally, there are some products that are required to clean the dies or to replace the dies in case parts are worn out, these products make up for a cost price of 42,568 euro. In total the cleaning of one die is equal to 178,723 euro. Since almost all die changes are considered to be a combi die change, the total cost of cleaning the dies is equal to a bit more than 357,446 euro.

It should be noted that a cleaning oven has been ordered, such that cleaning of the die does not have to be outsourced anymore. This oven will be installed in late June 2019, but it does not mean that external cleaning is immediately not required anymore. If the oven is present in the company and fully operating, the costs of cleaning will be reduced. However, since the installation of the oven takes places just before the end of this study, measuring the cost reduction will not be part of the study. To let the costs remain reliable, my suggestion is to measure the cost reduction when the oven is used in practice for a couple of months.

Colour and material change

In addition to die changes, colour and material changes play a role in the determination of the order costs. Similar to some aspects of the die change, all relevant data to determine the costs of a colour or material change is part of the measurement plan and is gained by observations.

When a change in colour or material occurs, the production line can still produce. The only cost factors in this case are the waste that is released and the number of FTE operators required to process the change. However, it is expected that the value of additional waste is relatively small compared to the waste that is released during normal production. To check this assumption, data will also be gained related to colour and material changes. The same measurement plan is used, with the contradiction that only one step is involved in the process meaning that only the overall start time and end time are required, together with the amount of waste and the number of involved operators. The average of the obtained data will be used to determine the costs of a colour and material change. One example of data, gained on April 11th, 2019, can be found in *Table 15*.

Table 15: *Example of obtained data by observing a colour change*

Type	Date	Production line	Waste before	Waste after	Waste difference	Time before	Time after	Time difference	#Operators	Remarks
Colour	11-4-2019	215-216	0	514	514	13:10	14:10	1:00	2	RCL > FG/OG

Based on this specific material and colour change, there was 514 kilo of waste involved, with a cost of a bit more than 289,587.6 euro. Additionally, there are 2 hours of FTE involved in the process change. By multiplying this value with the cost price of having an operator for one hour, which is equal to 7,825 euro, we find that the cost price of the FTE operators is equal to 15,650 euro. Combined, this specific combination of a colour and material change makes up for a cost price of 305,237.60 euro.

The following step is to analyse the gained data with the use of pivot tables. As a result, averages for the time spend on a change and the average waste that is released during a change are found and summarized in *Table 16.*

Table 16: Average results for the time and waste spend on a material and colour change

	Time	# FTE	Waste
Colour change	1:05:17	2	170.0714286
Material and colour change	1:45:00	2.666666667	220

Often, a material change is combined with a colour change. As a result we do not have enough data to make some statements about the average time spend on a material change. Therefore, the focus will be on a combination of both a colour and material change. On average there is 220 kilo of waste involved in a colour- and material change, responsible for a cost price of almost 123,948 euro. Additionally, there is on average 4 hours and 40 minutes of FTE involved, which make up for a cost price of 36,517.71 euro. By combining these values, we see that the total cost of having a combined material and colour change is equal to 160,465.71 euro.

Since the results are based on combinations of a colour and material change, we assume that the colour change makes up for 70% of the found cost price and a material change makes up for 30% of the found cost price, because a colour change does have more impact on the waste that is released and the time that is spend on a changeover. The percentages are deducted from the results of *Table 16*.

4.4 Values of the policy parameters

This section answers sub-question *10: What should the policy parameters per product be?* The safety stock, the reorder point and the economic order quantity are considered to be the policy parameters. The values of these parameters will be determined based on the formulas found in the literature, leading to values that are relevant to run the production facility. It should be noted, that the policy parameters will only be determined for products that are considered to be MTS.

4.4.1 Safety stock

Determination of safety stock

The safety stock is based on the safety factor, which in its turn is based on the cycle service level which is a result of the classification. Since the classification is already executed, we already found the target cycle service levels for all of the MTS products. The safety factor is the inverse of the standard normal cumulative distribution of the CSL. As a result, formulas *[4.6]* and *[4.15]* are used to determine the safety stock.

Furthermore, the safety stock depends on the standard deviation of the demand during lead time. This value changes over time, since the demand is dynamic and unstable. The standard deviation represents the standard deviation of the demand data of the last twelve months. By multiplying this value with the square root of L, we find the standard deviation of the demand during lead time.

Finally, if the company decides to take obsolescence into account, another column is added to determine the safety stock with inclusion of obsolescence. With the use of the probability theory, the probabilities found for products being in inventory for less than a year are multiplied with the found safety stocks, that way, a lower safety stock is determined for products that have a probability of facing obsolescence to minimize the chance of obsolescence.

Implementation of safety stock

For each of the MTS products, the safety stock is determined based on formula *[4.6]* and *[4.15].* The safety stock is subject to change when new demand data is included in the model, however, the seasonal index does not influence the safety stock. Additionally, the formulas are implemented for MTO products, however, they will not be executed when the product is considered to be MTO. As a result, we have found 44 safety stocks if the company decides not to take obsolescence into account. Furthermore, another 44 safety stocks are determined in a separate column with inclusion of obsolescence.

4.4.2 Reorder point

Determination of reorder point
The reorder point is based on formula:

$$s = D_L + SS \quad [4.17]$$

As we have seen, the safety stock is already determined. To determine the demand during lead time, the average demand of the last twelve months is taken and multiplied with the seasonal index for which a reorder point is required. This value is rewritten such that it represents a value for demand over a time frame equal to the lead time. Therefore, the following formula is used to determine the demand for a specific month:

$$V_n = \left(\frac{1}{m} * \sum_{i=1}^{m} T_i\right) * F_n \quad \text{for } \forall n \quad [4.18]$$

Where V_n represents the demand for a specific month and n represents the required month, m is equal to twelve and T_i represents the demand of the last twelve months.

Implementation of reorder point
The lead time is considered to be L weeks, the demand during lead time is determined by taking the average demand of the last 12 months, multiply it with the seasonal index for which the month for which parameters are required and multiply it with 12 (months) and divide it by X (the number of periods of L weeks in a year). In a formula this is equal to:

$$D_L = V_n * \frac{12}{X} \quad \text{for } \forall n \quad [4.19]$$

Where n represents the twelve months. That way, we receive the demand during lead time. By summing up this value with the safety stock, we get the reorder point.

The formulas are implemented for all products, but they will only be executed for products that are considered to be MTS. As a result, we found a value for a reorder point for 44 products.

4.4.3 Economic Order Quantity

Determination of economic order quantity
The economic order quantity is based on formula *[4.1]* from paragraph *4.2.1* . The demand is based on the demand of the season and rewritten as a value that represents a whole year with the use of the following formula (where X represents the number of times having the lead time in a year):

$$D = D_L * X \quad [4.20]$$

The order and holding costs are equal to the values found as input parameters. As a result, we find the preferred order quantity when the inventory level drops below the reorder point.

However, the company may decide to take obsolescence into account. If that is the case, formula *[4.11]* from paragraph *4.2.3* will be used to determine the economic order quantity.

Implementation of economic order quantity
Formula *[4.1]* is used to determine Q for each of the MTS products. Besides making use of Q, the company may also decide to produce a number that is already determined in a fixed order.

Therefore, Q serves as indication on the number of products that should be produced and will only be used in case the inventory level drops below the reorder point and there is no fixed order yet.

Besides, Q is determined while taking obsolescence into account. Since there is more data available, formula *[4.11]* may be rewritten as:

$$Q = \sqrt{\frac{2*K*D}{0.72*(cost\ price - selling\ price*\frac{61}{220})}} \qquad [4.21]$$

This formula is implemented in a separate column in the inventory control policy, such that the company is always able to make a decision on whether or not to include obsolescence.

Conclusion

Based on the formulas found in theory, we came up with the parameters relevant for the implementation of the inventory control policy. Explicit values are not mentioned, either for confidentiality and as a result of dynamic values that will change over time, dependent on the ever-changing demand data. The found values should be implemented in the ERP-system indicating whether a product should be produced or whether there is enough inventory available.

4.5 Entering the inventory control policy into the current ERP system

This section focuses on sub-question *11*: *How can the found inventory control policy be entered in current ERP system?* First of all, it is essential to get an understanding of the system and how the inventory control policy is linked in the system. Secondly, it should be determined how the parameters can be entered in the system.

One disadvantage of the ERP-system is that the parameters should be determined outside the system and updated within the system. Therefore, it is impossible to automatically update the parameters within the ERP-system. However, it is important to know how the parameters should be included and how to ease the process of updating the parameters.

The part of the ERP-system explicitly related to the inventory control policy is the planning data of an item. Herein, the reordering policy is chosen. There are four options available, namely:

- Fixed Reorder quantity
- Maximum quantity
- Order
- Lot-for-lot

An example of the tab at which the reordering policy can be filled in can be found *Figure 21*. The grey areas represent parameters that could not be filled in based on the chosen reordering policy.

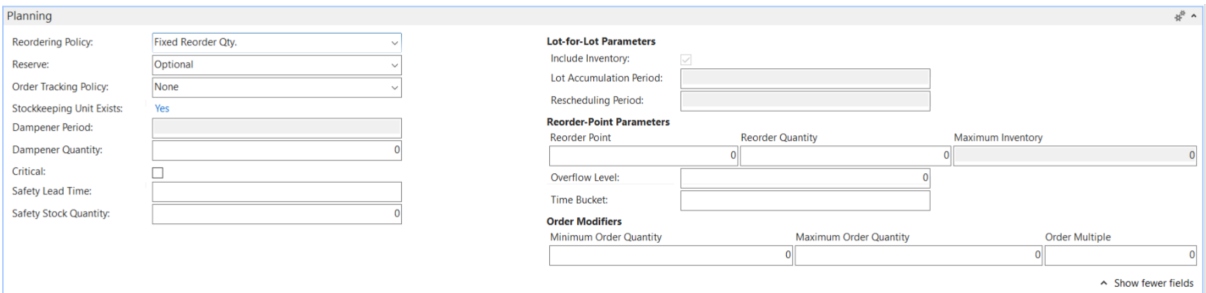


Figure 21: *Example of the planning tab at which the reordering policy could be filled in*

The first option, fixed reorder quantity, is equal to an inventory control policy with a fixed lot size. Within this policy, the reorder point, safety stock and order quantity should be filled in. That way, the planner will be informed when the inventory level drops below the reorder point and will be asked to schedule the product to be produced with the fixed order quantity.

Within the second option, maximum quantity, the maximum inventory level, safety stock and reorder point should be filled in. As a result, the planner is asked to schedule a quantity that increases the inventory to the maximum inventory level when the inventory drops below the reorder point.

The third option, order, only allows to schedule a production run of a product when actually an order is placed. Therefore, there is no value that should be filled in related to the inventory control policy.

The last option, lot-for-lot, requires a safety stock and other lot-for-lot specific parameters. Those are equal to the lot accumulation period and the rescheduling period. This is the most flexible policy, since it only reacts to actual and anticipated demand. It is aimed for products when inventory can be accepted but should be avoided. The lot accumulation period and the rescheduling period are required to define the company's reorder cycle (Microsoft, 2012). The goal of explaining the different options is to gain insight in what policies are available in the current ERP system.

If applicable, it is also possible to implement the minimum and maximum order quantity along with the order multiple. These values are known as the order modifiers. However, since we are producing each item within the company, this part will not be filled.

Although the option of avoiding inventory (lot-for-lot), seems quite interesting, there is chosen to implement the fixed order quantity policy. First of all, because the company should be able to survive the high season, it should already produce inventory in the low season, to avoid having to switch between the production of products a lot, when all demand arrives at the same time. This will give the company more leeway within production. Secondly, the fixed order quantity is chosen instead of the maximum quantity to avoid having the maximum inventory level at all times, which is costly. For example, if the inventory level drops below the reorder point and a fixed order quantity is produced, the inventory level will always be lower than the maximum inventory level, leading to less costs and still being able to attain a certain cycle service level.

As a result, we have to fill in the reorder point, the safety stock and the order quantity which are already determined. However, it is undoable to fill in the parameters manually for each MTS product. Therefore, we have to find a way to implement the parameters for all products at the same time.

There is an option to download an configuration package from the ERP system, which states the products that are part of the ERP system and has different columns representing the order quantity, the reorder point and the safety stock. By filling in this file and uploading it to the ERP system, one does not have to fill all data in into the ERP system separately. There is still one disadvantage, however, the data in the configuration package still has to be filled manually. *Figure 22* gives an overview on what the configuration package looks like.

ITEM_MRP_UPDATE Item 27

No.	Base Unit of Measure	Reorder Point	Reorder Quantity	Safety Stock Quantity	Reordering Policy
100001	KG				
100002	KG				
100003	KG				
100004	KG				
100005	KG				

Figure 22: *Impression of the configuration package*

One way to deal with the problem of having to fill in all parameters manually, is by adding the configuration package to the inventory control policy, which is also in Excel. With the use of VLOOKUP's and if-statements it is possible to fill in the configuration package automatically. Even though this will already simplify the implementation of the parameters in the ERP-system, the file does have to be adjusted in case a new item is added to the company as well as to the ERP-system.

Because it is not yet possible to automate the whole process, it should be checked whether the configuration package has changed each time the parameters have to be filled in. On the other hand, it will already become clear that there are new items if there is demand for a product which is not yet part of the inventory control policy. This will serve as additional indication that the configuration package has changed.

Besides uploading the data on item level, it is also preferred to update the parameters on a warehouse level. For that purpose a new configuration package will be made. The different steps on how to make a configuration package within the ERP system are given in *Appendix L*.

After following the required steps, we gained a configuration package called SKU_MRP_UPDATE of which an overview is given in *Figure 23*.

SKU_MRP_UPDATE Stockkeeping Unit 5700

Location Code	Item No.	Variant Cod	Reorder Poin	Maximum Inventor	Reorder Quantit	Safety Stock Quantit	Replenishment Systen	Reordering Polic	Transfer-from Cod
	100001								
	100002								
	100003								
	100004								
	100005								
	100006								
	100007								
	100008								
	100009								
	100010								
	100011								
	100012								
	100013								
	100014								
	100015								
	100016								
	100017								
	100018								
	100019								
	100020								

Figure 23: *Overview of the configuration package to update the parameters on a warehouse level*

Now that the configuration package is made, the next step is to fill in all fields. First of all, Location Code Location 3 is a location at the company which uses the products of Yarns as intermediate products and is part of a production facility that produces other products. The relevant parameters for this location are already filled in and so on we will not bother in changing these values, which leaves us with two important location codes, namely: Location 1 and Location 2.

Secondly, three fields should already be filled in and are not subject to change, namely: *Location Code, Item No.* and *Replenishment System*. Thereafter, the *Transfer-from Code* can easily be updated. Only Location 1 is able to produce products, thus, if the replenishment system is equal to Transfer, the *Transfer-from Code* should equal Location 1.

Since we only want to have inventory for MTS products, we set the Reordering Policy of MTS products equal to *Fixed Reorder Qty.* If a products is considered to be MTO, the *Reordering Policy* will be set as Order. This field will automatically be updated with the use of if-statements. As a result of using the fixed reorder quantity policy, we do not have to fill in the field of Maximum Inventory, therefore, this field is filled with zeroes for all products.

This leaves us with updating the reorder point, reorder quantity and safety stock quantity. Location 2 only stores products before they are send to the customers. To ensure that there is enough inventory available, the reorder points as found *Section 4.4.2* will be added to Location 1 if a product appears to be MTS, with the use of VLOOKUP's and if-statements. If the inventory level drops below reorder point, we want to send a full truck with products to Location 2, therefore, the order quantity for each of the MTS products at Location 2 is set at the value of a full truck load. That way, we avoid sending half-full trucks to the location.

To ensure that we are always able to send a full truck load to Location 2 we set the reorder points of MTS products at Location 1 equal to the value of a full truck load. Lastly, to ensure that the determined order quantities are produced, we set the order quantities at Location 1 equal to the order quantities for MTS products as found in *Section 4.4.3* with the use of VLOOKUP's and if-statements.

The last field that has to be updated is that of the safety stock. The safety stocks as found in *Section 4.4.1* are added to the MTS products stored at Location 2 with the use of VLOOKUP's and if-statements. That way, there is always enough inventory available and the production facility Location 1 has more space to temporarily store MTO products.

Now that the configuration package is added to the inventory control policy, it will automatically update the relevant fields in case the parameters change. By importing this configuration package to the ERP system, the parameters are also updated in the ERP system. This is done by validating and applying the configuration package to the ERP system. Thus, by uploading the data of the configuration packages to the ERP-system the inventory control policy is implemented.

4.6 Conclusion

This chapter answers sub-question *7* up to and including sub-question *11*.

The first question answered in this chapter is: *Are there requirements or restrictions involved to implement an inventory control policy?* There are four factors that may play an important role while developing the inventory control policy, namely: obsolescence, different selling prices, seasonality and outliers. Each factor can play a significant role when it comes to the determination of the parameters, therefore, these factors should be kept in mind while developing the inventory control policy. We should note, however, that obsolescence does not necessarily have to play a role in the development of the inventory control policy, since the parameters are only determined for MTS products. If all the products for which there is obsolescence appear to be MTO products, then obsolescence does not have to be taken into account. Therefore, we should determine whether obsolescence plays a role in the determination of the inventory control policy after the products have been classified.

The second question discussed during this chapter is: *How can we use existing data to develop the inventory control policy?* For that purpose, we first give a general overview of the model that is used to develop the inventory control policy, followed by the classification of the products. Thereafter, outliers, obsolescence and seasonality are included. Finally, it is determined whether a Normal distribution can be assumed, since the formulas for the inventory control policy are based on a Normal distribution. For each of the different aspects, a conclusion will be given.

The products are classified based on the ABC-XYZ classification. However, there are some products that always will be classified as MTS as a result of being an intermediate product, namely products: 100104, 110047, 110176, 110208, 110211, 110242, 110244, 110245 and 110326. Additionally, the differentiation between Y and Z is adjusted, such that products are considered to be classified as Y if they had demand in 6 to 9 months of the past 12 months and are considered to be classified as Z if there was demand in less than 6 months of the past 12 months. Based on the ABC-XYZ classification, products that are classified as AX, AY, BX, BY and CX will be labelled as MTS and receive a target CSL corresponding to their classification. As a result, 44 products are classified as MTS. Besides, it can be concluded that obsolescence should be taken into account since there are 7 products classified as MTS having some products in inventory for over a year.

For two MTS products there are outliers in 2018 that should be removed when the parameters of the inventory control policy are determined. Furthermore, it is found that obsolescence does play a role for some of the products. It is decided to take obsolescence into account by using a different formula for Q and by using the probability theory, where the probabilities are based on the chance of being in inventory for over one or two years. The found probabilities for a product being in inventory for more than a year are multiplied with the safety stock, leading to a lower safety stock, and therefore, also influencing the reorder point. Besides, we have checked whether seasonality plays a role. To gain a global overview of the products, general pattern information and demand certainty of products are determined, giving insight on what season a product might follow. To actually determine whether there is a season involved seasonal subseries plots are made. As a result it is found that seasonality has to be included in the inventory control policy, which is put into practice by introducing seasonal indices as described by Silver et al (2017). However, since the seasonal subseries plots were not always clear, also Chi-Square test have been executed to check whether the seasonal indices should actually be taken into account while determining the policy parameters. It appeared that only for 8 MTS products, the seasonal indices should be included.

To determine whether a Normal distribution for the demand of the products can be assumed, we include a rule-of-thumb that a product follows a Normal distribution in case the mean demand during lead time exceeds 10. It can be assumed that the demand of each of the MTS products follows a Normal distribution. As a result, we can use the inventory control policy as found in literature and as described during this chapter.

The third questions handled in this chapter is: *What should the values of the input parameters be?* The input parameters consists of the lead time, the holding costs and the order costs. The lead time for all products is fixed and equal to L weeks. For each of the products, the holding costs are assumed to be 22% of the total cost price per annum, while we keep in mind that the actual holding costs may be lower in practice. The order costs depend on the die changes as well as a colour or material changeover. The costs of a die change depends on several factors, namely: stop time (including waste), waste, FTE operators, mechanics and cleaning of the die. By combining these factors, the cost of a die change is equal to 1,653,282.25 euro. The costs of a colour and material change is found to be 160,465.71 euro, where a colour change represents 70% of the cost price and a material change represents 30% of the cost price. The order costs per product depend on the probabilities found in *Table 5,* which is part of *Section 2.2*, where we do not take die changes into account for tape products. It should be noted that the cost of cleaning, and thus the cost of a die change, will be reduced when the ordered cleaning oven is operational in the company. However, this cost reduction should be measured by the company when the oven is operational for a couple of months.

The fourth question for which an answer has been found in this chapter is: *What should the policy parameters per product be?* The policy parameters consists of the safety stock, the reorder point and the economic order quantity. Based on the formulas found in theory, we came up with the parameters relevant for the implementation of the inventory control policy. Explicit values are not mentioned, either for confidentiality and as a result of dynamic values that will change over time, dependent on the ever-changing demand data. An overview of the differences between the formulas of the proposed policy compared to the current policy can be found in *Table 17.*

***Table 17:** Differences between the formulas of the policy parameters for the current model as well as the proposed model*

	Current model	Proposed model
Safety stock	$SS = z * \sigma_L$	$SS = z * (\sigma * \sqrt{L}) * p_1$
Safety factor	$z = \phi^{-1}(CSL)$	$z = \phi^{-1}(CSL)$
Standard deviation of demand during lead time	$\sigma_L = \sigma_D * \sqrt{L * \left(\frac{12}{52}\right)}$	$(\sigma * \sqrt{L}) = \sigma_D * \sqrt{L * \left(\frac{12}{52}\right)}$
Reorder point	$s = SS + D_L$	$s = SS + D_L$
Demand during lead time	$D_L = \frac{D}{52} * L$	$D_L = V_n * \frac{12}{X}$ $V_n = \left(\frac{1}{m} * \sum_{i=1}^{m} T_i\right) * F_n$ for $\forall n$
Economic order quantity	$Q = (\frac{2KD}{h})^{\frac{1}{2}}$	$Q = \sqrt{\frac{2 * K * D}{(\rho + q) * (p - sv[\left(\frac{q}{\rho} + q\right)]}}$

The last question discussed during this chapter is: *How can the found inventory control policy be entered in current ERP system?* There are four different options available within the ERP system, namely: Fixed Reorder quantity, Maximum quantity, Order and Lot-for-lot. There is chosen to implement a fixed order quantity policy, where the reorder point, the safety stock and the order quantity have to be filled in into the ERP system. The update of the parameters will be executed with the use of configuration packages, which are Excel files that have to be filled in and uploaded to update all parameters.

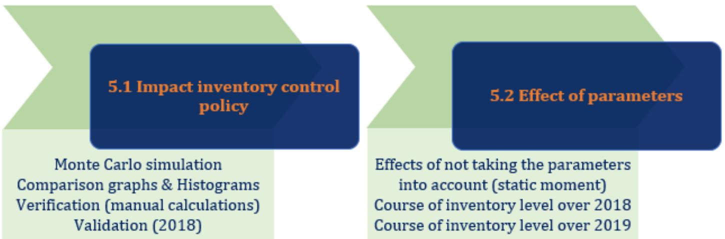
As a result of *Chapter 4,* an inventory control policy has been implemented in Excel. A manual has been written to describe which actions the user of the model should take in order to use the model correctly. This manual is given in *Appendix M*.

5. Analysis of results

This chapter is all about comparing the proposed model with the current model and to validate the proposed model. To compare the proposed model with the current inventory control policy, a Monte Carlo simulation is made. The results are compared based on costs, graphs and histograms, which will be explained during this chapter. To validate the proposed model, the inventory level of the 1st of January in 2018 is taken in the Monte Carlo simulation. As a result, the course of the proposed model can also be simulated with the use of the actual demand of 2018. If the costs based on the actual demand fall within the range of the Monte Carlo simulation, we can assume that the Monte Carlo simulation represents realistic values and is validated.

Furthermore, it may be the case that the current model is not complied with in practice. As a result, the differences between the proposed model and practice are not clear by only using a Monte Carlo simulation. Therefore, we look at a static point in time to see what the costs of the proposed model, the current model and the costs in practice probably will be. That way, we will check the influence of not taking the reorder points and economic order quantities into account.

Finally, the practical course of 2018 is also simulated with the use of actual demand and output of the production facility to see whether the company is using the parameters as they are currently available. With the already simulated course of the proposed model and current model, the results can be compared. Besides, the course of the inventory level is also simulated for the time period of January to May 2019 to look at the most up-to-date data. With the results found, an indication of the relevance of the parameters is given. The following flow chart represents a short summary of the aspects that are handled during this chapter and their consecutive order.



5.1 Impact inventory control policy

This section will focus on sub-question *12: What is the impact of implementing the proposed inventory control policy based on a simulation model?* As mentioned before, we will use a Monte Carlo simulation to determine the impact of the proposed model compared to the current model in terms of costs. A description on how to develop a Monte Carlo simulation is already part of *Section 3.4*, thus, this section will focus on the actual development of the Monte Carlo simulation followed by the results.

5.1.1 Monte Carlo simulation

The implementation of the model takes place in Excel. Determining the upper and lower limits of the probabilities for each of the products takes quite some time. Since we will only hold inventory for MTS products, we only execute the Monte Carlo simulation for these products, which limits the number of products included to 44. For each of the 44 MTS product a histogram of the past demand data is made. Based on these histograms, the probabilities and lower and upper limit of these probabilities could be determined, of which an example can be found in *Table 18*.

As said before, a random number between zero and one is generated to determine the random demand for a period. For example, if the random number appears to be 0.77, based on *Table 18*, the random demand data should be equal to Value 7. For each period, a new random number is generated, ensuring that every period has a different random demand level.

Table 18: *Example of found probabilities*

100021	x_i	Probability	Lower limit	Upper limit
Value 1	1	0.01	0.00	0.01
Value 2	8	0.09	0.01	0.10
Value 3	9	0.10	0.10	0.21
Value 4	16	0.18	0.21	0.39
Value 5	12	0.14	0.39	0.53
Value 6	15	0.17	0.53	0.70
Value 7	13	0.15	0.70	0.85
Value 8	6	0.07	0.85	0.92
Value 9	4	0.05	0.92	0.97
Value 10	3	0.03	0.97	1.00
$\sum x_i$	87			

Next up, formulas [3.5] up to [3.12] are used to implement the model. To determine the beginning inventory for the first period, data is obtained indicating the inventory level of the 1st of January 2018. All other relevant input data is already determined in *Chapter 4*, with exception of the stockout costs. The stockout costs for this specific company mainly consists of the cost of lost sales and is in consultation with the service cost centre assumed to be 24.3 percent of the costs price per annum for all products. *Table 19* summarizes all important input data which are not subject to change.

Table 19: *Fixed input parameters*

Input data	Value
L	L weeks
c_h	22 percent of the cost price
c_s	24.3 percent of the cost price

The cost price and order costs are product-dependent and may differ among the MTS products. All other factors depend on the model and are subject to change.

To actually run the model, we have to determine the run length and number of replications required to give feasible results. To set up the model, periods of L weeks are included to ease the inclusion of lead time. These periods equal the length of each discrete time in the simulation. Since we want to simulate demand data for one year, either for validation purposes, there will be $52/X$ periods in total. As a result, the total run length of the Monte Carlo simulation is equal to one year.

Next up, we have to determine the number of replications, which requires more work. For that purpose, the number of replications will be found in *Section 5.1.2*, with the use of the methodology as described in *Section 3.4*. If the number of replications is found, we are able to replicate the model and store the data with the use of a data table. To implement the data table, one can use a What-If Analysis in Excel. Furthermore, graphs and histograms could be made to draw conclusions. Per replication, the average cycle service level and total costs of all thirteen periods are taken. The average value of all replications is the value that is most likely to happen. We should note that the graph is only used to compare different options, therefore, the graph will only consist of two data points.

Besides, for each of the replications we get a value for the total costs and a value for the cycle service level. By determining the histogram for these results, we see the range in which the results probably will be and a smaller range of the values for the total costs which are most likely to occur independent of the random demand. An example of a histogram for an individual product can be found in *Figure 24*. The orange bars represent the total costs and the green bars represent the cycle service level. The x-axis respectively represents the values for the cost ranges and the values for the cycle service level ranges. The y-axis indicates the frequency of all replications that falls within this range. Such histograms will be used in the rest of the discussion.

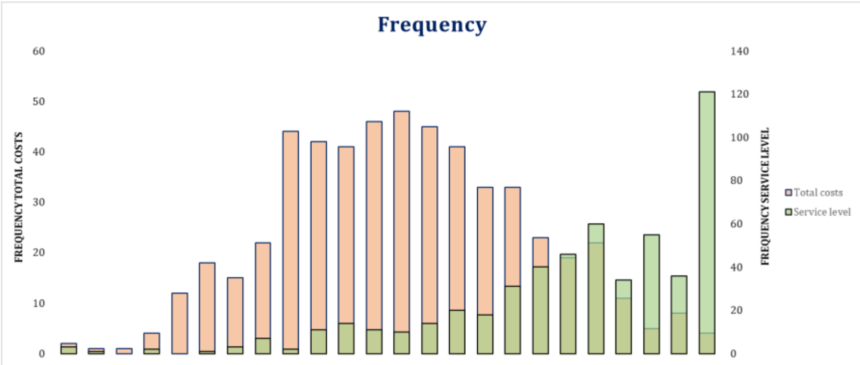


Figure 24: *Example of a histogram based on the results of the replications of the Monte Carlo simulation*

Based on this example, we see that the expected value for the total costs lies in the middle of all ranges and the expected value of the cycle service level is close to the maximum value found. Whereby the frequency of the total costs is more widely spread over the ranges, meaning that there is more variance over the different replications. Furthermore, we see that while the demand frequencies show a normal distribution, the cycle service level shows a skewed distribution. This shows how different they are in nature.

An overview of the dashboard of the implemented Monte Carlo simulation with exception of the graphs and histograms can be found in *Appendix N*.

5.1.2 Number of replications

To actually determine the number of replications, we have to gain data from the simulation model. First we will replicate the Monte Carlo simulation 1500 times assuming that this number will cover the required amount of replications. The total costs found for each replication are included to determine the moving average and moving variance of the data. The confidence interval that is taken into account is equal to 95% and the relative error allowed is said to be 0.05. As a result, there are enough replications when the found error is constantly below $\frac{0.05}{(1+0.05)} = 0.0476$. One example of the determination of the number of replications can be found in *Figure 25*, for which the values of the moving average, moving variance and t-value are hidden because of confidentiality reasons. As a result, for this specific product, 8 replications are already sufficient to provide reliable results of the Monte Carlo simulation.

n	Data Monte Carlo	Mean	Var	Tvalue	Error	Test
1						
2					0.28075	NOTOK
3					0.09226	NOTOK
4					0.06278	NOTOK
5					0.0595	NOTOK
6					0.06102	NOTOK
7					0.05632	NOTOK
8					0.04721	OK
9					0.04293	OK
10					0.03777	OK
11					0.03445	OK
12					0.03552	OK
13					0.03238	OK
14					0.02976	OK
15					0.02765	OK

Figure 25: *Example of the determination of the number of replications*

For the current inventory control policy as well as for the proposed inventory control policy, the number of required replications are determined for each MTS product. The number of replications that is used in the final model is the maximum value of the number of replications found for all individual MTS products. The results for the number of required replications for each of the MTS products can be found in *Table 20*.

Table 20: *Number of replications required per MTS product*

	Current model	Proposed model	100099	42	294	110110	198	35
Item	Nr Replications	Nr Replications	100104	82	492	110117	345	281
100004	**104**	55	100122	405	43	110176	39	31
100005	129	103	100124	135	226	110208	13	208
100007	323	462	110002	329	18	110211	34	42
100009	38	22	110007	143	268	110224	248	57
100021	196	120	110009	336	312	110225	276	288
100022	297	238	110010	59	19	110239	110	247
100023	10	19	110011	182	63	110242	348	369
100024	499	420	110018	193	313	110244	162	68
100025	8	15	110019	18	67	110245	7	44
100026	35	22	110020	255	478	110323	99	97
100027	89	97	110028	337	406	110324	169	177
100032	98	52	110030	296	496	110326	97	34
100038	101	540	110036	171	242	110332	32	47
100040	31	377	110047	383	396			

Based on the results, it is found that 540 replications are required to give reliable outcomes for the Monte Carlo simulation for each of the products. The number of replications can be reduced by extending the run length, however, this is not preferable when the Monte Carlo simulation has to be validated, therefore, there is chosen to let the run length remain one year.

5.1.3 Results of the Monte Carlo simulation

Now that the Monte Carlo simulation is implemented and the number of replications is known, the results of the model can be found. For each MTS product, the model is simulated separately. First, the model is simulated based on the parameters of the current inventory control policy. Thereafter, the same model is simulated based on the parameters of the proposed inventory control policy. If all results are stored, the different models can be compared based on the total costs and cycle service level.

Table 21 gives a summary of the overall results of the Monte Carlo simulation multiplied with a random factor. The overall results represent the sum of all individual results for each of the 44 MTS products, where an individual result is equal to the average of all 540 replications. The results for each MTS product individually can be found in *Appendix O*.

Table 21: *Overall results of the Monte Carlo simulation*

Model	Holding costs	Stockout costs	Order costs	Total costs	CSL
Current	€ 296,015,186.46	€ 35,262,360.90	€ 533,276,651.51	€ 864,554,198.87	0.89
Proposed	€ 250,043,539.95	€ 25,942,159.90	€ 344,458,190.20	€ 620,443,890.05	0.94
Difference	*€ -45,971,646.51*	*€ -9,320,201.00*	*€ -188,818,461.31*	***€ -244,110,308.82***	***0.05***

When we look at the table, we see that the proposed model appears to be cheaper in each possible way. Therefore, we can conclude that even though less inventory is held, it is still possible to fulfil demand. Since the results are not in line with the expectations, we want to compare the order quantities and reorder points for all MTS products. The results can be found in *Appendix P*.

If we compare the reorder points and economic order quantities of both models, we see that in general Q is higher for the proposed model when it appears to be an Type 2 product, in case of a Type 1 product, Q is in general lower. Besides, the reorder points for the proposed model are lower in general for all products, leading to lower inventory levels. Therefore, we can conclude that the reduction in holding costs are caused by lower reorder points, but that the longer production runs for MF products ensure that the company is still able to fulfil demand with less order costs, since the demand of Type 2 products are in general higher than the demand of Type 1 products. The only disadvantage of the proposed model compared to the current model is that there is more spread in the overall cycle service level, however, the maximum costs of the proposed model are always below the maximum costs of the current model, which outweighs the difference of the cycle service level.

To actually check how the options are related to each other, comparison graphs are made. Actual numbers are left out due to confidentiality reasons, however, all figures do have the same scale. First of all, an comparison graph has been made for the overall model to compare the two options. The results of the overall model is the sum of the results of all 44 MTS products. The comparison graph of the overall model can be found in *Figure 26*.

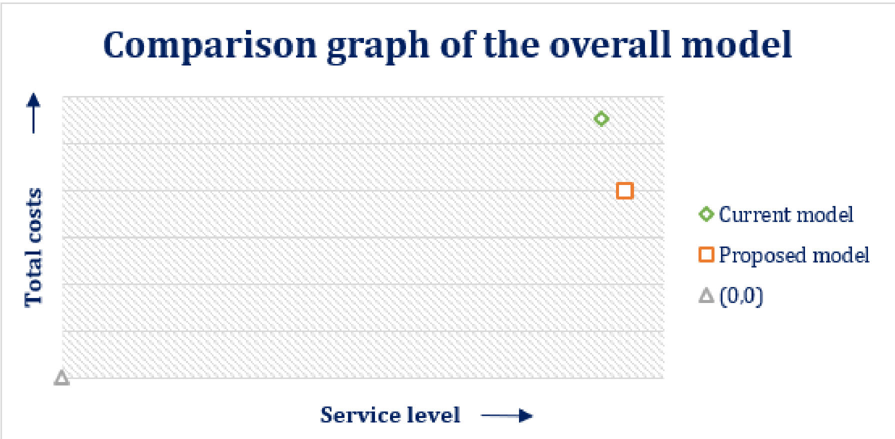


Figure 26: *Efficient frontier of the overall model*

Based on the graph, the proposed model is found to be the most promising model since the result of the proposed model is lower and more to the right compared to the current model, which indicates that the cycle service level is higher in combination with lower costs. Thus, based on the Monte Carlo simulation it is promising to implement the proposed model. To see the differences between the tape and the MF products, also comparison graphs for these products have been made, which can be found in Figure 27.

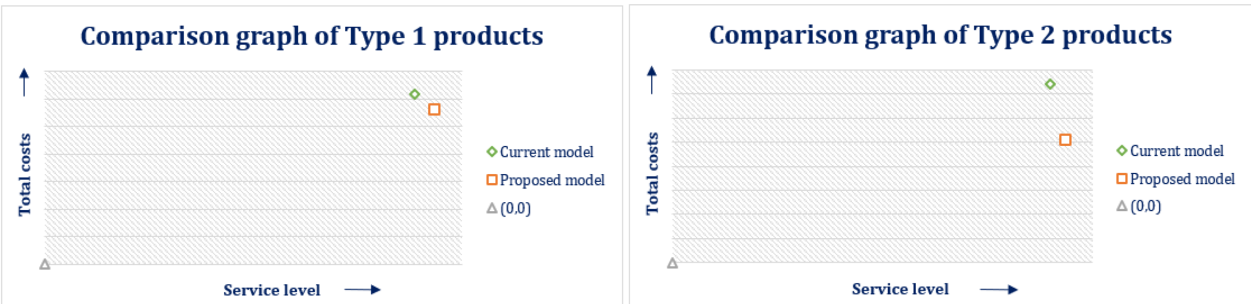


Figure 27: *Efficient frontiers of the Type 1 products as well as the Type 2 products*

The results of the proposed model for the Type 2 products are in line with the results we found for the overall model, and so, for Type 2 products it can be assumed that implementation of the proposed model is promising compared to the current model. However, for Type 1 products, the costs appear to be close to each other. Still, the proposed model still seems to be cheaper in combination with a higher cycle service level, therefore, we can conclude that it remains promising to implement the proposed model. To see whether the costs may differ a lot from the results, histograms of the replications have been made for each of the products.

One example of a histogram can be found in *Figure 28*. For each histogram it holds that the more the spread, the more variance there may be in the outcomes. It should also be noted that the first range starts with the minimum value of the outcomes, which ensures that even though there is a lot of spread, the difference may still be small. Based on the example given in *Figure 28*, we can conclude that there is some spread between the results of the costs for individual replications. The cycle service level is quite certain and the total costs are subject to change with a large probability to fall within the 10th upon the 13th range. All histograms are given in *Appendix Q*.

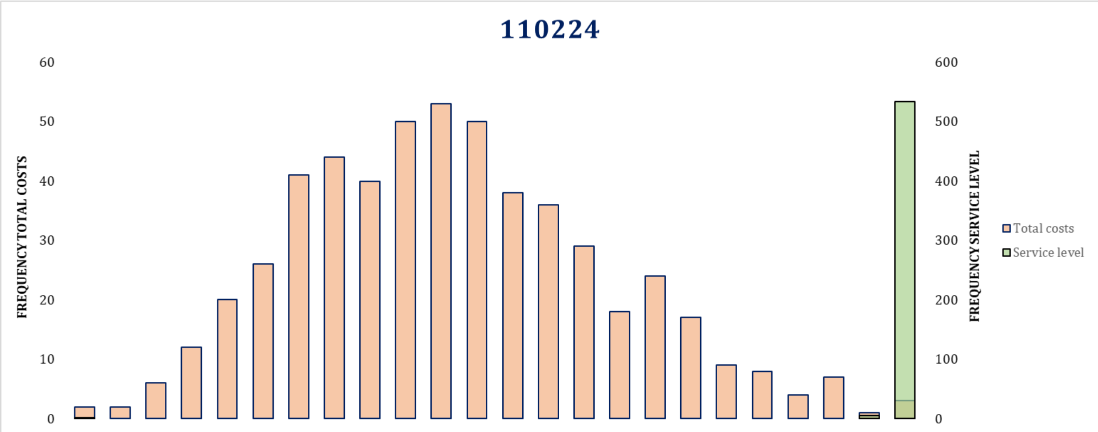


Figure 28: *One example of the results of the replications in a histogram*

The most interesting data that can be extracted from the histograms is the change in histograms for the same product. If the histograms for an individual product look-a-like, the ratio between the results is most likely to be correct. However, when one histogram has way more spread or follows another pattern compared to another histogram for the same product, this means that the ratio between the two options may change. When we compare all histograms of *Appendix Q,* we see that for most of the products the patterns of the proposed model and the current model are similar to each other, especially when one looks at the total costs. However, when we look at the histograms of the cycle service level, we see that for 16 products the histograms of the cycle service level are not completely following the same pattern. Therefore, we may conclude that there is more spread in the cycle service level and, as a result, the difference in outcome may become smaller. This remark is in line with the spread already noted in the cycle service level found for the proposed model. However, since a cost reduction of a bit more than 28 percent is significant, we can still conclude that the proposed model is more promising.

5.1.3 Verification and validation of the Monte Carlo simulation

Verification

To verify the Monte Carlo simulation, we will first calculate some results manually and check whether the Monte Carlo simulation provides the same results. For that purpose, we will calculate the results of two MTS products individually, one product that does have a constant reorder point and order quantity during the entire year and one product that does have changing parameters as a result of including seasonality.

The first product that is calculated manually is product 100004, which has the same parameters during the entire year. To calculate the results manually, we assumed that the beginning inventory was equal to 12.52 million and that the demand of each period is equal to 15.65 million.

The second product for which the results are calculated manually, is product 110332, which is facing different parameters during the year. The beginning inventory is assumed to be 156,500 and the demand during one period is assumed to be 1,565 million. The reorder points and order quantities multiplied with a random factor are similar to the values found in the proposed model and can be found in *Table 22.*

Table 22: *Reorder points and order quantities that are used to calculate the results manually*

100004	Jan	Feb	Mar	Apr	May	Jun
Q	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6
S	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21
	Jul	Aug	Sep	Oct	Nov	Dec
Q	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6	4,911,345.6
S	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21	17,075,142.21
110332	Jan	Feb	Mar	Apr	May	Jun
Q	1,354,638.96	2,722,705.62	8,263,178.09	1,973,928.24	2,744,859.76	3,973,103.06
S	1,055,852.29	1,434,159.74	5,562,185.28	1,195,653.75	1,442,372.86	2,001,982.43
	Jul	Aug	Sep	Oct	Nov	Dec
Q	556,448.27	0	2,030,722.09	2,027,729.81	2,252,272.88	1,282,936.92
S	952,396.40	931,397.23	1,211,078.38	1,210,255.19	1,275,431.18	1,043,025.55

The manually calculated results of product 100004 can be found in *Table 23.* Where *BI* represents the beginning inventory of a period. The manually calculated results for product 110332 can be found in *Table 24.*

Table 23: *Manually calculated results for product 100004 when the proposed policy was used*

Period	BI	Demand	Filled	Stockout	End inv	Order	#Orders	Inv+Ord	C_h	C_s	C_{order}
1	12,520,000.00	15,650,000	12,520,000	3,130,000	0.00	Yes	4	19,645,382.40	0	135,763.75	600,784.72
2	19,645,382.40	15,650,000	15,650,000	0	3,995,382.40	Yes	3	18,729,422.33	156,897.51	0	450,588.54
3	18,729,422.33	15,650,000	15,650,000	0	3,079,420.77	Yes	3	17,813,459.13	120,927.55	0	450,588.54
4	17,813,459.13	15,650,000	15,650,000	0	2,163,458.50	Yes	4	21,808,841.53	84,957.59	0	600,784.72
5	21,808,841.53	15,650,000	15,650,000	0	6,158,841.53	Yes	3	20,892,878.33	241,855.10	0	450,588.54
6	20,892,878.33	15,650,000	15,650,000	0	5,242,878.33	Yes	3	19976,918.26	205,885.14	0	450,588.54
7	19,976,918.26	15,650,000	15,650,000	0	4,326,918.26	Yes	3	19060,955.06	169,915.18	0	450,588.54
8	19,060,955.06	15,650,000	15,650,000	0	3,410,955.06	Yes	3	18144,991.86	133,945.22	0	450,588.54
9	18,144,991.86	15,650,000	15,650,000	0	2,494,991.86	Yes	3	17229,028.66	97,975.26	0	450,588.54
10	17,229,028.66	15,650,000	15,650,000	0	1,579,029.29	Yes	4	21224,411.06	62,008.43	0	600,784.72
11	21,224,411.06	15,650,000	15,650,000	0	5,574,411.06	Yes	3	20,308,450.99	218,902.81	0	450,588.54
12	20,308,450.99	15,650,000	15,650,000	0	4,658,450.99	Yes	3	19,392,487.79	182,932.85	0	450,588.54
13	19,392,487.79	15,650,000	15,650,000	0	3,742,487.79	Yes	3	18,476,524.59	146,966.02	0	450,588.54
Total costs									1,823,168.66	135,763.75	6,308,239.56

Table 24: *Manually calculated results for product 110332 when the proposed policy was used*

Period	BI	Demand	Filled	Stockout	End inv	Order	#Orders	Inv+Ord	C_h	C_s	C_{order}
1	156,500	1,565,000	156,500	1,408,500.00	0	Yes	1	1,354,638.96	0.00	102,761.03	1,241,608.40
2	1,354,638.96	1,565,000	1,354,638.96	210,361.04	0	Yes	1	2,722,705.62	0.00	15,347.64	1,241,608.40
3	2,722,705.62	1,565,000	1,565,000	0	1,157,705.62	Yes	1	9,420,883.71	76,469.03	0	1,241,608.40
4	9,420,883.71	1,565,000	1,565,000	0	7,855,883.71	No	0	7,855,883.71	518,900.79	0	0
5	7,855,883.71	1,565,000	1,565,000	0	6,290,883.71	No	0	6,290,883.71	415,529.41	0	0
6	6,290,883.71	1,565,000	1,565,000	0	4,725,883.71	No	0	4,725,883.71	312,158.03	0	0
7	4,725,883.71	1,565,000	1,565,000	0	3,160,883.71	No	0	3,160,883.71	208,783.52	0	0
8	3,160,883.71	1,565,000	1,565,000	0	1,595,883.71	No	0	1,595,883.71	105,412.14	0	0
9	1,595,883.71	1,565,000	1,565,000	0	30,883.71	Yes	1	2,061,602.67	2,040.76	0	1,241,608.40
10	2,061,602.67	1,565,000	1,565,000	0	496,602.67	Yes	1	2,524,332.48	32,802.40	0	1,241,608.40
11	2,524,332.48	1,565,000	1,565,000	0	959,332.48	Yes	1	3,211,602.23	63,366.85	0	1,241,608.40
12	3,211,602.23	1,565,000	1,565,000	0	1,646,605.36	No	0	1,646,605.36	108,761.24	0	0
13	1,646,605.36	1,565,000	1,565,000	0	81,602.23	Yes	1	1,436,244.32	5,389.86	0	1,241,608.40
Total costs									1,849,614.03	118,108.67	8,691,258.80

To verify the Monte Carlo simulation, we will look at the results of the costs and CSL when the Monte Carlo simulation is used. If the results are similar to the results that are calculated manually, we can assume that the Monte Carlo simulation meets its intended goals and if verified. The results of the Monte Carlo simulation multiplied with a random factor for both product 100004 and product 110332 can be found in *Table 25.*

Table 25: *Results of the Monte Carlo simulation for products 100004 and 110332*

Product 100004						Product 110332					
Period	c_h	c_s	c_{order}	**Total cost**	**CSL**	**Period**	c_h	c_s	c_{order}	**Total cost**	**CSL**
1	0	135,763.75	600,784.72	736,548.47	0.00	1	0.00	102,761.03	1,241,608.40	1,344,369.43	0.00
2	156,897.51	0	450,588.54	607,486.05	1.00	2	0.00	15,347.64	1,241,608.40	1,256,956.04	0.00
3	120,927.55	0	450,588.54	571,516.09	1.00	3	76,469.03	0	1,241,608.40	1,318,077.43	1.00
4	84,957.59	0	600,784.72	685,742.31	1.00	4	518,900.79	0	0	518,900.79	1.00
5	241,855.10	0	450,588.54	692,443.64	1.00	5	415,529.41	0	0	415,529.41	1.00
6	205,885.14	0	450,588.54	656,473.68	1.00	6	312,158.03	0	0	312,158.03	1.00
7	169,915.18	0	450,588.54	620,503.72	1.00	7	208,783.52	0	0	208,783.52	1.00
8	133,945.22	0	450,588.54	584,533.76	1.00	8	105,412.14	0	0	105,412.14	1.00
9	97,975.26	0	450,588.54	548,563.80	1.00	9	2,040.76	0	1,241,608.40	1,243,649.16	1.00
10	62,008.43	0	600,784.72	662,793.15	1.00	10	32,802.40	0	1,241,608.40	1,274,410.80	1.00
11	218,902.81	0	450,588.54	669,491.35	1.00	11	63,366.85	0	1,241,608.40	1,304,975.25	1.00
12	182,932.85	0	450,588.54	633,521.39	1.00	12	108,761.24	0	0	108,761.24	1.00
13	146,966.02	0	450,588.54	597,554.56	1.00	13	5,389.86	0	1,241,608.40	1,246,998.26	1.00
Total	1,823,168.66	135,763.75	6,308,239.56	8,267,171.97	0.92	Total	1,849,614.03	118,108.67	8,691,258.80	10,658,981.50	0.85

When we compare *Table 23* and *Table 24* with *Table 25*, we see that the results for the costs are similar. Besides, we see that the CSL is in line with the stockouts found during the manual calculation. Therefore, we can conclude that the Monte Carlo simulation is free of errors and meets its intended goals, irrelevant whether the parameters change on a monthly basis.

Validation

To validate the Monte Carlo simulation, we simulate the course of the inventory level on a daily basis in case the proposed model or current model was used in practice in 2018, based on the actual demand and the same starting point, namely the inventory level of the 1st of January in 2018.

Since it is very time consuming to simulate the inventory level of all 44 MTS products, there is chosen to simulate the inventory level for products that had a demand of at least a predetermined number during the last twelve months, which holds for products: 100021, 100022, 100027, 110002, 110007, 110028, 110036 and 110224.

Since we know on a daily basis how much is in inventory, it is possible to determine the holding costs. The holding costs on a daily basis are equal to the daily inventory level multiplied with 0.22 and divided with 365, this value is then multiplied with the cost price of a product. When we take the sum of all holding costs, we get the holding costs on a yearly basis. Besides, the Monte Carlo simulation calculates the number of orders that are placed , therefore, we will count the number of orders in the simulated inventory level over 2018. By multiplying this number with the order costs, as found in *Section 4.3.3*, we get the yearly order costs. We should note, however, that different orders that lie close to each other, can be combined into one order in practice, leading to lower order costs.

The results of the values based on the actual demand along with the results of the Monte Carlo simulation for the proposed model multiplied with a random factor for confidentiality reasons can be found in *Table 26*. Followed by the results for the current model in *Table 27*.

Table 26: *Results of the actual values along with the results of the Monte Carlo simulation for the proposed model*

	Values based on actual demand			Monte Carlo simulation			
Item	Holding costs	Number of times Q is added	Order costs	Holding costs - minimum	Holding costs - maximum	Order costs – minimum	Order costs - maximum
100021	€ 11,959,992.92	46	€ 6,909,011.76	€ -	€ 12,294,893.53	€ -	€ 9,762,732.92
100022	€ 8,418,620.15	31	€ 4,656,072.19	€ 975,790.02	€ 8,488,137.45	€ 3,454,505.88	€ 9,161,951.33
100027	€ 8,830,947.57	23	€ 3,454,505.88	€ 4,121,399.33	€ 9,015,623.83	€ 1,652,154.85	€ 5,557,249.27
110002	€ 16,459,039.27	9	€ 11,174,488.12	€ 861,156.90	€ 17,908,626.78	€ 3,724,828.33	€ 17,382,536.38
110007	€ 27,134,714.94	11	€ 11,676,198.95	€ 12,576,681.17	€ 33,120,151.34	€ 6,368,836.36	€ 24,413,868.54
110028	€ 16,787,276.11	15	€ 7,182,749.04	€ 2,150,228.62	€ 17,340,209.39	€ 3,830,800.74	€ 18,675,145.00
110036	€ 17,842,073.59	11	€ 16,274,945.19	€ 1,243,117.06	€ 20,769,647.10	€ -	€ 41,427,130.65
110224	€ 25,511,575.19	22	€ 10,534,697.34	€ 15,231,055.76	€ 28,485,569.73	€ 1,436,551.06	€ 10,534,697.34

Table 27: Results of the actual values along with the results of the Monte Carlo simulation for the current model

	Values based on actual demand			Monte Carlo simulation			
Item	Holding costs	Number of times Q is added	Order costs	Holding costs - minimum	Holding costs - maximum	Order costs – minimum	Order costs - maximum
100021	€ 13,831,801.78	25	€ 3,754,898.24	€ 4,727,210.83	€ 14,843,943.62	€ 3,003,917.34	€ 6,458,423.22
100022	€ 9,722,108.65	16	€ 2,403,135.75	€ 3,219,815.35	€ 16,567,881.89	€ 1,652,154.85	€ 5,857,641.63
100027	€ 9,574,482.20	16	€ 2,403,135.75	€ 5,211,321.67	€ 10,789,588.89	€ 901,173.95	€ 4,055,290.60
110002	€ 16,105,840.68	15	€ 18,624,144.78	€ 6,113,287.51	€ 16,423,416.74	€ 4,966,439.86	€ 29,798,632.90
110007	€ 28,241,899.23	14	€ 14,860,614.00	€ 10,884,687.68	€ 28,489,219.31	€ 7,430,307.00	€ 37,151,538.13
110028	€ 20,587,168.10	12	€ 5,746,197.98	€ 9,910,756.88	€ 23,275,309.13	€ 1,915,400.37	€ 8,619,296.97
110036	€ 17,804,735.82	19	€ 28,111,265.55	€ 3,013,945.86	€ 17,852,164.71	€ 19,234,025.28	€ 73,977,017.90
110224	€ 29,012,955.95	23	€ 11,013,546.65	€ 16,657,387.37	€ 32,243,644.92	€ 957,698.62	€ 11,971,248.40

Based on the results of the values based on actual demand, we see that the found costs all fall within the range of the output of the Monte Carlo simulation. However, it seems that the holding costs of the validation method are often close to the maximum holding costs of the Monte Carlo simulation, which means that the model may be a little too optimistic in terms of holding costs.

We should note that the holding costs are based on the inventory level on a daily basis. To determine the inventory level we assumed that the production facility is able to produce 1,565,000 kilo of one product on a daily basis, which is approximately the highest attainable value when one takes the capacity into account. However, it may be the case that there is less production in practice due to capacity restrictions or problems within the production. As a result, the holding costs will be somewhat lower in practice. Therefore, we still assume that the Monte Carlo simulation represents realistic values as outcome of the model.

Besides, the order costs of the values based on actual demand always fall within the range of the order costs that serve as output of the Monte Carlo simulation. Thus, the order costs of the Monte Carlo simulation are in line with reality.

Another note that should be made is that stockout costs are not taken into account for the validation. The reason is that the inventory level was never equal to or close to zero wit the use of the proposed model or the current model in combination with the actual demand of 2018, which means that there should be no stockouts when the proposed or current model is used. Thus, if the proposed model is completely used in practice based on the demand of 2018, there would have been no stockouts, leading to a CSL of 1, which is equal to the maximum value of all products. So, we are able to conclude that the Monte Carlo simulation represents realistic results.

5.2 Effect of the parameters of the inventory control policy

This section elaborates on sub-question *13: What is the effect of the parameters of the inventory control policy?* We already know that it is promising to implement the proposed model when we compare it to the current model. However, it may be the case that the parameters of the current model are not used in practice. If the parameters of the current policy are not used in practice, we want to see the effect of using the proposed model compared to practice and, thus, see the effects of using the parameters.

Determination of the effects of not taking the policy into account

To see whether the company is following the current policy, we will check whether the current inventory level is at least equal to the determined reorder points. If the inventory level is below reorder point and the product is not scheduled to be produced, we can conclude that the company is not following the current inventory control policy properly. Furthermore, it may be the case that products are in inventory even if they are not considered to be MTS products, which is also in contrast to the inventory control policy and will lead to higher holding costs.

To compare the practical situation with the situation in which the current inventory control policy is fully used, we will determine the holding costs as well as the stockout costs. The holding costs for the practical situation are determined by multiplying the number of products in inventory with 22% of the cost price per annum. For the policy, the holding costs are determined by multiplying the reorder points with 22% of the cost price per annum for each of the MTS products, assuming that this value should always be in inventory. The stockout costs, on the other hand, are based on the sales orders available in the ERP system. The amount of products that cannot be delivered directly from stock will be multiplied with 24.3% of the cost price, assuming that this value represents the stockout costs. By summing up the holding costs with the order costs, we can compare the practical situation to the situation at which an inventory control policy is fully used. If the latter appears to be much cheaper, we can conclude that the company lacks in following the current inventory control policy, which will reduce the costs for the company.

Normally, the order costs also have to be included to determine the total costs. However, it is impossible to determine the order costs since we are looking at one static moment in time at which no orders take place. To compare the order costs, one has to observe how many times products were ordered in a predetermined period and compare it to the results when a policy is fully used. Since we already determined the course of the inventory level over 2018 for both the current model as well as the proposed model while validating the Monte Carlo simulation, we can easily compare it by determining the practical inventory course. For that purpose, we also take the output of production into account. We should note that for the validation of the Monte Carlo simulation, the number of orders that are placed are calculated. However, in practice, a multiplication of Q that is required to get above reorder point is combined into one order. That way, we can compare the current model as well as the proposed model with the actual course of 2018. Since it is undoable to simulate the course of the inventory level on a daily basis for all MTS products, we continue with the eight products that had a demand of at least a predetermined number during the last twelve months.

Implementation of the determination of the effects of not taking the policy into account

Effects resulting from the data of one fixed moment in time

The first step in determining the effects of the policy is to determine the current inventory level. This data is retrieved from the ERP system on the 4th of June. Furthermore, the reorder points and economic order quantities as calculated in the current model are retrieved to check whether the company is following the policy. Since we use an inventory level that is retrieved in June, the parameters used are also calculated for June. By comparing the reorder points with the current inventory level, we see that 24 MTS products do have an inventory level below reorder point and are not following the policy. Based on the current inventory control policy, 41 products are classified as MTS and do have a reorder point in the system. As a result, almost 59 percent of the MTS products do not follow the policy.

Now that we know that the policy is not (fully) used in practice, we want to see the effects on the costs of not following the inventory control policy. As mentioned before, these costs consist of the holding- and stockout costs. These costs are determined for each product individually and summed up to get the total costs of the model.

The holding costs in practice are determined by multiplying the value that is in inventory with 22% of the cost price. For the current model as well as the proposed model, the holding costs are determined by multiplying the reorder points with 22% of the cost price, assuming that this value will always be in inventory. The stockout costs are determined by multiplying 24.3% with the number of products from the sales orders that cannot be fulfilled with the current inventory level. Again, we assume that the inventory level of the current model as well as the proposed model are equal to the reorder points. The results of the holdings costs as well as the stockout costs for all models that are multiplied with a random factor for confidentiality reasons can be found in *Table*

28. As one can see, the order costs are not calculated here, since we cannot determine the number of orders when only looking at one static moment in time.

Table 28: *Results of the comparison between practice and fully implementing the policy*

Total costs	Practice	Current model	Proposed model
Holding costs	€ 591,201,714.81	€ 419,027,519.91	€ 337,805,149.84
Holding costs - MTS	€ 349,416,517.10	€ 419,027,519.91	€ 337,805,149.84
Stockout costs	€ 375,349,947.43	€ 393,002,033.15	€ 467,478,048.17
Stockout costs - MTS	€ 303,201,153.14	€ 217,926,002.73	€ 292,402,014.62
Total costs	€ 966,551,662.24	€ 812,029,553.06	€ 805,283,198.01
Total costs - MTS	€ 652,617,670.24	€ 636,953,522.64	€ 630,207,164.46

By comparing the different options, we see that the cheapest option is that of the proposed model, which mainly results from a reduction in holding costs. The stockout costs, however, appear to be most expensive with the use of the proposed model. If we compare the current model with the proposed model, it makes sense that the stockout costs are higher, since the proposed model holds less inventory and can, therefore, deliver less products directly from stock. However, we only look at one static point in time, meaning that there are opportunities to produce sales orders within a predetermined period, leading to lower stockout costs. Thus, if we look at the total costs and keep in our minds that a reduction in stockout costs is possible, we assume that it is best to follow the proposed model. Following the proposed model could already save the company more than 160 million euro compared to the practical situation.

Since the decision has been made that MTO products should not be in inventory, we also want to compare the models with a focus on the results for MTS products. As a result, we can conclude that not having MTO products in stock already saves the company almost 242 million euro. By only looking at the total costs for MTS products, we see that the differences in costs have become smaller. However, we do see that the proposed model is able to have less inventory in combination with less stockout costs compared to practice, therefore, the proposed model is always a better option compared to practice when we purely look at costs. When we compare the current model with the proposed model, we do see that the stockout costs are way less for the current model, however, this does not overrule the reduction of holding costs when taking the proposed model into account. That way, the proposed model will always be selected to use when we take a possible cost reduction of stockout costs into account and purely look at the total costs.

Another factor that influences the decision on whether or not to use a policy is the cycle service level. Since we already determined the number of products that could not be delivered from stock within a replenishment cycle, we can also determine the cycle service level, which is equal to the fraction of replenishment cycles that end with all the customer demand being met. As a result we find the cycle service levels as represented in *Table 29*.

Table 29: *Cycle service levels*

Cycle service level	Practice	Current model	Proposed model
Total model	0.4441	0.4161	0.3593
Only MTS	0.5510	0.6736	0.6168

As one can see, the cycle service levels are not that high. One of the reasons is that we only look at the inventory and reorder points at one point in time, while the sales orders may also represent orders that do not have to be delivered directly. The company has some weeks to produce the product which are not taken into account, but which can improve the cycle service level. Furthermore, we see that the overall cycle service level of the real time situation is higher than the cycle service level if we have implemented the model. This results from the fact that the company has inventory of MTO products which should not have been in inventory. Therefore, we only have to look at the MTS products to get reliable results and see that the cycle service level of MTS products is higher if we implement one of the models correctly.

When we compare the current model with the proposed model, we see that the current model scores better on the cycle service level. The difference of almost 0.06 is considerable, in favour of the current model. Thus, if the company put a lot of emphasis on the cycle service level, it may still decide to follow the current model instead of the proposed model, even though that will cost them a lot of money. Therefore, a trade-off exists between reducing the costs and attaining a certain cycle service level. Since there is a possibility to improve the cycle service level with the production of products, our suggestion would still be to follow the proposed model when we take the holding and stockout costs into account.

A remark that should be made is that there are 4 products which are not mentioned before, that also represent intermediate products. They are not considered to be MTS, because they are not used in at least six months. However, not having the products in inventory will lead to standstill in the production facility. Therefore, we want to have these products in inventory. The product number belonging to these products are 110045, 110210, 110286 and 110301. Since there is no large number required for these products, we will choose to let these products be exceptions to the model and have one pallet in inventory for each of these products. In that case, we will set the reorder point for these products equal to 500 and the economic order quantity equal to 300.

With inclusion of reorder points and order quantities for each of the four products, we will calculate the new results. These results can be found in *Table 30*.

Table 30: *Final results of the comparison between practice and fully implementing the policy*

Total costs	Practice	Current model	Proposed model
Holding costs	€ 591,201,714.81	€ 419,380,687.20	€ 338,158,317.13
Holding costs – MTS	€ 349,416,517.10	€ 419,380,687.20	€ 338,158,317.13
Stockout costs	€ 375,349,947.43	€ 393,002,033.15	€ 467,478,048.17
Stockout costs – MTS	€ 303,201,153.14	€ 217,926,002.73	€ 292,402,014.62
Total costs	€ 966,551,662.24	€ 812,382,720.35	€ 805,636,362.17
Total costs - MTS	€ 652,617,670.24	€ 637,306,689.93	€ 630,560,331.75

When we compare the results, we only see that the holding costs have changed. The reason is that there are no sales orders for each of the four products at the moment of data collection. Even though the costs of the policy have increased, the overall conclusions remain the same.

To actually see how the different models and practice evolve over time, we will look at the course of inventory on a daily basis for a predetermined period. Since we want to compare the models on a yearly basis, we will simulate the inventory levels on a daily basis with the use of data over 2018. Furthermore, we should note that there is a possibility that the order costs are higher when one of the policies is used, which is also taken into account while comparing the models based on the data of 2018. As a result, we can conclude whether the proposed model should be used in practice, or whether another options seems to be more promising.

Effects resulting from historic data

To see the effect of the model compared to reality, we will look at the inventory level on a daily basis. For that purpose, we have established how the inventory has changed on a daily basis during 2018 based on orders and demand and how it would have changed if we had used the proposed inventory control policy. The course of the inventory level on a daily basis if the policy was fully used is already determined during the validation of the Monte Carlo simulation, with the change that we now combine different orders into one order when possible. The following step is to simulate the course of the inventory on how it went in practice in 2018. Since it is undoable to execute this method for all MTS products, we still focus on the eight products with a demand that is higher than a predetermined number. The results in terms of costs multiplied by a random factor for confidentiality reasons can be found in *Table 31*. The value that is stated above the column of orders costs represents the order costs for the corresponding product. An overview of the course of the inventory levels over 2018 can be found in *Figure 29*.

Table 31: *Results in terms of costs for the course of the inventory level over 2018 for the 8 most demanded products*

100021 € 150,195.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	25,762,664.73	58,266,990.13	0	€ 5,562,534.76	24	3604701.709	9167236.465
Current model	25,762,664.73	31,441,549.68	24,005,746.29	€ 13,831,800.62	11	1652154.95	15483955.57
Proposed model	25,762,664.73	43,100,270.47	19,398,790.46	€ 11,959,991.65	14	2102742.664	14062734.31

100022 € 150,195.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	23,036,706.41	44,067,253.72	1,079,869.72	€ 5,797,117.08	17	2553330.378	8350447.461
Current model	23,036,706.41	16,122,970.89	16,122,970.89	€ 9,722,107.89	14	2102742.664	11824850.55
Proposed model	23,036,706.41	23,139,591.88	13,400,898.11	€ 8,418,619.51	15	2252938.568	10671558.07

100027 € 198,661.68

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	12,184,939.13	18,347,389.87	1,349,868.21	€ 3,775,505.61	17	€ 2,553,330.38	€ 6,328,835.99
Current model	12,184,939.13	19,915,565.45	8,289,303.78	€ 9,574,481.77	13	€ 1,952,546.76	€ 11,527,028.53
Proposed model	12,184,939.13	20,511,541.50	8,209,693.46	€ 8,830,947.33	13	€ 1,952,546.76	€ 10,783,494.09

110002 € 1,241,609.69

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	11,479,966.42	31,645,932.92	1,930,972.12	€ 10,101,402.95	6	€ 7,449,658.14	€ 17,551,061.08
Current model	11,479,966.42	44,669.06	11,479,966.42	€ 16,105,839.40	7	€ 8,691,267.83	€ 24,797,107.23
Proposed model	11,479,966.42	44,885,096.47	11,479,966.42	€ 16,459,040.61	7	€ 8,691,267.83	€ 25,150,308.44

110007 € 1,061,472.51

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	118,636,646.35	88,599,444.22	0	€ 25,499,598.36	15	€ 15,922,087.72	€ 41,421,686.09
Current model	118,636,646.35	36,002,539.96	36,002,539.96	€ 28,241,898.81	4	€ 4,245,890.06	€ 32,487,788.87
Proposed model	118,636,646.35	63,454,836.16	25,832,585.05	€ 27,134,715.22	6	€ 6,368,835.09	€ 33,503,550.31

110028 € 478,849.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	40,866,114.77	4,682,341.34	284,830.00	€ 9,614,388.00	8	€ 3,830,799.24	€ 13,445,187.23
Current model	40,866,114.77	26,008,620.04	21,567,681.67	€ 20,587,167.34	10	€ 4,788,499.05	€ 25,375,666.39
Proposed model	40,866,114.77	26,777,627.90	10,732,019.16	€ 16,787,274.72	10	€ 4,788,499.05	€ 21,575,773.76

110036 € 1,479,540.33

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	36,772,095.74	46,503,783.44	0	€ 10,918,553.31	9	€ 13,315,863.00	€ 24,234,416.30
Current model	36,772,095.74	46,425,759.57	27,370,396.54	€ 17,804,735.95	11	€ 16,274,943.66	€ 34,079,679.62
Proposed model	36,772,095.74	40,634,429.66	22,765,814.22	€ 17,842,072.85	6	€ 8,877,242.00	€ 26,719,314.85

110224 € 478,849.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	24,484,528.92	619,321.83	0	€ 7,417,567.73	13	€ 6,225,048.76	€ 13,642,616.50
Current model	24,484,528.92	34,487,223.34	7,192,626.34	€ 29,012,954.77	11	€ 5,267,348.95	€ 34,280,303.72
Proposed model	24,484,528.92	35,793,115.00	6,666,179.05	€ 25,511,575.98	9	€ 4,309,649.14	€ 29,821,225.12

	Holding costs	Order costs	Total costs
Practice	€ 78,686,667.80	€ 55,454,819.32	€ 134,141,487.12
Current model	€ 144,880,986.55	€ 44,975,393.92	€ 189,856,380.47
Proposed model	€ 132,944,237.86	€ 39,343,721.09	€ 172,287,958.96

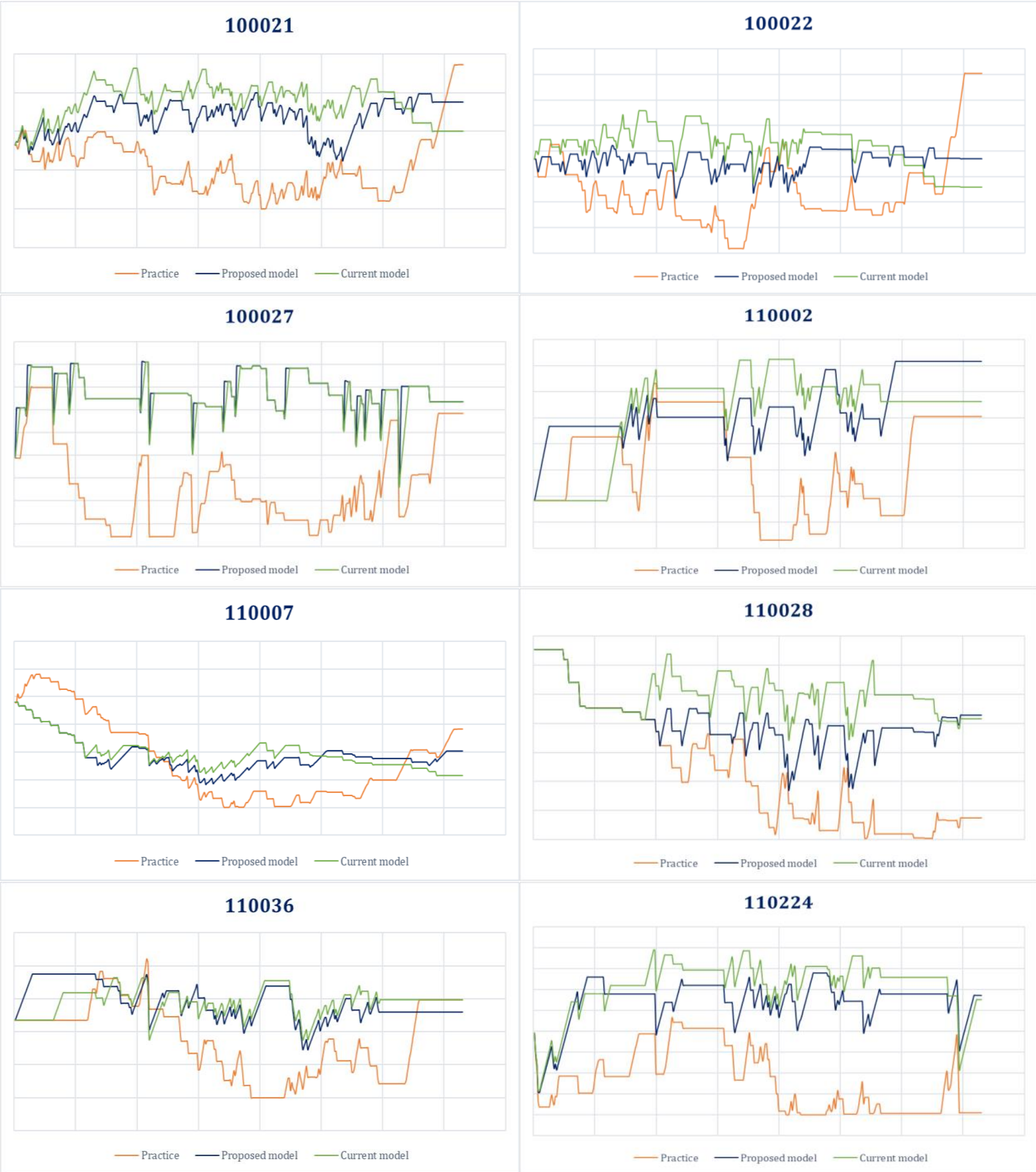


Figure 29: *Overview of course of the inventory level on a daily basis for 2018 for the 8 most demanded products*

Based on the results, we can conclude that the cheapest option is to keep it the way it is, mainly as a result of having low holding costs. However, the stockout costs are not taken into account, which may cause another option to be more promising. When we look at *Figure 29*, we see that the chance of facing a stockout is extremely small in case the proposed model or the current model is fully used, since there is always a buffer of inventory available. However, when we look at the practical course of the inventory level over 2018, we see that there is always a period that the inventory level is close to or equal to zero. To check this assumption, also the minimum inventory level is added to the results of *Table 31*. The maximum value that is ordered for a product in one day is equal to 2,817,000, therefore, each value that is below 2,817,000 is highlighted in grey meaning that there is a chance of facing a stockout. We see that for each of the 8 products there is a chance of facing a stockout when we look at the practical situation, however, we cannot check whether the company actually had lost sales or was not able to comply with agreements, since they do not keep track of such data. For example, when the company postpones the delivery date of a product that has been agreed on with customers, they do not see it as a stockout, but they see it as demand that is demanded in a later stage. Since they do not take notes of such postponements, there is no data available to see the influence of not having the products in inventory and trace it back in a later stage. As a result, stockout costs cannot be determined, because there are no specific values available.

Furthermore, it appears that the order costs can be reduced with more than 10 million euro when one of the policies is used. On the other hand, there are two products for which the order costs appear to be more expensive with the use of a policy, namely for products 110002 and 110028. Both products combined are responsible for difference of a bit more than 2,199,000 euro, however, compared to the total difference we consider the difference to be irrelevant. Based on the total order costs, less die changes are required, the company can produce longer production runs and do not have to switch between a lot of products at all times. Therefore, it is also more desirable to follow the policies to make it run smoother in production and have less unnecessary changeovers that take a lot of work.

This leaves us with two questions. The first question is whether the difference of more than 38 million in total costs between practice and the proposed model can be overruled with the difference between the stockout costs and better working conditions within the production facility. The second question is whether we have the same results when we simulate the course of the inventory level for all 44 MTS products.

To see whether we gain similar results when we look at the latest available data, we will execute the same method for a time period between January and May of 2019. The results in terms of costs multiplied by a random factor for confidentiality reasons can be found in *Table 32.* An overview of the course of the inventory levels over the first months 2019 can be found in *Figure 30*.

In contrast to the results found over 2018, we see that following a policy costs more in terms of holding costs as well as in terms of order costs. However, the difference in order costs is extremely small. Since the high season has only started, the effects of switching a lot between products to survive the high season is not visible yet. Still, we can conclude that the chance of facing a stockout is only considerably present when one follows the practical situation. Thus, if a company want to avoid facing seasons, it is suggested to follow one of the policies, where the proposed model seems to be more promising.

In *Figure 30* we see that there are 4 products in the practical situation that do not have a buffer to survive the high season, namely products: 110002, 110007, 110036, 110224. Because there is also a need to schedule MTO production orders within a predetermined period when the order arrives, it is desirable to have a buffer available for MTS products to be able to fulfil all demand during a period. Therefore, it is suggested to follow the proposed model, even though that is more costly, especially in terms of holding costs.

A remark that should be made is that within the simulation of the policies it is assumed that the required products can be produced at all times. However, in practice, it may be the case that they are not able to produce the required order quantity or that they have to finish orders sooner as a result of capacity restrictions or quality issues. As a result, the holding costs can be lower in practice and the order costs may be somewhat higher to produce all required products. Altogether, we cannot say with certainty whether the cheapest option is to keep going the way it is or to follow the proposed model. While keeping in mind that the ultimate goal is to deliver the products to customers within a reasonable timeframe, it is suggested that the company follows the proposed model.

Table 32: *Results in terms of costs for the course of the inventory level over 2019 for the 8 most demanded products*

100021 — € 150,195.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	58,266,990.13	62,863,108.32	37,662,253.49	€ 9,721,680.79	8	€ 1,201,567.24	€ 10,923,248.03
Current model	58,266,990.13	56,226,507.09	35,023,565.56	€ 8,590,323.16	6	€ 901,175.43	€ 9,491,498.59
Proposed model	58,266,990.13	43,622,223.64	31,536,388.52	€ 7,513,474.47	4	€ 600,783.62	€ 8,114,258.09

100022 — € 150,195.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	34,941,340.59	40,065,473.98	14,218,230.13	€ 5,413,831.50	4	€ 600,783.62	€ 6,014,615.11
Current model	34,941,340.59	26,326,843.57	21,835,272.64	€ 5,265,798.91	6	€ 901,175.43	€ 6,166,974.34
Proposed model	34,941,340.59	21,695,771.27	16,659,607.48	€ 4,371,391.94	7	€ 1,051,371.33	€ 5,422,763.27

100027 — € 150,195.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	18,347,389.87	22,474,586.47	10,852,312.84	€ 4,108,662.88	5	€ 750,979.52	€ 4,859,642.41
Current model	18,347,389.87	24,731,623.31	14,115,340.43	€ 3,917,613.21	7	€ 1,051,371.33	€ 4,968,984.54
Proposed model	18,347,389.87	19,883,103.18	12,207,721.44	€ 3,686,317.46	7	€ 1,051,371.33	€ 4,737,688.79

110002 — € 1,241,609.69

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	31,645,932.92	10,583,897.81	10,583,897.81	€ 5,222,837.34	1	€ 1,241,609.69	€ 6,464,447.03
Current model	31,645,932.92	37,123,823.39	26,329,506.16	€ 6,983,504.32	4	€ 4,966,438.76	€ 11,949,943.08
Proposed model	31,645,932.92	32,700,826.28	22,515,347.61	€ 7,471,402.74	3	€ 3,724,829.07	€ 11,196,231.81

110007 — € 1,061,472.51

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	88,599,444.22	6,139,405.17	499,942.38	€ 8,795,562.40	6	€ 6,368,835.09	€ 15,164,397.49
Current model	88,599,444.22	53,942,651.95	46,063,046.26	€ 12,248,893.51	6	€ 6,368,835.09	€ 18,617,728.60
Proposed model	88,599,444.22	48,701,338.82	35,782,277.16	€ 10,385,620.38	4	€ 4,245,890.06	€ 14,631,510.44

110028 — € 478,849.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	4,682,341.34	27,681,165.25	2,355,586.98	€ 1,910,817.41	5	€ 2,394,249.52	€ 4,305,066.93
Current model	4,682,341.34	33,686,466.57	3,564,591.08	€ 4,584,961.95	5	€ 2,394,249.52	€ 6,979,211.48
Proposed model	4,682,341.34	23,188,534.85	4,682,341.34	€ 6,374,300.43	5	€ 2,394,249.52	€ 8,768,549.95

110036 — € 1,479,540.33

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	46,503,783.44	15,680,595.75	131,147.00	€ 4,470,425.18	3	€ 4,438,621.00	€ 8,909,046.17
Current model	46,503,783.44	54,794,009.15	28,858,479.18	€ 7,469,497.02	6	€ 8,877,242.00	€ 16,346,739.02
Proposed model	46,503,783.44	59,298,310.93	28,858,479.18	€ 6,860,962.42	3	€ 4,438,621.00	€ 11,299,583.42

110224 — € 478,849.90

	Beginning inventory	Ending inventory	Minimum inventory	Holding costs	#Orders	Order costs	Total costs
Practice	619,321.83	1,288,215.47	619,321.83	€ 1,191,567.76	4	€ 1,915,399.62	€ 3,106,967.38
Current model	619,321.83	42,172,375.07	619,321.83	€ 10,663,568.53	4	€ 1,915,399.62	€ 12,578,968.14
Proposed model	619,321.83	34,301,177.65	619,321.83	€ 9,889,579.64	4	€ 1,915,399.62	€ 11,804,979.26

Practice	€ 40,835,385.25	€ 18,912,045.30	€ 59,747,430.55
Current model	€ 59,724,160.60	€ 27,375,887.17	€ 87,100,047.78
Proposed model	€ 56,553,049.48	€ 19,422,515.55	€ 75,975,565.03

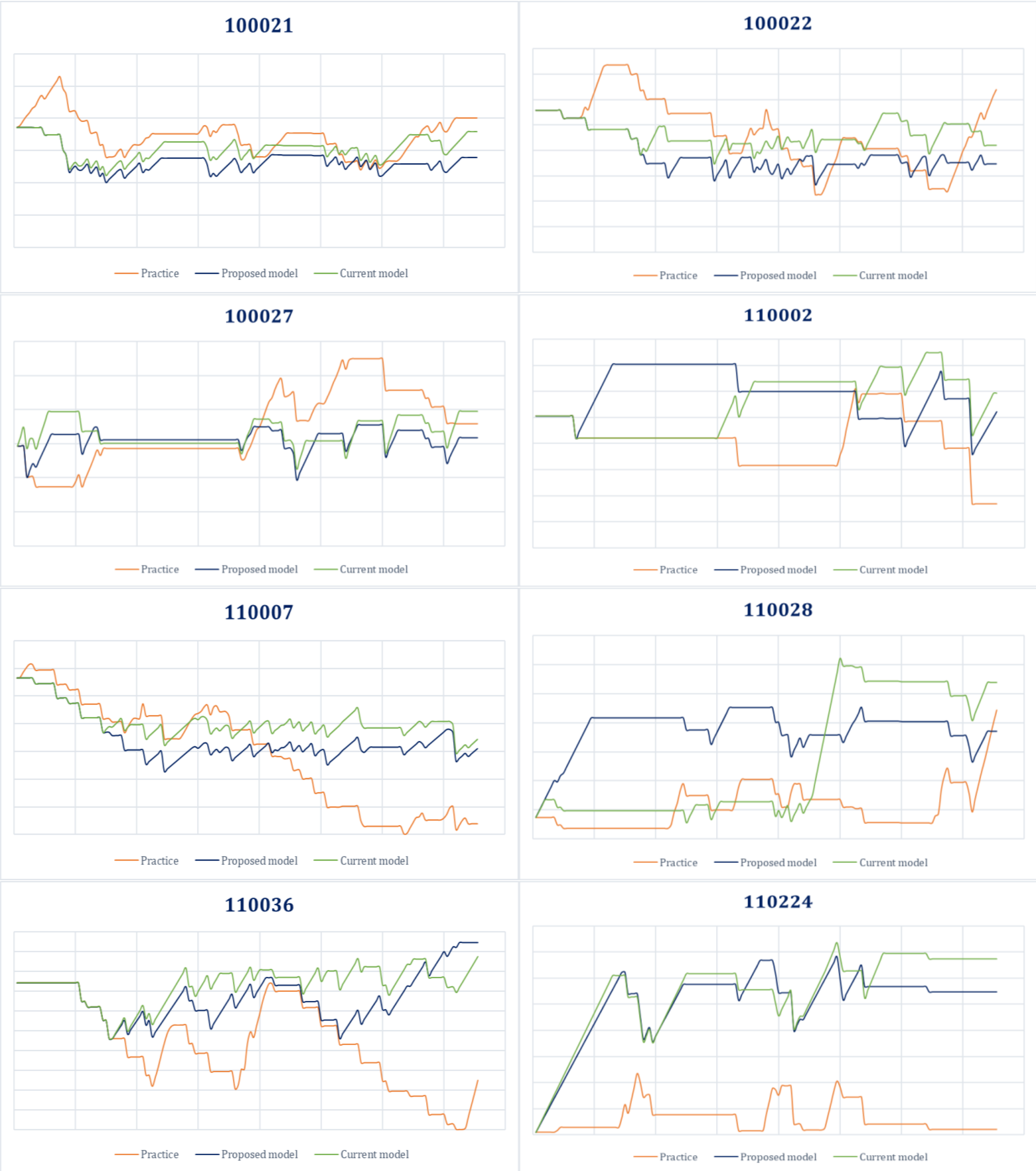


Figure 30: *Overview of course of the inventory level on a daily basis for 2019 for the 8 most demanded products*

5.3 Conclusion

Chapter 5 focuses on answering sub-question *12* and *13.*

The first question that is handled during this chapter is: *What is the impact of implementing the proposed inventory control policy based on a simulation model?* Based on the results of the Monte Carlo simulation, we can conclude that it is promising to implement the proposed model and overrule the current one. By implementing the proposed model, more than 244 million euro could be saved on a yearly basis, which is a cost reduction of a bit more than 28 percent compared to the current model. In the results of the Monte Carlo simulation, it is even found that the cycle service level is not affected, and has even improved from 0.89 to 0.94. It should be noted, however, that there is more variation in the cycle service level when the proposed model is used, therefore, the reduction in the cycle service level may not hold in practice. Even though there is no certainty that the cycle service level will be improved when the proposed model is used in practice, the difference in costs is extremely large, resulting in a recommendation to use the proposed model instead of the current one.

To check whether the results of the Monte Carlo simulation can actually be used to draw any conclusions, the simulation was verified and validated. To verify the Monte Carlo simulation, we manually calculated the results of the costs for two MTS items, one product facing the same parameters during the year and one product facing different parameters during the year as a result of including seasonality. It appeared that the manually calculated results are in line with the results of the Monte Carlo simulation for both products, meaning that the Monte Carlo simulation is free of errors and meets its intended goals, irrelevant whether the parameters change on a monthly basis.

To validate the Monte Carlo simulation, we simulated the course of the inventory level on a daily basis for both the current model as well as the proposed model based on the actual demand over 2018. That way, the holding costs and order costs are determined if the policies were fully used. The order costs for the Monte Carlo simulation are based on the number of orders that are placed during a year, therefore, also the number of orders that should be placed based on the actual demand of 2018 are determined to calculate the order costs. It appears that all costs fall within the range of the replications of the Monte Carlo simulation, thus, based on the costs, we can assume that the Monte Carlo simulation gives representative results and a conclusion can be drawn from the simulation. Additionally, if the policies are fully used in practice, there would never have been a stockout based on the actual demand, meaning that the CSL in practice would have been equal to one, which is in line with the range or the CSL according to the Monte Carlo simulation.

The second question that is answered during this chapter is: *What is the effect of the parameters of the inventory control policy?* For that purpose, it is checked whether the company is using the current inventory control policy or not. It turned out that the company is not following the inventory control policy completely which leads to an increase in costs for more than 161 million euro if we look at one fixed moment in time.

To get a clearer view of the effects of the model, the course of the inventory level is simulated on a daily basis with implementation of the current policy, the proposed policy and compared with the course of the inventory level that is based on how the course of the inventory level went in practice. First, using the proposed model or the current model has been compared to practice for all data of 2018 and, secondly, using the proposed model or the current model has been compared to practice for the data from January of 2019 to May of 2019. It appeared that using the policy leads to lower order costs on a yearly basis and in combination with always having a buffer available, reducing the chance of facing stockouts. Since the stockout costs cannot be calculated, it is questionable whether the increase in costs of the proposed model compared to the practical situation can be overruled with a reduction in stockout costs. Furthermore, it is asked whether the same conclusions hold when the course of the inventory level is simulated for all 44 MTS products.

Besides, it may be possible that the course of the inventory control policy had been different due to capacity restrictions or quality issues. Therefore, only conclusions could be drawn under the assumptions that the company is always able to produce the required number of products.

Altogether, it can be concluded that the use of the policy parameters will have a major influence on the order costs and will reduce the chance of facing stockouts. Therefore, it is suggested that the company should embrace the proposed inventory control policy and use it in practice to actually reduce the order costs and deliver products to customers right away.

6. Conclusions and recommendations

This chapter describes the conclusions and recommendations of this research. Since we already answered all sub questions during other chapters, this chapter focuses on answering the research question as proposed in *Section 1.4.* Thereafter, recommendations will be provided divided upon three different categories, namely: recommendations that can be put into practice by the company immediately, recommendations that can be applied in the future by the company and recommendations for further research on the same topic.

6.1 Conclusions

The research question that is attempted to answer during this study is:

How to improve the current inventory control policy considering the trade-off between meeting a target cycle service level and reducing inventory costs along with the mapping of changeover costs and how to implement it into the current ERP system?

To determine how the current inventory control policy can be improved, the first thing to get clear was how the current policy functions. As a result, we found that the current policy already contained the basics, but that it was mostly based on common sense. The input data was not underpinned and obsolescence and outliers were not taken into account. Furthermore, seasonality has to be updated manually and the classification of products could be improved.

To summarize the improvements that can be made compared to the current inventory control policy, the main contributions of this study are mentioned below:

- This study shows the influence of using parameters of an inventory control policy in practice and it shows the company how they score in practice.
- This study compares the proposed model with the current model as already developed by the company with the use of a Monte Carlo simulation.
- This study adds configuration packages to the inventory control policy that are automatically updated. Thereafter, these files only have to be uploaded in the ERP system to have all relevant parameters in the ERP system.
- This study gives the company some insights into their demand with the use of extensive analyses.
- This study measures all relevant data, when not available within the company. For example, the order costs based on changeovers are measured with observations.
- This study takes obsolescence into account, to avoid that the company has to sell products against relatively low prices.
- This study determines one selling price per product, that is used for the calculations to classify the different products.
- This study uses seasonality factors, that are determined based on actual demand and can be updated when new demand arrives. Furthermore, an additional check has been added to see whether seasonality should actually be taken into account for specific products.
- This study determines outliers that may have a negative impact on the outcomes of the inventory control policy and excludes these outliers while calculating parameters.
- This study extends the classification of the products by also taking the cost price and selling price into account. Besides, the classification is also based on the number of months at which a product is demanded.
- This study does not base target cycle service levels on common sense, but underpins the target cycle service levels with theory. Products that are considered to be less important can have lower targeted cycle service levels to reduce the costs.

To compare the current inventory control policy with the proposed inventory control policy, a Monte Carlo simulation is made. For both models, the policy parameters for the order quantities and reorder points are calculated and implemented in the simulation. While these policy parameters are the only difference between the models, it appeared that the proposed model scores better in all types of costs without affecting the cycle service level. The reduction in holding costs is a result of having lower reorder points, which usually results in a lower inventory level. However, the reduction in stockout costs as well as order costs may be a result of having less demand, since the demand is random and subject to change. Still, the reduction in order costs is also a result of having higher order quantities. Therefore, the Monte Carlo simulation is validated to check whether the simulation provides reliable results. The simulation is validated by checking the actual costs when the policies were used in 2018 based on actual data. It appeared that the holding costs as well as the order costs fall within the range of costs simulated by all replications and that there were no stockouts if the policies were fully used in 2018. As a result, we can conclude that the Monte Carlo simulation shows reliable results, meaning that the proposed model scores better in terms of costs. Besides, the Monte Carlo simulation is verified by comparing the results with manually calculated results, to check whether the simulation is free of errors and meets its intended goals, which seemed to be the case.

To see whether the parameters of the current model are actually used in practice, it is checked whether the value of the reorder points of the current policy are at least in inventory, meaning that the inventory level of a product is above reorder point. It appears that this was not the case, besides, the company could already save more than 242 million euro in holding costs by not having MTO products in inventory. To compare the current model and the proposed model with the practical situation, the actual inventory level on a daily basis is simulated and compared to the results found when the Monte Carlo simulation was validated. It appeared that the holding costs are much lower in practice, however, the company has a chance of facing stockouts and has to produce a lot of products simultaneously in the high season, leading to high order costs. Since it is stated that the cycle service level is extremely important, it can be concluded that it is advisory to use any of the inventory control policies, to build a buffer to survive the high season and be able to attain a relatively high cycle service level.

As we have found that the proposed model is way more promising compared to the current model in terms of costs and it is irrelevant for the cycle service level which of the models is used, it can be concluded that the proposed model should be used in practice. That way, we can conclude that by implementing the proposed model in the company the current inventory control policy is improved while considering the trade-off between meeting a target cycle service level and reducing the inventory costs.

The last part of the question that still has to be answered is how the proposed model can be implemented into the current ERP system. Since the ERP system is not capable of having the inventory control policy processed in the system, we made the inventory control policy outside the ERP system and update the parameters within the ERP system.

Altogether, we can conclude that a proposed inventory control policy is made that determines the policy parameters while taking obsolescence and outliers into account. Furthermore, the influence of seasonality is calculated based on historic data and do not have to be manually updated and all other relevant data is based on measurements and observations. The proposed model will be implemented in the current ERP system with the use of configuration packages. As mentioned before, this study adds configuration packages to the inventory control policy that are automatically updated. Thereafter, these files only have to be uploaded in the ERP system to have all relevant parameters in the ERP system. The parameters will be updated on an item level as well as on a warehouse level. By having the parameters on item level, the whole system and total inventory of a product remains clear and by having the parameters on a warehouse level, advices can be generated. By importing, validating and implementing the configuration packages, the parameters are updated in the system and can be used to let the system calculate advices in terms of required transfers and required production orders.

Altogether, we can conclude that it is advisory to use the proposed inventory control policy to determine the policy parameters. Besides, the proposed model will be implemented in the current ERP system with the use of configuration packages.

6.2 Recommendations

This section elaborates on recommendations that can be put into practice by the company or future researchers. To make a distinction between the different kinds of recommendations, they are all subdivided upon three different categories.

6.2.1 Recommendations that can be put into practice by the company immediately

Use the proposed inventory control policy in practice

Use the parameters as determined within the inventory control policy, thus, schedule a production order when the inventory level drops below reorder point with an amount of n times Q that is required to exceed the reorder point again. Use the policy based on a priority list. The first step is to determine whether there are actual sales orders. If there are sales orders for MTS products and the required amount is not available in inventory, start with producing these products with n times Q to get above reorder point and to fulfill the sales orders for these specific products. If there are no sales orders of MTS products that cannot be delivered immediately, check whether there are some sales orders for MTO products. If that is the case, start producing the required amount of MTO products. If all sales orders are met, start producing to build inventory according to the inventory control policy, thus, by producing MTS products that have an inventory level below reorder point.

Ensure that there is inventory available for intermediate products that are not classified as MTS

Within this study we found four products that are intermediate products, but that will not be classified as MTS since they are used in less than six months. If these products are not in inventory, it may lead to standstill of the production facility, therefore it is important to have inventory of these products at all times. To have the lowest possible inventory level, it is suggested that the company makes sure that there is only one pallet in inventory for each of these products. The intermediate products that are found during this study and for which there should already be one pallet in inventory are: 1100045, 110210, 110286 and 110301.

Enter the parameters of the inventory control policy in the ERP system

The parameters can be entered into the ERP system on two different levels, namely on item level and on warehouse level. If the parameters are entered on item level, it provides a clear overview of the parameters, however, it will not be used by the ERP system to give advice on transfer needs or production needs. Therefore, one also has to make sure that the parameters are updated on warehouse level. To update the parameters, configuration packages have been made which are automatically updated in the inventory control policy when new data is added. It is suggested that the company updates the parameters on both item level as well as on warehouse level and has to upload the configuration packages to the ERP system. If the configuration packages are validated and applied, the parameters are updated within the ERP system.

6.2.2 Recommendations that can be applied in the future by the company

Collect the data to calculate the cycle service level

The company does not keep track of data that is required to determine the cycle service level. For example, they do not store the number of MTS products that can be delivered directly from stock and the number of MTS products that cannot be delivered directly from stock. Furthermore, if the company makes new agreements with customers or postpones the first agreed delivery date, they do not save this data such that it can be traced back in a later stage. Therefore, they do not have actual numbers on how they score in favour of customers. Even though the goal is to deliver good quality products to customers on time, they do not have any data validating that they are on the right track. Besides, the cycle service level is an indication whether there are enough products in inventory, if that is the case, they may decide to lower the reorder points and order quantities to reduce costs and still be able to fulfil all demand. However, this specific decision can only be made when there is proof that they meet all agreements with customers.

Determine whether obsolescence has to play a role

In the proposed model, obsolescence is taken into account. It appeared that reducing the reorder points and order quantities as a result of including obsolescence did not have a negative impact on the cycle service levels, since the existing reorder points were relatively high. The introduction of obsolescence leads to lower reorder points and lower order quantities, even though it is favourable to have the production runs as long as possible to have smoother production. It is decided to take obsolescence into account since there are products that are in inventory for over a year, leading to lower selling prices. Since the quality of the products does not change over the years, the company may decide not to take obsolescence into account anymore. If the company thinks that the reduction in selling price is negligible or when the company thinks that the selling prices should not be reduced at all, the company is able to use the parameters that are determined without the inclusion of obsolescence. Furthermore, the company may decide that taking obsolescence is important, however, not in the proportion as it is taken into account now. If that is the case, the company may decide to soften the inclusion of obsolescence, by changing the formula. Since it must be a free choice of the company, different columns are added to the inventory control policy, such that the company only has to take the data of a different column when it decides not to take obsolescence into account anymore.

Determine whether the lead time is fixed and not subject to change

Within this study, we assumed that raw material is always available when a production order is scheduled. However, in practice this may not be the case. Therefore, the lead time may change leading to different results of the inventory control policy. Furthermore, it is assumed that the lead time is fixed, while it may be the case that the lead time differs in practice. Therefore, it is suggested that the company conducts research on the actual lead time and whether there is variation in the actual lead time.

Determine the reduction of the order costs when dies are cleaned inhouse

Nowadays, the dies are outsourced for cleaning. In the future, they want to clean the dies inhouse with the use of a cleaning oven. Besides, the company strives to fulfil the die changes without mechanics. Both aspects will lead to lower die change costs, therefore, it is suggested that the company measures the cost reduction when the cleaning oven is fully used in practice and the die changes are fully performed by operators. The new found cost price or a die change should be added to the inventory control policy, which automatically calculates the updated parameters.

Determine the influence of lower holding costs

For this study, it is assumed that the holding costs represents 22% of the cost price per annum. The actual holding costs, on the other hand, may be somewhat lower. Since it is undoable to determine the actual holding costs, it is suggested that the company maps the influence of the holding costs on the order quantity, safety stock and reorder point. The lower the holding costs, the higher the order quantity. However, the company does not want to have too much inventory, since having products in inventory for over a year leads to lower selling prices. Therefore, the company has to decide whether it would like to increase the order quantity, while taking into account that an order quantity that is too high is not preferable in terms of obsolescence.

Reclassify products as MTS or MTO

Within this study, we classified all of the products as either MTS or MTO based on the demand of the last twelve months and the profit margin. In the future, products that are nowadays considered to be MTS may become less important and products that are considered to be MTO nowadays may be MTS products in the future. Reclassification of the products is already part of the inventory control policy, however, we want to make sure that the company is aware of the consequences of changing the classification. Since changing the classification of a product from MTS to MTO means that there is still inventory of the product, thus, there will be inventory of MTO products. Furthermore, it may be the case that a product will be classified as MTS while it is only demanded by one customer, which is a high risk. Therefore, it is suggested that the company checks the classification and changes the classification when the classification of some products does not seem reliable.

Update the probabilities
There are two kind of probabilities within the proposed inventory control policy that are calculated manually, namely, the probabilities of having inventory for over a year and the probabilities of facing a certain changeover. The company has to decide in which time period the probabilities have to be updated or whether the probabilities remain the same over the years. For the probabilities of facing a certain changeover, it is suggested to update the probabilities when the ratio of occurrence between shapes drastically seem to change, since the probabilities affect the order costs. Updating the probabilities of having inventory for over a year is related to the decision whether or not obsolescence is taken into account. If obsolescence is taken into account, the probabilities have to be updated every once in a while. However, these probabilities only have a small impact on the results of the inventory control policy, therefore, it is suggested that the probabilities will only be updated when there are MTS products that seem to be in inventory for a long period.

6.2.3 Recommendations for further research on the same topic

Determine the implications of classifying the products in practice
Within this study, the products have been classified as either MTO or MTS. However, what is the impact of this classification? It is suggested that someone searches whether there are any implications when the classification is put into practice, and if so, how the classification method can be improved.

Check the assumptions made within this study
Several assumptions have been made to develop a working inventory control policy. For example it is assumed that the lead time is fixed and that the holding costs are equal to 22% of the cost price. It is suggested to check whether these assumptions are reliable, and if not, how they should be adjusted. Besides, it is suggested that the influence of these assumptions is determined in future studies.

Determine whether it is possible to automatically update the probabilities
As said before, we have two kinds of probabilities that are included in the inventory control policy, namely: the probabilities of having inventory for over a year and the probabilities of facing a certain changeover. These probabilities are nowadays calculated manually by looking at historic data, therefore, it is suggested that in future studies one searches for ways to automatically update the probabilities.

Determine how the policy can be used when a different ERP system is used
This study focuses on entering the parameters in the ERP system of Microsoft Dynamics Navision. This system is not capable of fully planning the production and/or having the complete inventory control policy implemented in the ERP system. It is only capable of giving some advice on what should be produced and what should be transferred. In contrast, there are several other ERP systems which may also be used by a company. Thus, it is suggested to dive into different ERP systems and to see how the parameters can be updated within these systems. Besides, different ERP systems may have different functionalities, thus, it is also suggested to research whether the inventory control policy can be fully implemented in the ERP system.

Determine how the number of die changes can be reduced
This study focuses on getting insight on the costs of die changes, however, it does not focus on reducing the number of die changes. As we have seen, the number of die changes have drastically increased in 2018 compared to previous years. Therefore, it is suggested another student performs a study to determine how this number can be reduced by rescheduling the production planning, for example by combining different products from the ribbed rectangular or diamond shape, or whether there are other ways to reduce the number of die changes.

Investigate whether the time spend on changeovers can be reduced
In a similar manner as the suggestion to determine how the number of die changes can be reduced, it is also suggested to determine how the time spend on changeovers can be reduced. However, the reduction of time spend on changeovers is not only relevant for the company, but also for other companies. Therefore, this recommendation is made for a new study in general. It is suggested to check whether any of the following methods can actually be used in practice to reduce the time spend on changeovers: SMED, schedule jobs in pairs, schedule jobs using group technology and making changeover time visual. It is also suggested to search for other ways to reduce the time spend on changeovers.

Improve the forecasting method
Since the demand may fluctuate a lot, it is worthwhile to spend time on improving the forecast for the company. Therefore, it is suggested that someone dives into the different ways of forecasting and tries to find the best possible way to forecast the demand for the company. As a result, the forecasted demand can be used to further improve the inventory control policy.

7. Bibliography

- ArcherPoint, (2019). *A Visual History of Microsoft Dynamics NAV (Infographic).* Visited on: Site ArcherPoint (February 2019)

- Axsäter, S., (2006). *Inventory control.* Springer Science + Business Media, LLC, 2nd edition

- Axsäter, S., (2013). *When is it feasible to model low discrete demand by a normal distribution?* OR Spectrum, January 2013, Volume 35, Issue 1, pp 153-162

- Chopra, S., Meindl, P., (2013). *Supply Chain Management – Strategy, Planning and Operation.* Pearson Education Limited 2013, 5th edition

- Cleveland, W.S., (1993). *Visualizing Data.* Murray Hill, NJ, Hobart Press

- Delft, van, C.H., Vial, J.P., (1996). *Discounted costs, obsolescence and planned stockouts with the EOQ formula.* International Journal Production Economics 44 (1996) 255 - 265

- Demirtas, D., Schuur, P., (2018). *Warehouse storage capacity versus inventory control.* Lecture 5 of the course Warehousing, obtained through Blackboard

- Duncan, W.P., (2011). *Methods for reducing changeover times through scheduling.* Open Access Master's Theses. Paper 91

- Durlinger, P.P.J., (2012). *Inventory and Holding costs – A white paper approach for managers.* Durlinger consultancy, version 1.0

- Durlinger, P.P.J., (2013). *Voorraad- en bestelkosten: de oplossing?!* Visited on: Site Durlinger (April 2019)

- ERP Search, (2019). *Microsoft Dynamics NAV Software Review.* Visited on: Site ERP Search

- Flores, B.E., Whybark., D.C., (1987). *Implementing multiple criteria ABC analysis.* Journal of Operations Management 7 (1–2), 79–85

- Gashaw, T., Jilcha, K., Birhan, E., (2014). *Modeling and Simulation of Inventory Management System of Artistic Printing Enterprise.* Obtained by ResearchGate

- Goyal, S.K., Giri, B.C., (2001). *Recent trends in modeling of deteriorating inventory.* European Journal of Operational Research 134 (2001) 1 – 16

- Harris, F.W., (1913). *How many part to make at once.* Factory, The Magazine of Management, Volume 10, No. 2, pp. 135-136, 152

- Heijden, M., van der, (2018). *Safety stocks – Basic theory.* Lecture 3 of the course Supply Chain & Transportation Management, obtained through Blackboard

- Heijden, M. van der, Diks, E.B., (2018). *Inventory allocation in distribution networks.* Modified version of the publication: "Verdeel en heers: Voorraadallocation in distributienetwerken" in Praktijkboek magazijnen en distributiecentra 18, 2.7.b, 1999

- iCepts Technology Group, (2016). *Product Overview and Capability Guide – Microsoft Dynamics NAV 2017.* Supply Chain & Technology Experts

- Jones, A. (2017). *Inventory Optimization utilizing an ABC-XYZ Analysis.* Visited on: Site Jones (February, 2019)

- Kampen, T.J., van, Akkerman, R., Donk, D.P., van, (2012). *SKU classification: a literature review and conceptual framework.* International Journal of Operations & Production Management, Vol. 32 Issue 7, pp. 850 – 876

- Kleijnen, J.P.C., (1995). *Verification and validation of simulation models.* European Journal of Operational Research 82 (1995) 145 – 162

- Law, A.M., (2014). *Simulation Modeling & Analysis*. 5th edition, McGraw-Hill

- Martin, Q., (2012). *Wat zijn voorraadkosten, de 3 R's.* Visited on: Site Martin (May, 2019)

- MathBootCamps, (2019). *How to make a box-plot (box and whiskers plot) by hand.* Visited on: Site MathBootCamps (May, 2019)

- Microsoft (2012). *Supply Planning in Microsoft Dynamics NAV 2013.* Technical White Paper

- Nahmias, S., (1982). *Perishable Inventory Theory: A Review.* Operations Research, Vol. 30, No. 4 (Jul. – Aug., 1982), pp. 680-708

- Oral, M., Salvador, M.S., Reisman, A., Dean, B.V., (1972). *On the Evaluation of Shortage Costs for Inventory Control of Finished Goods.* Management Science Vol. 18 Issue 6, pp. 344-351

- Pujawan, N., Arvitrida, N.I., Asihanto, B.P., (2010). *Monte Carlo Simulation for Sparepart Inventory.* The 11th Asia Pacific Industrial Engineering and Management Systems Conference, the 14th Asia Pacific Regional Meeting of International Foundation for Production Research.

- Ramanathan, R., (2006). *ABC inventory classification with multiple-criteria using weighted linear optimization*, Computers & Operations Research, Vol. 33 Issue 3, pp. 695-700

- Renard, P., Alcolea, A., Ginsbourger, D., (2013). *Stochastic versus deterministic approaches.* Chapter 8 of Environmental Modelling: Finding Simplicity in Complexity, Second Edition

- RiskAMP, (2019). *What is Monte Carlo Simulation?* Visited on: Site RiskAMP (April, 2019)

- Sajono, H., (2014). *The Calculation of Extra Carrying Costs (ECC) and Stock out Cost (SOC) to Determine the Raw Material's Optimal Arrival Lead Time.* Applied Mathematical Sciences, Vol. 8 Issue 83, pp. 4115 – 4124

- Sharma, L., (2017). *Difference between Verification and Validation.* Visited on: Site Sharma (July, 2019)

- Silver, E.A., Pyke, D.F., Thomas, D.J., (2017). *Inventory and Production Management in Supply Chains.* Tylor & Grancis Group, LLC, 4th edition

- Snapp, S., (2017). *How to best calculate Supply Chain lead times.* Brightwork, supply planning. Independent Research & Analysis

- StatisticsHowTo (2019). *Chi-Square Statistic: How to Calculate It / Distribution.* Visited on: Site StatisticsHowTo (June, 2019)

- Supply Chain Management (2014). *Berekening veiligheidsvoorraden.* Obtained through Blackboard

- Symbol, (2018). *Lean Six Sigma Green Belt.* Lecture 6 of the course Lean Six Sigma Green Belt, pp. 411, obtained through Blackboard

- Vorne, (2019). *Reduce changeover times.* Visited on: Site Vorne (February, 2019)

- Winston, W.L., (2004). *Operations Research – Applications and Algorithms.* Brooks/Cole, Cengage Learning, 4th edition

- Zhou, P., Fan, L.W., (2007). *A note on multi-criteria ABC inventory classification using weighted linear optimization*, European Journal of Operational Research, Vol. 182 Issue 3, pp. 1488-91

Appendices

Appendix A: The cost of the inventory level at 18-02-2019

This *Appendix* is left out because of confidentiality reasons.

Appendix B: Products in inventory for over a year

Table 33: *Products with inventory for over a year*

Item No	Inventory over a year	Inventory over two years
100001	98,595	0
100002	1,904,605	0
100007	361,202	0
100016	2,023,856	0
100019	0	160,256
100028	246,957	0
100029	81,380	0
100030	20,658	0
100031	957,154	0
100039	3,026,084	0
100042	1,165,299	0
100099	77,937	0
100125	0	1,718,370
110008	1,070,460	0
110018	93,587	0
110021	8,084,477	1,625,722
110032	0	1,170,307
110037	724,282	0
110039	427,245	0
110040	68,860	0
110062	0	464,805
110063	0	3,884,643
110066	0	887,668
110067	811,922	0
110117	8,566,497	4,458,685
110146	11,256,732	0
110178	0	108,611
110194	286,708	0
110204	97,969	2,021,667
110210	0	91,709
110213	89,205	0
110220	98,908	389,685
110223	510,190	0
110235	430,688	53,210
110240	445,399	0
110242	1,715,240	0
110243	0	322,077
110278	319,886	0
110286	245,079	0
110302	431,314	0
110314	256,660	0
110320	151,805	0
110321	204,076	0
110322	220,039	0
110323	137,720	0
110324	442,895	0
110327	1,150,275	0
110333	338,979	0
110337	131,460	0
Total	**48,772,286**	**17,357,415**

The values are multiplied with a random factor for confidentiality reasons.

The products that are found to have some products in inventory for over a year are based on data retrieved in Week 16 of 2019.

Products that are in inventory for over a year will be sold for fifty percent of the total price and products that are in inventory for over two years will be sold for ten percent of the total price. Thus, even though the quality of the products does not change, we may have to take obsolescence into account if products from this table appear to be MTS products.

Appendix C: Determination of the most important products

This *Appendix* gives an analysis of the most important products by only reviewing the demand data. As a result, we have an overview of products that are sold with certainty and should probably be classified as MTS, which will be checked during the actual classification. The following figures represent which products do have the most influence based on the sum of the demand or the number of months at which the product is sold for the period of 2012 to 2018 and 2018 alone.

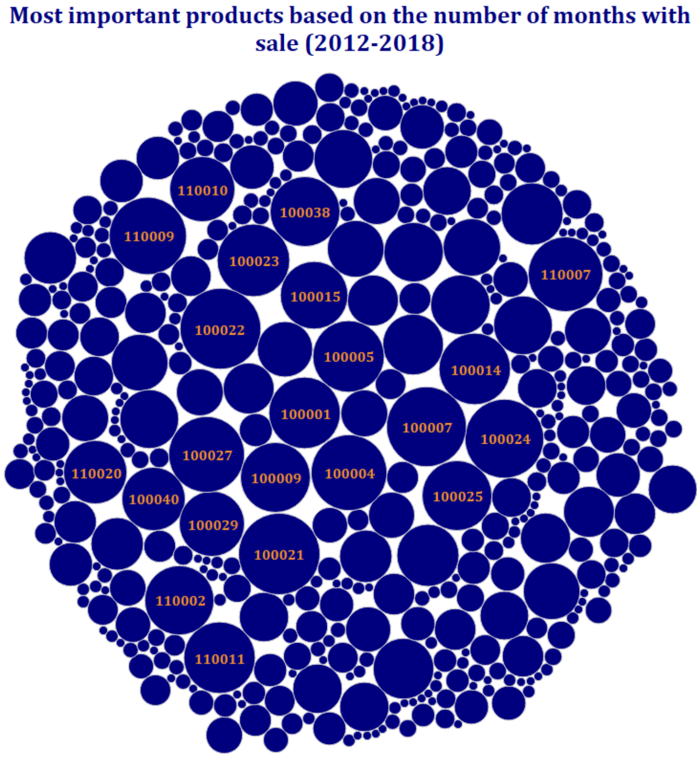


Figure 31: *Determination of the most important products based on the number of months with sales of 2012 to 2018*

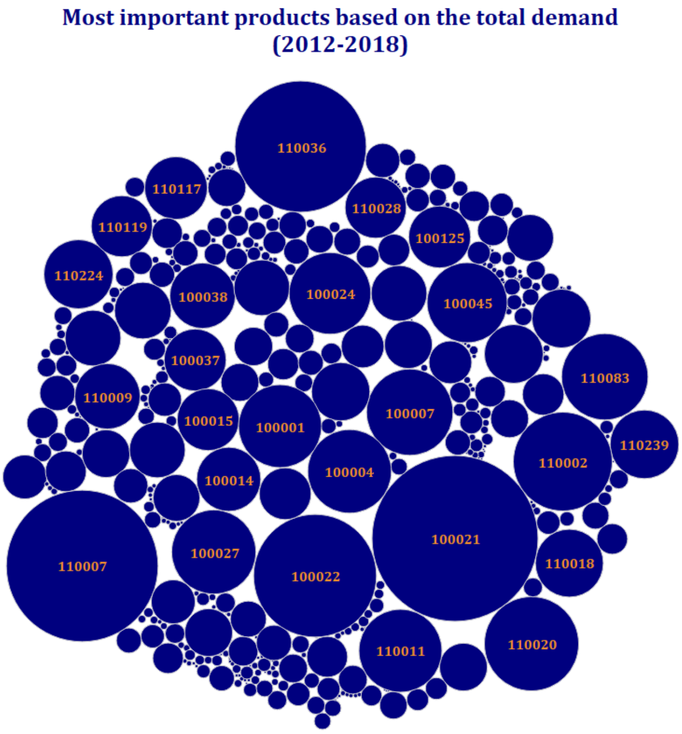


Figure 32: *Determination of the most important products based on the demand volume of 2012 to 2018*

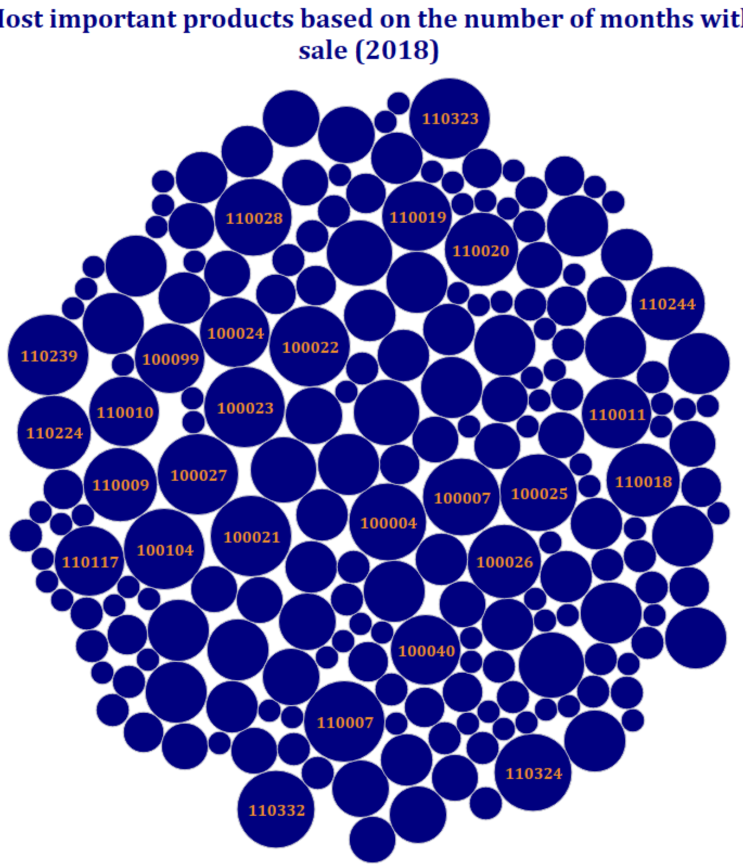


Figure 33: *Determination of the most important products based on the number of months with sales of 2018*

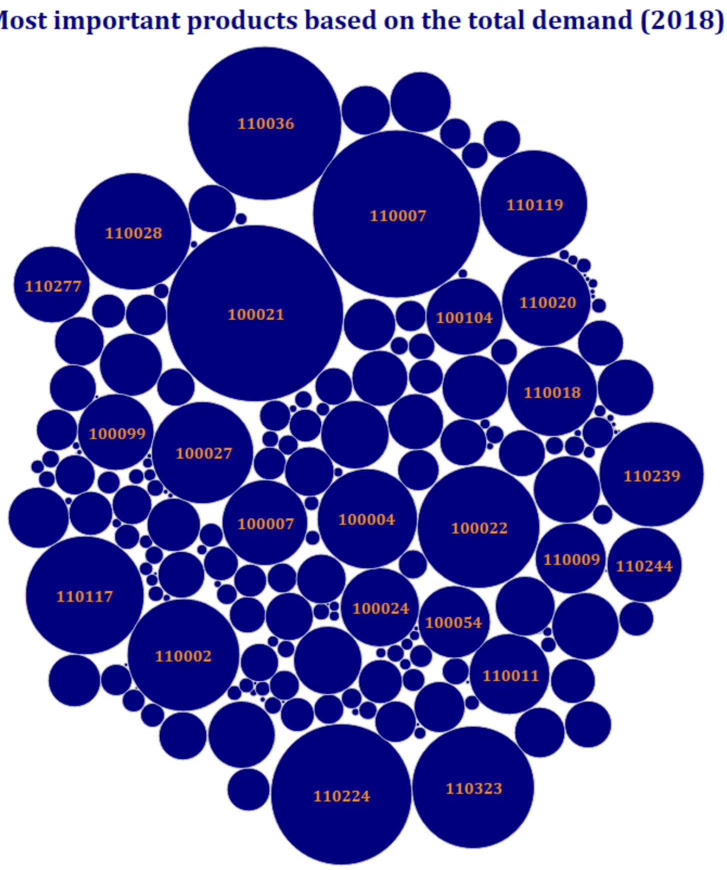


Figure 34: *Determination of the most important products based on the demand volume of 2018*

There are only a couple of products that are highlighted in each of the figures above. These products are represented in *Table 34*.

Table 34: *Most important products based on the demand volume as well as the number of months with sale*

Product number
100004
100007
100021
100022
100024
100027
110007
110009
110011
110020

For each of these products, the overall demand is high as well as the number of months at which the product is sold. Therefore, we can conclude that these products are important and need to be considered as MTS.

Additionally, there are a couple of products that are sold consequently during last year and the sum of the demand is high. However, the number of months at which the product is sold during 2012 to 2018 is not that high. One of the reasons may be that the product is only sold for the last (couple of) year(s). Therefore, these products will also be considered as MTS and represented in *Table 35*.

Table 35: *Most important products based on the demand volume, but they are not sold frequently during 2012 to 2018*

Product number
110018
110028
110117
110224
110239

Lastly, there are a couple of products that are only considered to be important based on the data of 2018. Since the data is limited, we cannot draw any conclusions, but we should take these products into account when new data arrives and see whether they still appear to be important. If that is the case, these products should also be considered as MTS. These products are represented in *Table 36*.

Table 36: *Most important products purely based on the data of 2018*

Product number
100099
100104
110244
110323

Concluding, we could say that each of the products mentioned in the tables above are considered to be MTS and will be included in the inventory control policy. The target CSL will depend on the ABC-XYZ classification. For all other products, the classification will be purely based on the ABC-XYZ classification.

Appendix D: Cost price per product

This Appendix is left out because of confidentiality reasons.

Appendix E: Selling price per product

This *Appendix* is left out because of confidentiality reasons.

Appendix F: Determination of outliers in the demand

Product	Periods for which the demand data is considered to be an outlier, based on boxplots (2012-2018)
100001	P7-2012 P6-2015 P5-2016
100002	P6-2012 P8-2012 P10-2012 P11-2102 P1-2013 P6-2013 P10-2013 P11-2013 P12-2013 P3-2014 P10-2014 P6-2015 P11-2015 P1-2016 P2-2016 P4-2016 P9-2016 P1-2018
100004	P1-2013
100005	P8-2017
100007	P2-2012 P3-2012 P2-2013 P2-2016
100009	P4-2013 P6-2013 P3-2017
100011	P1-2012 P5-2012 P7-2012 P8-2012 P10-2012 P3-2013 P5-2013 P6-2013 P9-2013 P3-2014
100012	P9-2012 P3-2013 P6-2012 P9-2013 P3-2016 P6-2016
100013	P4-2013 P4-2015 P3-2016
100014	P9-2015
100015	P4-2014 P4-2015 P9-2015 P5-2018
100016	P3-2015 P11-2015
100018	P3-2015 P4-2015 P8-2015 P4-2016 P6-2017
100022	P6-2015
100023	P12-2015
100024	P3-2013 P3-2015 P6-2015
100025	P6-2015
100026	P6-2016 P3-2017 P5-2017
100027	P4-2015 P10-2018
100028	P3-2016 P5-2017 P4-2018 P7-2018
100029	P4-2012 P6-2013
100031	P3-2012 P7-2012 P3-2013 P6-2013
100032	P5-2012 P6-2013 P3-2015 P6-2015 P4-2016 P5-2016 P11-2016 P4-2017 P5-2017 P5-2018 P6-2018 P7-2018 P10-2018 P11-2018
100036	P7-2013 P9-2013 P5-2014 P3-2015 P7-2015 P9-2015 P6-2016
100037	P2-2013 P1-2014 P4-2014
100038	P6-2012 P7-2012 P6-2013 P3-2014
100039	P6-2012 P6-2013 P7-2013 P12-2014 P10-2015 P6-2017 P7-2017
100040	P1-2012 P6-2012 P9-2013 P1-2014 P7-2014 P6-2015 P7-2016
100042	P6-2012 P7-2015
100043	P3-2015 P11-2015 P12-2017
100045	P6-2013 P3-2015 P4-2015
100069	P9-2013 P2-2014 P3-2014 P6-2014 P10-2014 P2-2015 P4-2015 P6-2015 P1-2016 P5-2016 P6-2016 P7-2016 P4-2017 P5-2017 P6-2017 P11-2017
100082	P6-2013 P7-2013 P1-2014 P5-2014 P7-2014 P8-2014 P9-2014 P11-2014 P1-2015 P2-2015 P3-2015 P5-2015 P7-2015 P9-2017
100099	P3-2016 P4-2016 P7-2016 P8-2016 P10-2016 P12-2016 P2-2017 P3-2017 P4-2017 P5-2017 P6-2017 P1-2018 P2-2018 P3-2018 P4-2018 P5-2018 P6-2018 P8-2018 P10-2018 P11-2018
100104	P6-2016 P7-2016 P8-2016 P9-2016 P5-2017 P6-2017 P7-2017 P9-2017 P2-2018 P3-2018 P5-2018 P6-2018 P7-2018 P8-2018 P9-2018 P10-2018 P11-2018 P12-2018
100125	P3-2012 P2-2013 P1-2014 P4-2014
110001	P12-2016 P6-2017 P6-2018
110008	P11-2013 P4-2015 P1-2017 P5-2017 P1-2018
110010	P6-2013 P5-2014 P1-2017 P2-2017 P6-2017 P4-2018
110011	P5-2016
110013	P2-2014 P5-2017 P6-2017
110018	P3-2016
110019	P6-2014 P1-2015 P1-2016 P11-2016 P2-2017 P5-2017 P1-2018 P4-2018
110020	P10-2014 P10-2015 P7-2016 P8-2016 P10-2016
110021	P6-2014 P9-2014 P4-2015 P8-2015 P9-2015 P10-2015 P3-2016 P6-2016 P8-2016 P9-2016 P11-2016 P12-2016 P2-2017 P5-2017 P9-2018
110028	P4-2016 P3-2017 P5-2017 P9-2017 P6-2018 P7-2018 P8-2018 P9-2018
110030	P3-2015 P5-2015 P8-2015 P10-2015 P1-2016 P3-2016 P5-2016 P6-2016 P8-2016 P11-2016 P2-2017 P3-2017 P8-2017 P9-2017 P3-2018 P4-2018 P9-2018
110036	P8-2017
110043	P3-2015 P4-2015 P5-2015 P6-2015 P7-2015 P8-2015 P9-2015 P10-2015 P6-2016 P7-2016 P8-2016 P9-2016 P12-2016 P3-2017 P5-2017 P6-2017 P7-2017 P8-2017 P9-2017 P11-2017 P1-2018 P2-2018 P8-2018
110059	P3-2014 P4-2014 P5-2014 P6-2014 P7-2014 P8-2014 P9-2014 P11-2014 P12-2014 P1-2015 P2-2015 P3-2015 P4-2015 P6-2015 P7-2014 P8-2014 P9-2015 P12-2015 P2-2016 P3-2016 P4-2016 P5-2016 P6-2016
110062	P6-2013 P7-2013 P9-2013 P3-2014 P6-2014 P7-2014 P8-2014 P3-2015 P6-2015 P2-2016 P7-2016
110071	P5-2016 P9-2016 P2-2017 P2-2018
110103	P1-2012 P7-2012 P8-2012 P9-2012 P10-2012 P2-2013 P3-2013 P4-2013 P6-2013 P7-2013 P8-2013 P9-2013 P11-2013 P12-2013 P2-2014 P3-2014 P5-2014 P6-2014 P7-2014 P8-2014 P9-2014 P5-2015
110117	P1-2016 P3-2016 P5-2016 P6-2016 P7-2016 P8-2016 P9-2016 P1-2017 P5-2017 P6-2017 P7-2017 P8-2017 P9-2017 P10-2017 P2-2018 P3-2018 P4-2018 P5-2018 P6-218 P7-2018 P8-2018 P10-2018
110119	P1-2016 P5-2016 P6-2016 P7-2016 P8-2016 P9-2016 P10-2016 P12-2016 P1-2017 P2-2017 P3-2017 P7-2017 P8-2017 P9-2017 P2-2018 P4-2018 P6-2018 P7-2018 P8-2018 P12-2018
110139	P4-2016 P9-2016 P10-2016 P12-2016 P2-2017 P3-2017 P5-2017 P6-2017 P7-2017 P8-2017 P9-2017 P10-2017 P11-2017 P3-2018 P6-2018 P7-2018 P11-2018 P12-2018
110140	P4-2016 P9-2016 P10-2016 P11-2016 P12-2016 P1-2017 P2-2017 P3-2017 P4-2017 P5-2017 P6-2017 P7-2017 P8-2017 P9-2017 P10-2017 P11-2017 P3-2018 P6-2018 P7-2018 P11-2018
110224	P8-2013 P5-2017 P6-2017 P11-2017 P1-2018 P4-2018 P6-2018 P7-2018 P8-2018 P9-2018 P12-2018
110239	P3-2016 P5-2016 P11-2016

Figure 35: *Products that have outliers in the demand*

Note: All white product numbers represent MTS products.

Appendix G: Probabilities of having inventory for over a year

Table 37: *Probabilities of having inventory for over a year or two years*

Item No	P(Inventory less than a year)	P(Inventory over a year)	P(Inventory over two years)
100001	0.9964	0.0036	0.0000
100002	0.1421	0.8579	0.0000
100007	0.9966	0.0034	0.0000
100016	0.9076	0.0924	0.0000
100019	0.8754	0.0000	0.1246
100028	0.9923	0.0077	0.0000
100029	0.9972	0.0028	0.0000
100030	0.0000	1.0000	0.0000
100031	0.9399	0.0601	0.0000
100039	0.8165	0.1835	0.0000
100042	0.8457	0.1543	0.0000
100099	0.9990	0.0010	0.0000
100125	0.7937	0.0000	0.2063
110008	0.9735	0.0265	0.0000
110018	0.9990	0.0010	0.0000
110021	0.7614	0.1987	0.0399
110032	0.0000	0.0000	1.0000
110037	0.8324	0.1676	0.0000
110039	0.0000	1.0000	0.0000
110040	0.0000	1.0000	0.0000
110062	0.0000	0.0000	1.0000
110063	0.0000	0.0000	1.0000
110066	0.0000	0.0000	1.0000
110067	0.8974	0.1026	0.0000
110117	0.9299	0.0461	0.0240
110146	0.3654	0.6346	0.0000
110178	0.0000	0.0000	1.0000
110194	0.0000	1.0000	0.0000
110204	0.9115	0.0041	0.0844
110210	0.4767	0.0000	0.5233
110213	0.3910	0.6090	0.0000
110220	0.0785	0.1866	0.7349
110223	0.6165	0.3835	0.0000
110235	0.9585	0.0369	0.0046
110240	0.0000	1.0000	0.0000
110242	0.8279	0.1721	0.0000
110243	0.0000	0.0000	1.0000
110278	0.9930	0.0070	0.0000
110286	0.7463	0.2537	0.0000
110302	0.9690	0.0310	0.0000
110314	0.9234	0.0766	0.0000
110320	0.8265	0.1735	0.0000
110321	0.0061	0.9939	0.0000
110322	0.0000	1.0000	0.0000
110323	0.9993	0.0007	0.0000
110324	0.9969	0.0031	0.0000
110327	0.9645	0.0355	0.0000
110333	0.9572	0.0428	0.0000
110337	0.0000	1.0000	0.0000

Each white item number represents a MTS product, which shows that there was only a limited amount of inventory over two years and the probability of facing obsolescence is relatively small. Each orange item number represents a product for which there was no demand during the last twelve months (at Week 16 of 2019).

Appendix H: Determination of patterns in the demand

This *Appendix* summarizes all products that show a pattern when the demand is analysed.

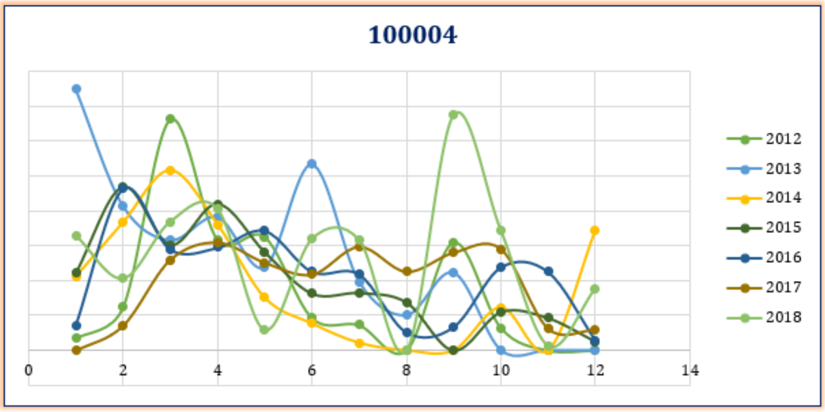


Figure 36: *Course of the demand from 2012 to 2018 for product 100004*

This product (100004) shows a pattern of the demand at the beginning of the year being higher than the demand during the rest of the year. It shows a general decrease in demand, with exception of the demand for month 9. Additionally, we see that in the end of the year (e.g. month 12) the demand is rising again. However, there are some outliers that do not follow the overall pattern.

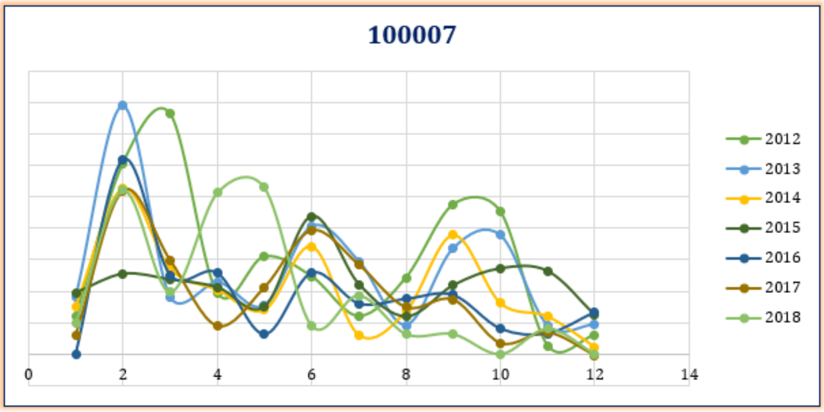


Figure 37: *Course of the demand from 2012 to 2018 for product 100007*

The overall pattern of product 100007 is that the demand hugely rises in the second month and, thereafter, decreases to the lowest point again. In month 4, 6, and 9 there is a general pattern for a temporary increase in demand.

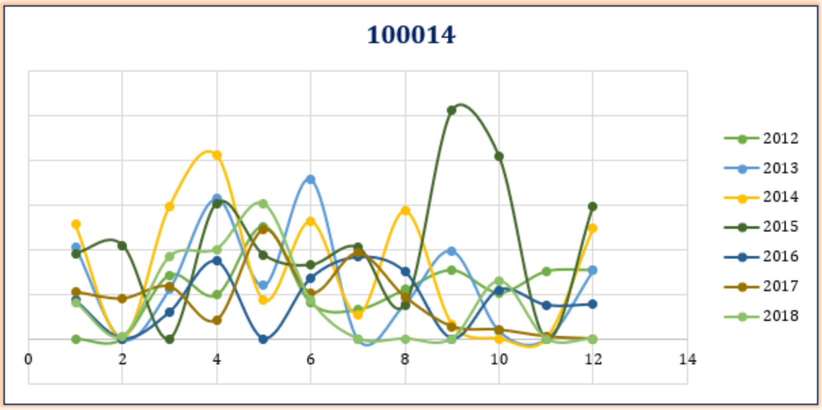


Figure 38: *Course of the demand from 2012 to 2018 for product 100014*

Product 100014 shows fluctuations in demand, however, most of the times it reaches its noun in the second month and it strongly rises again from the third month. The actual months in which peaks and nouns happen are not constant, therefore, we cannot link the pattern to a specific month.

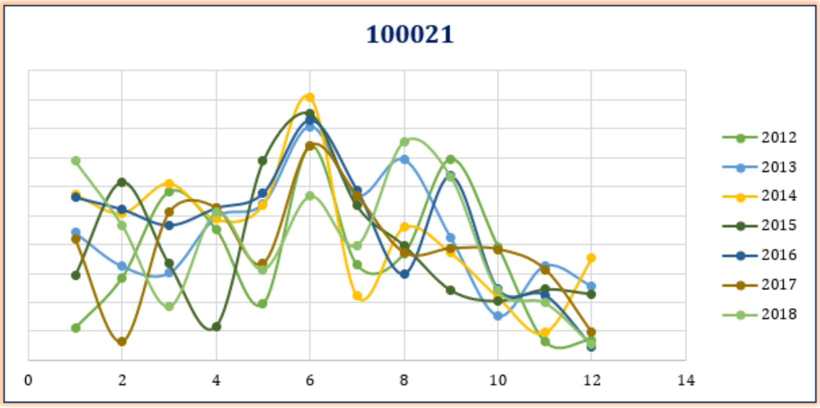


Figure 39: *Course of the demand from 2012 to 2018 for product 100021*

This figure shows a quite stable pattern related to product 100021. The demand rises until the 6th month and then drops again. In the 12th month is reaches its noun. However, this does not hold for 2014, where the demand is rising in the 12th month. Therefore, this year is considered to be an outlier to the pattern.

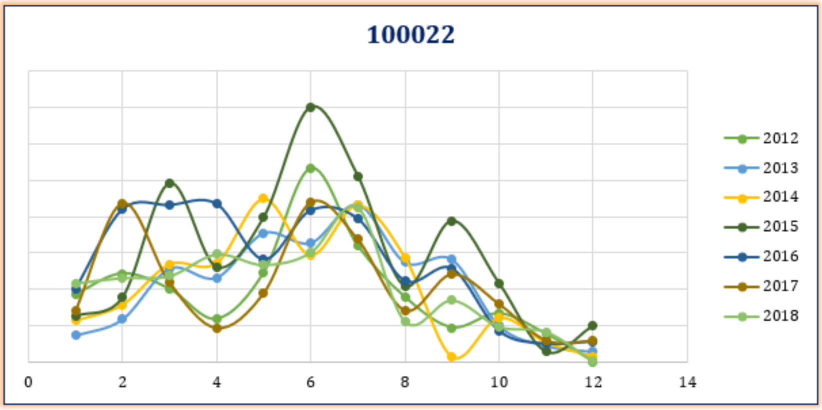


Figure 40: *Course of the demand from 2012 to 2018 for product 100022*

Product 100022 shows a quite similar pattern than that of product 100021. The same holds for product 100024, which can be seen below.

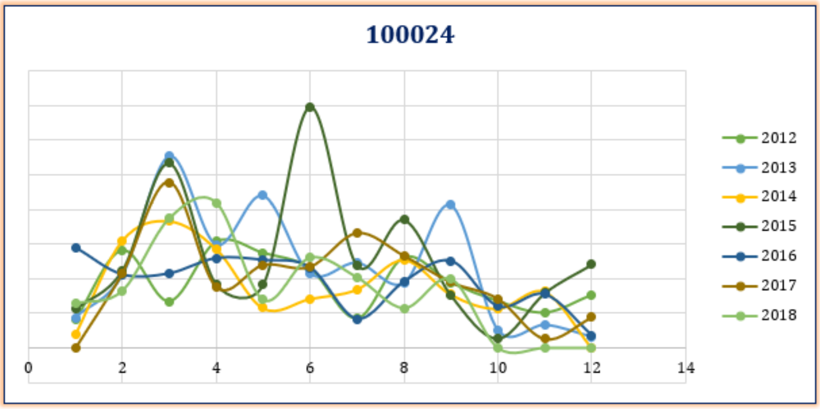


Figure 41: *Course of the demand from 2012 to 2018 for product 100024*

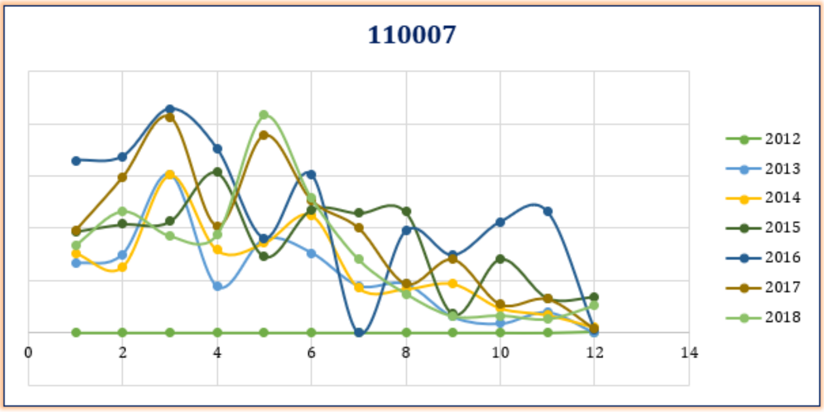


Figure 42: *Course of the demand from 2012 to 2018 for product 110007*

As one can see, product 110007 was introduced in 2013. There is a global pattern that shows that the demand decreases during the year, with small fluctuations. Therefore, we can assume that the demand in the beginning of the year should be higher than the demand at the end of the year.

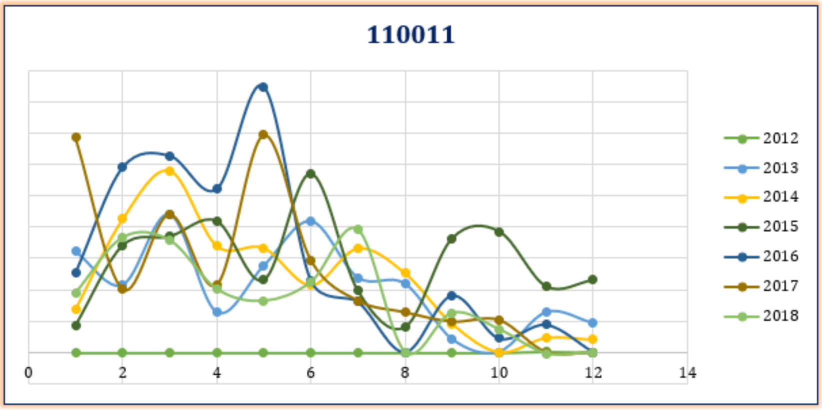


Figure 43: *Course of the demand from 2012 to 2018 for product 110011*

In general, the demand of product 110011 appears to be rising at the beginning of the year, and from the 5th month the demand decreases again, with exception of the 9th month. However, we also see that the demand of 2019 has the same start as the line of 2017, therefore, the demand of this year will not follow the general pattern. But globally, we can expect the demand to rise from now on.

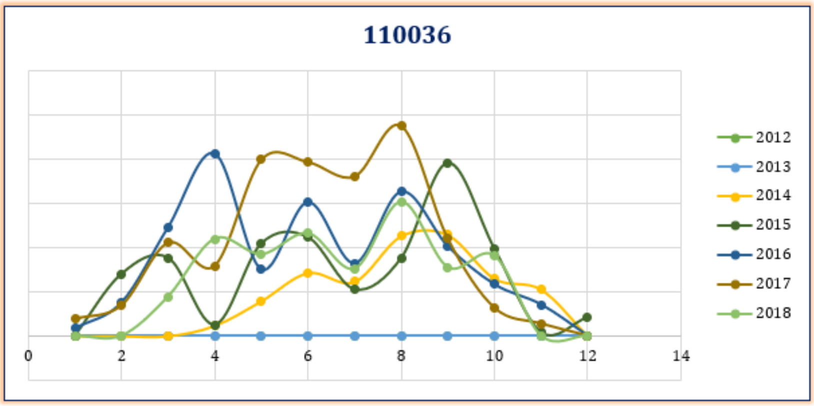


Figure 44: *Course of the demand from 2012 to 2018 for product 110036*

Product 110036 was introduced in 2014. It shows a 'mountain' pattern. First the demand is going up, and then it is going down again along with some demand fluctuations.

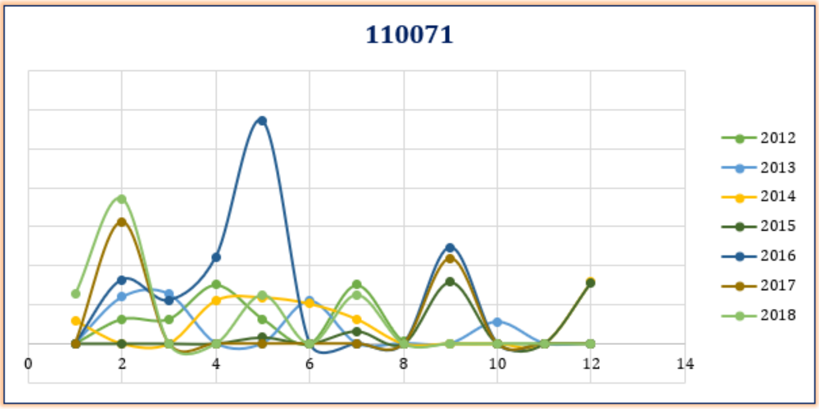


Figure 45: *Course of the demand from 2012 to 2018 for product 110071*

With exception of the demand line of 2016, we see that the demand of product 110071 shows quite the same pattern. In the 2nd, 7th and 9th month there are some peaks. Notably, there was never demand in the 8th and 11th month. Therefore, we can assume that this will also hold in the future.

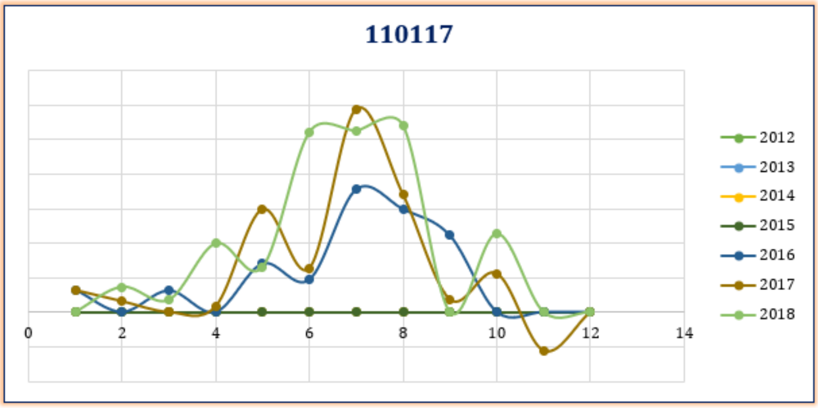


Figure 46: *Course of the demand from 2012 to 2018 for product 110117*

Product 110117 is only in production for the last three years (starting from 2016). However, it appears to have a general pattern. First the demand is going up until the 7th month and thereafter the demand decreases again. For the last three years, the demand of the product was always equal to zero in the 12th month.

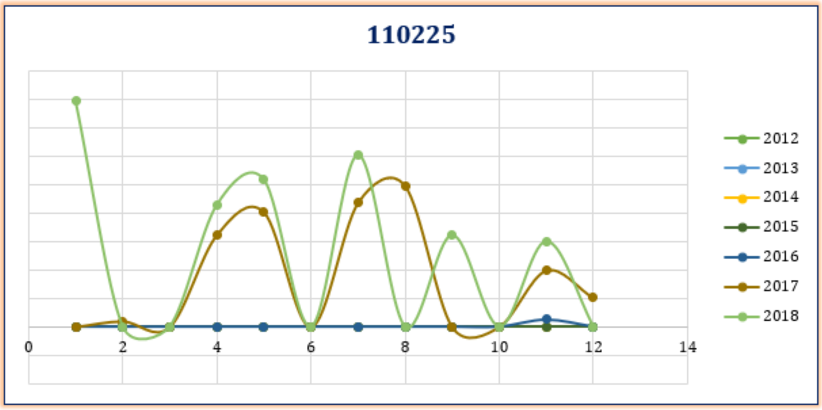


Figure 47: *Course of the demand from 2012 to 2018 for product 110225*

Product 110225 was introduced late in 2016. Therefore, we have to determine a pattern only over two years. There are clear fluctuations around the 4/5th month, 7/8th month and 11th month. Therefore, we expect also a demand growth this year during these months.

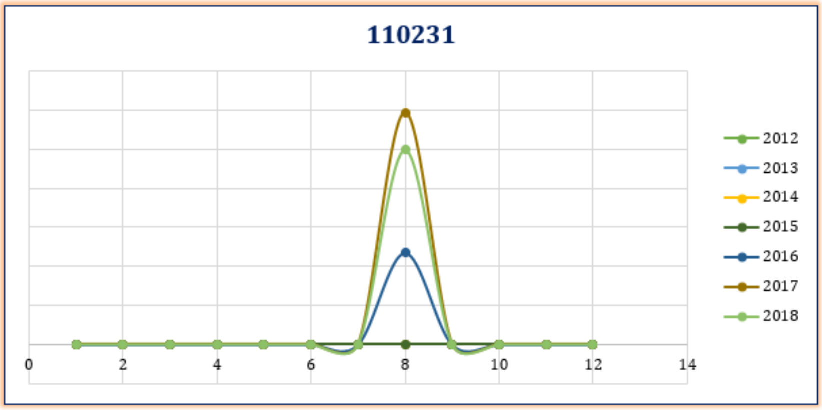


Figure 48: *Course of the demand from 2012 to 2018 for product 110231*

The pattern related to product 110231 is quite clear; there is only demand in the 8th month.

The remainder of the products are not handled for any of the following reasons:

- The demand varies over the years, not showing general patterns.
- There was no demand in 2018 (and 2019), which means that the product is not sold anymore.
- There is only data available for one year, since the product was only sold for a year or recently introduced.

As a result the found patterns may give an indication of the seasons that the products are probably following. To check whether there is actually a season that should be taken into account, another method is used.

Appendix I: Products with demand in each of the last three years

First of all, we want to see which products had a demand for at least one month in each of the last three years (2016 to 2018). The products that meet this restriction at a certain month can be seen in a table at the last page of this *Appendix.* The table has been made to see which products did have demand in a month for at least 3 years and the month for which there was demand in each of the last three years. As a result, we find products that will be sold with a great probability during future months. Additionally, we may find seasons for which there is certainly demand that could be included in the inventory control policy.

A couple of products seemed to have demand in each of the last 3 years in at least 9 of the 12 months. This holds for the products in *Table 38*.

Table 38: *Products with demand in each of the last 3 years for at least 9 months*

Item No
100004
100007
100021
100022
100027
110007
110011
110018
110028
110239

All of the products mentioned in the table above are classified as MTS. According to the months in which the products had demand with certainty, they will probably have the following seasons as summarized in *Table 39*.

Table 39: *Seasons that the products with demand in each of the last 3 years in at least 9 months probably will face*

Item No	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Season
100004													P2-P12
100007													P2-P11
100021													Whole year
100022													Whole year
100027													Whole year
110007													Whole year
110011													P1-P10
110018													P1-P10
110028													P2-P11
110239													Whole year

As mentioned before, the *Table 40* summarizes for which of the products at least one month was found with demand in each of the last three years and the months for which there was demand in each of the last three years. We see that there are a lot of products with only one to three months with demand in each of the last three years, therefore, it is hard to determine a season for each of these products. However, it is good to have an overview for which months there is demand certainty, to make some assumptions about future demand.

Table 40: *Products with demand in each of last 3 years and the corresponding months*

Item No	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	#Periods
100001	1		1	1	1			1	1				6
100002	1												1
100004		1	1	1	1	1	1		1	1	1	1	10
100005			1	1	1		1	1	1	1			7
100007		1	1	1	1	1	1	1	1		1		9
100009		1	1			1				1			4
100010					1						1		2
100013		1	1							1			3
100014	1		1	1		1				1			5
100015	1		1	1		1							4
100016					1	1							2
100018					1	1							2
100019		1											1
100020				1									1
100021	1	1	1	1	1	1	1	1	1	1	1	1	12
100022	1	1	1	1	1	1	1	1	1	1	1	1	12
100023			1	1	1	1	1	1	1	1			8
100024		1	1	1	1	1	1	1	1				8
100025	1	1	1	1		1	1	1		1			8
100026			1		1		1	1					4
100027	1	1	1	1	1	1	1	1	1	1	1		11
100028					1								1
100029	1								1				2
100031	1			1		1							3
100032				1	1								2
100038				1					1	1			3
100040							1						1
100042					1								1
100099		1	1	1		1							4
110001		1	1		1								3
110002			1			1	1	1	1				5
110004							1						1
110006									1				1
110007	1	1	1	1	1	1		1	1	1	1	1	11
110008				1									1
110009	1	1	1	1	1	1	1				1		8
110010	1	1		1	1	1			1	1			7
110011	1	1	1	1	1	1	1		1	1			9
110018	1	1	1	1	1		1	1	1	1			9
110019		1					1				1	1	4
110020	1	1	1	1	1	1		1	1				8
110021		1											1
110026									1				1
110028		1		1	1	1	1	1	1	1	1		9
110030			1					1					2
110036			1	1	1	1	1	1	1	1			8
110043								1					1
110044												1	1
110045								1					1
110071		1											1
110099							1						1
110110					1			1					2
110117					1	1	1	1					4
110119						1	1	1					3
110139			1	1							1		3
110140			1	1							1		3
110176							1				1	1	3
110203								1					1
110204					1								1
110211											1	1	2
110213												1	1
110223											1		1
110225											1		1
110227								1		1			2
110231								1					1
110239	1	1	1	1	1	1	1	1	1	1	1		11
110242												1	1
110244												1	1
110270					1	1							2

Note: *This table represents products which had demand in each of the last three years and the corresponding months for which there was demand in each of the last three years. White product numbers represent MTS products.*

Appendix J: Seasonal subseries plots

This *Appendix* gives an overview of the results of the seasonal subseries plots for products for which there was a general pattern and are considered to be MTS products. Each part of the plot represents a month. If there are only small fluctuations, it can be assumed that the demand is quite stable and the month may be part of a season, however, if there are a lot of fluctuations, the demand is uncertain and only if the demand does not face the possibility of facing zero demand, it can be assumed that the demand is part of a season. The blue lines represent the average value of the demand for a month of all years and the orange lines represent the course of the demand over all years for a specific month

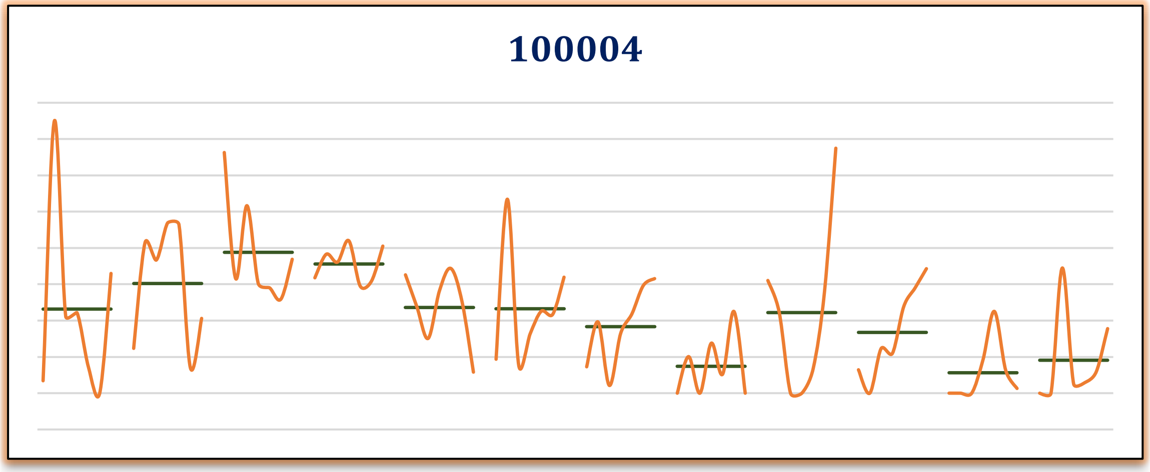


***Figure 49:** Seasonal subseries plot for product 100004*

The seasonal subseries plot of item 100004 shows a season in the beginning of the year, at which the demand increases during the first three months and thereafter decreases. At the end of the year, there are a lot of fluctuations in de demand with the possibility of facing zero demand at a month. Therefore, it can be assumed that month 2 until month 7 are facing a season.

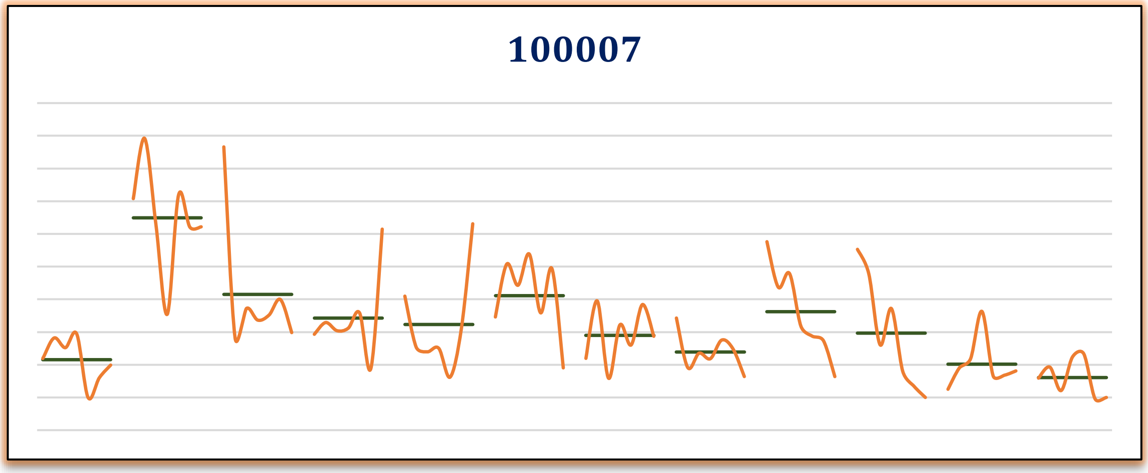


***Figure 50:** Seasonal subseries plot for product 100007*

The seasonal subseries plot of item 100007 shows multiple seasons, ensuring that the demand of month 2 until month 9 and month 11 are non-zero. Some of the months do have some large fluctuations, however, as a result of the non-zero demand, we assume that these months are part of a season.

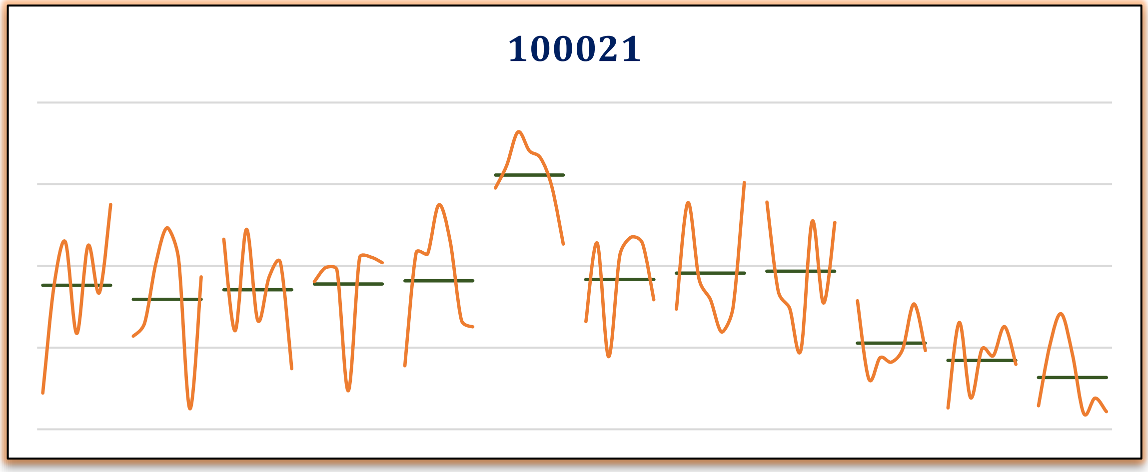


Figure 51: Seasonal subseries plot for product 100021

Product 100021 shows a stable season, with the absolute peak of demand in the sixth month. The demand is always non-zero, showing that the whole year is part of a season.

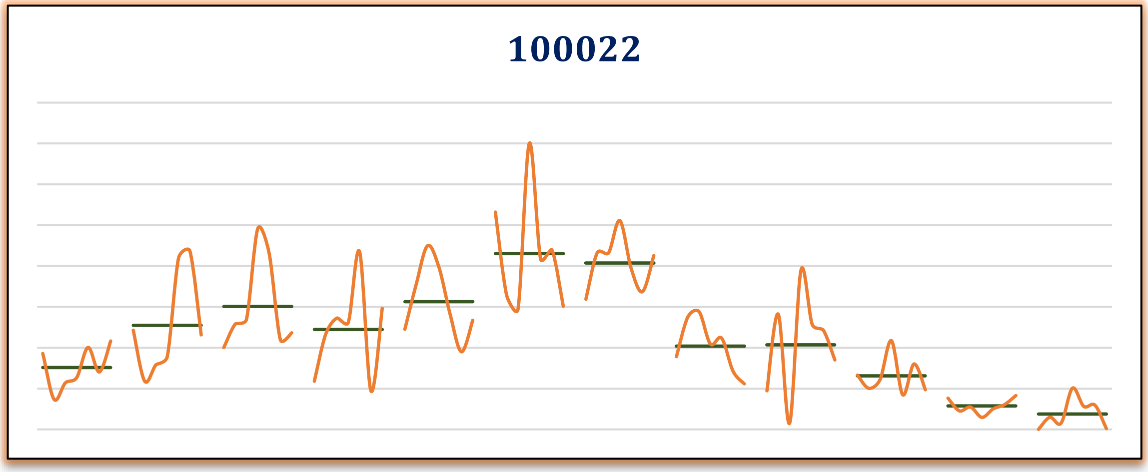


Figure 52: Seasonal subseries plot for product 100022

Similar to product 100021, product 100022 shows quite a stable pattern. The only exception is that demand in the twelfth month is not guaranteed. However, since the fluctuations of the twelfth month are relatively small, we still consider the twelfth month to be part of a season. Therefore, seasonal factors do have to be determined for the whole year.

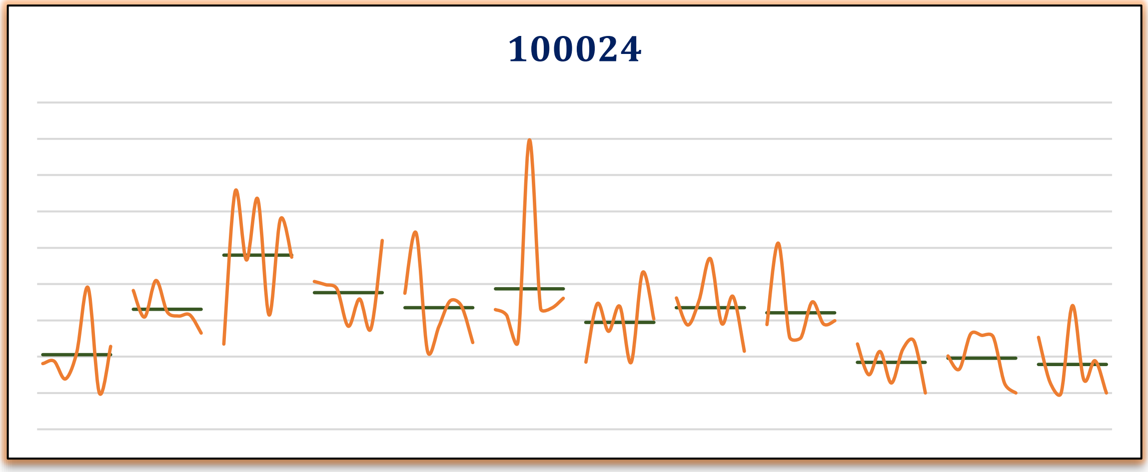


Figure 53: Seasonal subseries plot for product 100024

The high season of product 100024 is found to be in the second until the ninth month. Since these are also the months for which there is non-zero demand with certainty, we only consider these months to be part of a season.

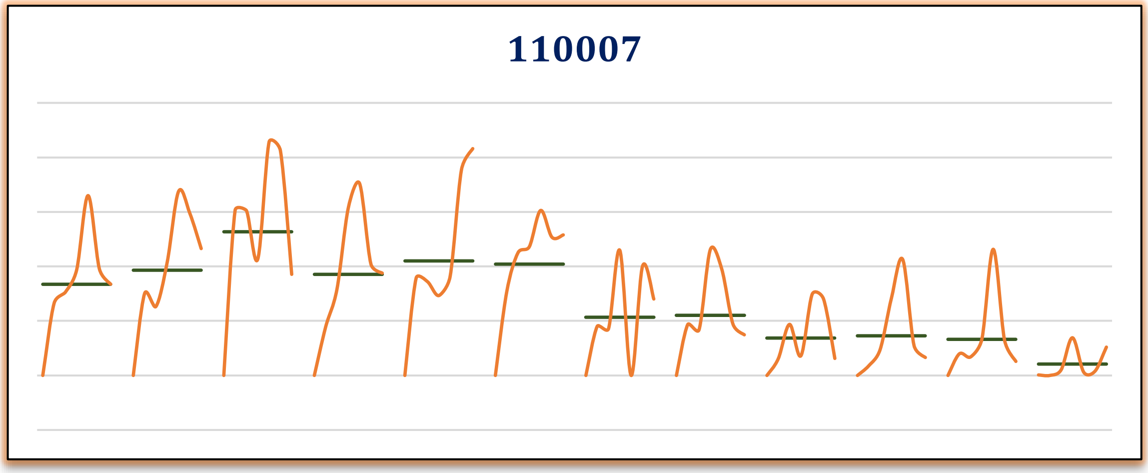


Figure 54: *Seasonal subseries plot for product 110007*

Product 110007 shows large fluctuations, especially in the first 6 months. Thereafter, the fluctuations become smaller, but also the average demand becomes smaller. Taking into account that the product was not sold in the first year, it appears to be the case that the first 6 months and the 8 until 11th month do have non-zero demand. Therefore, we consider these months to be part of a season.

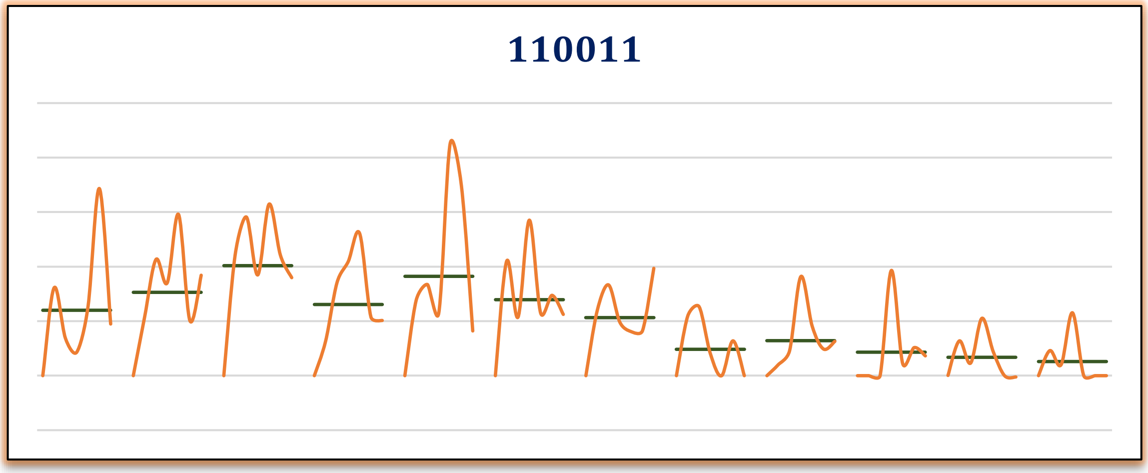


Figure 55: *Seasonal subseries plot for product 110011*

Similar to product 110007 we see that product 110011 was not sold during the first year. Therefore, if we exclude the first data point, we see that the 1st until the 7th and the 9th and 10th month do have non-zero demand at all times. The highest fluctuation occurs in the fifth month as a result of one data point, however, this data point was already found to be an outlier. Therefore, we can assume that there is some seasonality in months 1, 2, 3, 4, 5, 6, 7, 9 and 10.

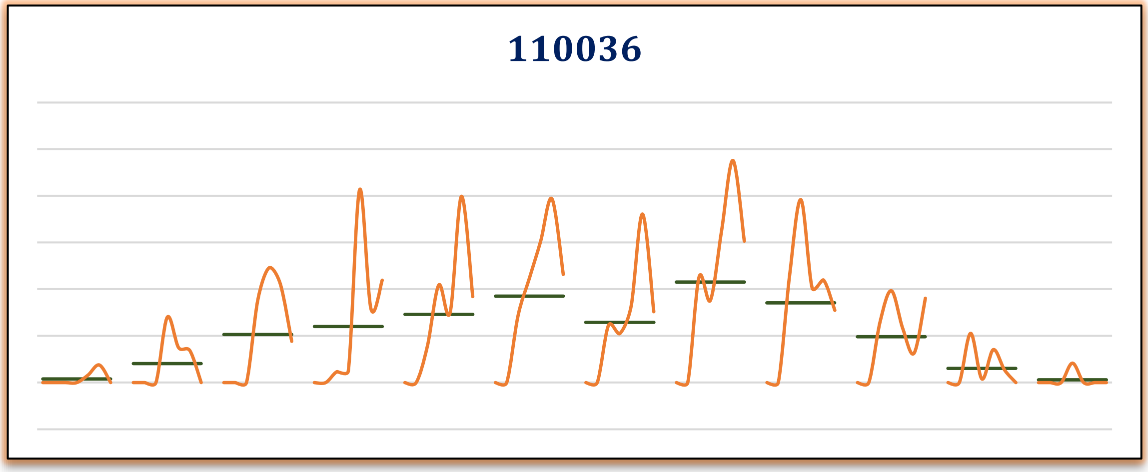


Figure 56: *Seasonal subseries plot for product 110036*

Product 110036 was not sold until the beginning of 2014. As a result, most of the demand data of the product seem to face non-zero demand. This holds for at least months 3 until 10, which are considered to be part of a season.

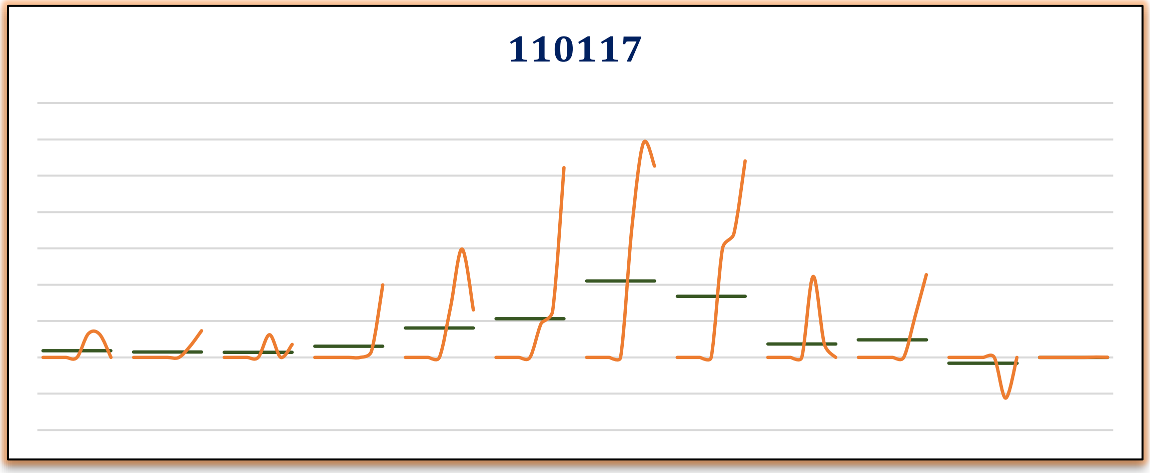


Figure 57: *Seasonal subseries plot for product 110117*

The absence of a clear seasonal subseries plot is a result of the fact that product 110117 was only in production starting from 2016. Based on the figure we cannot conclude with certainty whether there is non-zero demand, however, it appears to be the case that there is a seasonal pattern starting from the 4th month and ending in the 10th month.

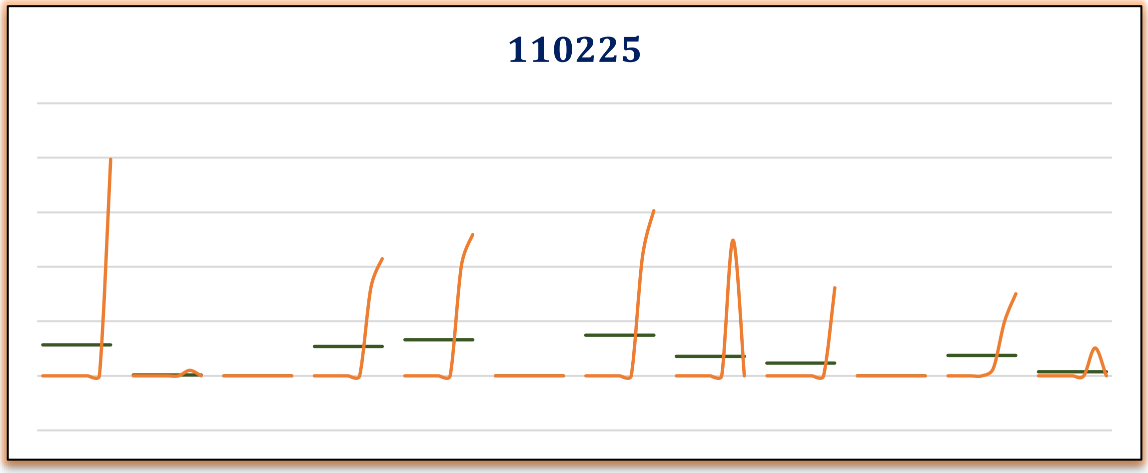


Figure 58: *Seasonal subseries plot for product 110225*

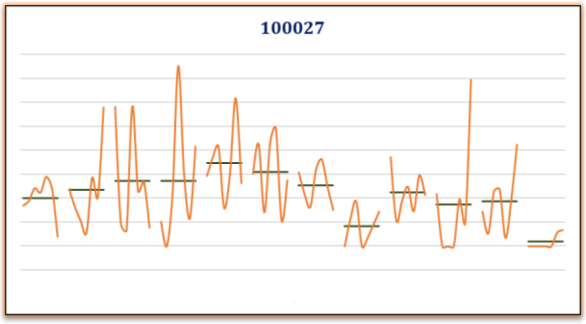
Again, we deal with a product that was introduced in a later stage. As a result, there is only two years of data available for product 110225. Since the season is not clear right away, we assume that the product is not following a specific season. However, since there are non-zero demand months according to the data of the last two years, it may still be helpful to determine seasonality factors.

The following table summarizes the months in which seasons happen which were found for the products that seemed to have a general pattern and are considered to be MTS.

Table 41: *Months that are part of a season for MTS products*

Item No	Months that are part of a season
100004	2 – 3 – 4 – 5 – 6 – 7
100007	2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 11
100021	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 – 11 – 12
100022	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8 – 9 – 10 – 11 – 12
100024	2 – 3 – 4 – 5 – 6 – 7 – 8 – 9
110007	1 – 2 – 3 – 4 – 5 – 6 – 8 – 9 – 10 – 11
110011	1 – 2 – 3 – 4 – 5 – 6 – 7 – 9 – 10
110036	3 – 4 – 5 – 6 – 7 – 8 – 9 – 10
110117	4 – 5 – 6 – 7 – 8 – 9 – 10
110225	–

Furthermore, we will check for all other MTS products whether there seems to be a season involved. For almost all of the MTS products, there is at least one non-zero demand month. However, the overall pattern of the seasons are not clear, except for products 100027 and 110009 which still seem to follow a clear season. An overview of the seasonal subseries plots of both products can be found in the figures below. Product 100027 even has some outliers, causing the high fluctuations in second and fourth month. However, there are still some high fluctuations in both products that are inexplicable, therefore, these products were not found during the determination of a general pattern.



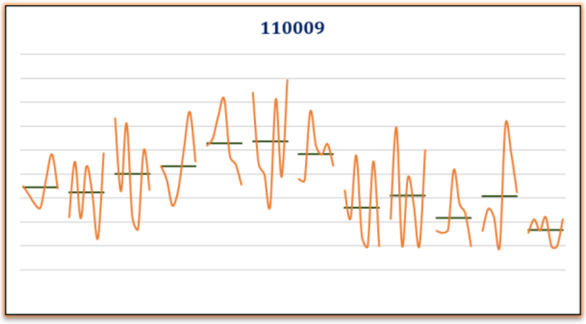


Figure 59: *Seasonal subseries plot for products 100027 and 110009*

Based on the seasonal subseries plots we could see that seasonality does have to take part in the determination of the inventory control policy. However, we should note that the differences between the months are not relatively large, therefore, we still have to execute the Chi-Square test when seasonal indices have been made, to check whether seasonality actually plays a significant role.

Appendix K: Measurement plan (in Dutch)

TENCATE GRASS

Dit meetplan is opgesteld ten behoeve van het afstudeeronderzoek van A. Tijhuis. Het doel is om in kaart te krijgen wat de kosten zijn van een proces verandering en de factoren waar deze kosten van afhankelijk zijn. Bij voorbaat dank voor de medewerking!

Wat is het soort proces verandering?

☐ Die change ☐ Kleurwissel ☐ Materiaalwissel ☐ Anders, namelijk:

Wat is de datum waarop deze verandering wordt uitgevoerd?

Op welke productielijn vindt de proces verandering plaats?

Hoeveel afval zit er in de afvalbak voor de proces verandering plaats vindt (in kilo's)?

Hoeveel afval zit er in de afval bak na afloop van de proces verandering (in kilo's)?

In het geval van een die change:	
Starttijd Step 1	Eindtijd Step 1
Starttijd Step 2	Eindtijd Step 2
Starttijd Step 3	Eindtijd Step 3
Starttijd Step 4	Eindtijd Step 4
Starttijd Step 5	Eindtijd Step 5
Starttijd Step 6	Eindtijd Step 6
Starttijd Step 7	Eindtijd Step 7
Starttijd Step 8	Eindtijd Step 8
Starttijd Step 9	Eindtijd Step 9
Starttijd Step 10	Eindtijd Step 10
Starttijd Step 11	Eindtijd Step 11
Starttijd Step 12	Eindtijd Step 12
Starttijd Step 13	Eindtijd Step 13
Starttijd Step 14	Eindtijd Step 14
Starttijd Step 15	Eindtijd Step 15

Notities (indien er opvallende dingen zijn bij de proces verandering, die mogelijk invloed hebben op de tijd dat eraan besteed wordt en/of de hoeveelheid afval dat erbij vrij komt, deze graag hier vermelden)

In het geval van een materiaal- of kleurwissel	
Starttijd:	Eindtijd (nieuwe product loopt):

Aantal betrokken operators/TD: ☐

Mocht u vragen hebben, dan kunt u contact opnemen met: a.tijhuis@tencategrass.com

Figure 60: *Measurement plan to determine the order costs (in Dutch)*

Appendix L: Steps for making a configuration package in the ERP system

Step 1: Search in the upper right corner for '*Configuration Packages*'

Step 2: Press on '*New*', such that a configuration package card opens. An example of an empty configuration package card can be found below.

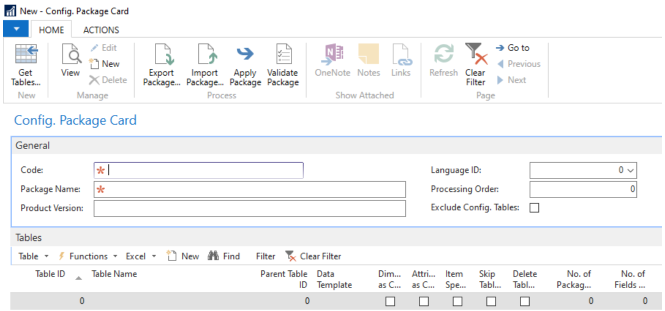


Figure 611: *Example of an empty configuration package Card*

Step 3: Fill in a '*Code'* name that fits the purpose of the configuration package and which is easy to recognize. The '*Package Name'* may be similar to that of the '*Code'*.

Step 4: Press on the first row below '*Table ID'* and search for the table you want to update. For the purpose of updating the parameters of the policy on a warehouse level, we need '*Table ID'* 5700, which represents the table Stock keeping Unit.

Step 5: Since we are only interested in updating the table with values that result from the inventory control policy, we need to delete unnecessary fields. To delete these fields, one needs to press on '*Table > Fields'* as shown in the figure below.

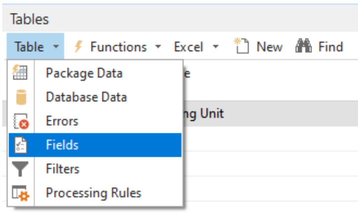


Figure 62: *Road to deleting all unnecessary fields of the configuration package*

Step 6: Select the following fields at '*Include field'*:

- *3. Location Code* (This field represents the warehouse location)
- *1. Item No.* (This field represent the item for which the parameters will be updated)
- *34. Reorder Point* (This field represents the reorder point per warehouse)
- *35. Maximum Inventory* (This field represents the maximum inventory level per warehouse)
- *36. Reorder Quantity* (This field represents the order quantity per warehouse)
- *5413. Safety Stock Quantity* (This field represents the safety stock per warehouse)
- *5419. Replenishment System* (This field tells us whether the location is used to produce products, purchase products or only to store products, in the latter case a transfer is needed)
- *5440. Reordering Policy* (This field represents the chosen policy, which is the Fixed Reorder Qty. in our case)
- *5700. Transfer-from Code* (If the warehouse is not able to produce itself, it will be stocked from other locations. This field tells us from which locations the products are gained).

If the fields are selected, press '*OK*'. Thereafter, the configuration package only contains these required fields.

Step 7: This study only focuses on Yarns, therefore, we need to filter on both the location code and item number. To filter on values, one needs to press on *'Table > Filter'* as shown in the figure below.

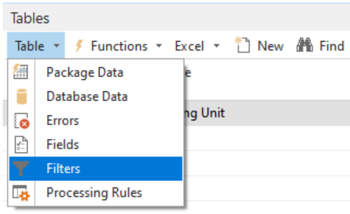


Figure 63: *Road to filtering all relevant values of the configuration package*

Step 8: For Yarns, there are 3 locations at which the products may be stored. However, one location is recently replaced by another, which leads to 4 locations that should be added to the filter. Besides a filter for the item numbers should be added to only have products that are produced at Yarns. The specific filters that should be included to get the configuration package for Yarns are given in the figure below. If the filters are included, press '*OK*'.

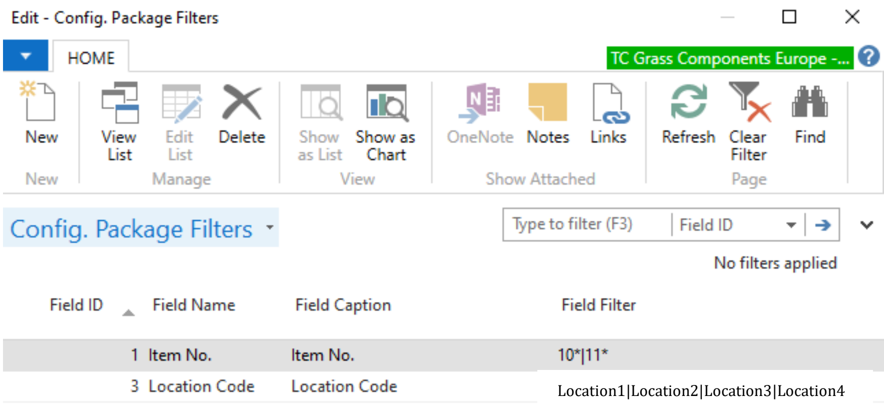


Figure 64: *Specific filters that should be applied to have a configuration package for Yarns*

Step 9: The configuration package is complete. To get the configuration package in Excel, press '*Excel > Export to Excel'*. As a result, a configuration package as shown in the following figure is gained.

SKU_MRP_UPDATE	Stockkeeping Unit	5700							
Location Code	Item No.	Variant Code	Reorder Point	Maximum Inventory	Reorder Quantity	Safety Stock Quantity	Replenishment System	Reordering Policy	Transfer-from Code
	100001								
	100002								
	100003								
	100004								
	100005								
	100006								
	100007								
	100008								
	100009								
	100010								

Figure 65: *Overview of the configuration package that is made for Yarns*

Step 10: Fill in all fields, except for the Variant Code, which may remain empty.

Step 11: Import the configuration package to the ERP system, by pressing on '*Excel > Import from Excel*' within the configuration package. As a result, your library will be opened. Search for the configuration package you just downloaded and filled in. Press '*Open*' when you selected the right file.

Step 12: Validate the file by clicking on '*Validate Package'.* If there are no errors, the package could be implemented by clicking on '*Apply Package'* These buttons are part of the top row of the configuration package Card, which can also be found in *Figure 61*.

Appendix M: Manual for the inventory control policy

The proposed inventory control policy is implemented in Excel. This manual will elaborate on how the model can be used and how it should be updated when data changes. The model consists of several sheets, of which an overview is given below.

Navision update	Demand	Safety stock & Reorder point	EOQ	Classification

Figure 66: *Overview of the sheet of the proposed model*

For each of the sheets, an overview in terms of a figure is given in combination with some explanations of the sheet. It is also mentioned how the sheets have to be updated when input data changes. When one follows this manual, he or she must be able to update the model and use the parameters to update the ERP system.

Navision update

The first sheet of the model is that of the *Navision update*. The following figure gives an overview of the sheet.

ITEM_MRP_UPDATE 44 *Fill in the month for which data is required at sheet 'Safety stock & Reorder point'*

No.	Base Unit of Measure	Reorder Point	Reorder Quantity	Safety Stock Quantity	Reordering Policy
100001	KG				
100002	KG				
100003	KG				
100004	KG				
100005	KG				
100006	KG				
100007	KG				
100008	KG				
100009	KG				
100010	KG				
100011	KG				
100012	KG				
100013	KG				
100014	KG				
100015	KG				
100016	KG				
100017	KG				
100018	KG				
100019	KG				
100020	KG				

Figure 67: *Overview of the sheet* Navision update

First of all, the number in the middle (in this case 44) states how many products currently have parameters that have to be included in the ERP system. Secondly, as one can see, the month for which the parameters are required has to be entered in another sheet. The sheet will automatically be updated when any value for either the reorder point, order quantity or safety stock changes. These values can easily be copied and pasted to the configuration package which can be implemented in the ERP system.

Even though this already eases the process of implementing the found parameters in the ERP system, there is one disadvantage. When a new product is made and included in the ERP system, it is not automatically changed in the sheet even though it will be part of the configuration package. Therefore, new items have to be added to the *Navision update* sheet manually. Nevertheless, the formulas can be extended, thus, adding a new item does not mean that a new formula has to be generated. As a result, when one downloads the configuration package, he or she has to check whether there are new items compared to the *Navision update* sheet and update the number of products when required.

Demand

The second sheet that will be handled is that of the *Demand.* As the name suggest, it is a sheet to store the demand data. An overview of the sheet is given in the following figure.

TENCATE GRASS YARNS

Item No	Description	P1 - 2019	P2 -2019	P3 -2019	P4 - 2019	P5 - 2019	P6 - 2019
100001							
100002							
100003							
100004							
100005							
100006							
100007							
100008							
100009							
100010							
100011							
100012							
100013							
100014							
100015							
100016							
100017							
100018							
100019							
100020							
100021							
100022							
100023							
100024							

Figure 68: *Overview of the sheet Demand*

The data of this sheet influences the model by being used to determine the seasonal indices. Furthermore, it serves as a place where data is stored that may be analysed in the future. The demand data of 2012 to 2018 is already filled in and not subject to change. The demand of future periods can be updated when a period is locked. That way, the sheet can be updated by inserting the demand of a period.

Safety stock & Reorder point

The next sheet that is handled is that of the *Safety stock & Reorder point*. This sheet gives an overview of various parameters and calculates the safety stock and reorder point based on this data. The figure below gives an overview of the sheet, where all parameters are updated automatically. With the use of additional columns, the user has the ability to make a decision on whether or not to take obsolescence into account at all times.

(2 = Jan, 3 = Feb, 4 = Mar, 5 = Apr, 6 = May, 7 = Jun, 8 = Jul, 9 = Aug, 10 = Sep, 11 = Oct, 12 = Nov, 13 = Dec)

Month	2

44

Item No	MTS/MTO	z	σ_L	SS	Seasonal index	D_L	Demand	Reorder point	SS obsolescence	ROP obsolescence
100001										
100002										
100003										
100004										
100005										
100006										
100007										
100008										
100009										
100010										
100011										
100012										
100013										
100014										
100015										
100016										
100017										
100018										
100019										
100020										

Figure 69: *Overview of the sheet Safety stock & Reorder point*

The first input that is required is the month for which the parameters are required, where 2 represents the month January and 13 represents the month December. In contrast to the month there are no other input parameters on this sheet that have to be filled in by the user, since they are retrieved from other sheets or calculated automatically.

To ensure that the user of the model does not always have to update the formulas, he or she has to make sure that the demand of the last twelve months is part of the sheet. For that purpose, another table is added to the sheet, of which a figure can be found below.

Demand (last year)

Item No	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Average	Sum
100001														
100002														
100003														
100004														
100005														
100006														
100007														
100008														
100009														
100010														
100011														
100012														
100013														
100014														
100015														
100016														
100017														
100018														
100019														
100020														

Figure 70: *Table in the sheet Safety stock & Reorder point that consists of the demand data of the past twelve months*

When a new period is locked and the demand data can be retrieved, it has (besides updating the sheet *Demand*) to be included in this table. That way, the demand that is used in the formulas is updated automatically.

EOQ

Another parameter that is determined with the use of the policy is that of the economic order quantity. The sheet *EOQ* is a display of relevant parameters that are used to determine the EOQ. These parameters do not have to be updated within this sheet and the EOQ is automatically calculated. An overview of the sheet can be found in the following figure:

Item No	MTS/MTO	Cost price	Demand	Order costs	Holding costs	EOQ	EOQ obsolescence
100001							
100002							
100003							
100004							
100005							
100006							
100007							
100008							
100009							
100010							
100011							
100012							
100013							
100014							
100015							
100016							
100017							
100018							
100019							
100020							

Figure 71: *Overview of the sheet EOQ*

The only aspect that needs a decision by the user is whether or not obsolescence should be taken into account. The user has to take the column of its preference as policy parameter.

Some of the data is not available yet and has to be gained outside the model. For example, the order and holding costs are not part of the model. These costs are given in a hidden sheet, which will be discussed later. When all data is presented in the sheet, the EOQ is calculated.

Classification

The last sheet of the model is that of the *Classification*. Two important aspects to execute the classification are the cost price and the selling price. Both aspects are determined outside the model and included to the model as hidden sheets. Data for these aspects are then retrieved from the hidden sheets. The hidden sheets are handled in a later stage of the manual.

An overview of the sheet is given below.

Item No	Price	Costs	Demand (last 12 months)	Sales	ABCXYZ	Target CSL	Safety factor	45 MTS/MTO
100001								
100002								
100003								
100004								
100005								
100006								
100007								
100008								
100009								
100010								
100011								
100012								
100013								
100014								
100015								
100016								
100017								
100018								
100019								
100020								

Update?

Item	Sales	Ratio	Normalized	ABC
		0.10	0.10	A
		0.07	0.17	A
		0.06	0.23	A
		0.05	0.28	A
		0.05	0.32	A
		0.05	0.37	A
		0.04	0.42	A
		0.04	0.45	A
		0.04	0.49	A
		0.03	0.52	A
		0.02	0.54	A
		0.02	0.56	A
		0.02	0.58	A
		0.02	0.59	A
		0.01	0.61	A
		0.02	0.63	A
		0.01	0.64	A
		0.01	0.66	A
		0.01	0.67	A
		0.02	0.69	A

Item	Months with sale	XYZ
100001		
100002		
100003		
100004		
100005		
100006		
100007		
100008		
100009		
100010		
100011		
100012		
100013		
100014		
100015		
100016		
100017		
100018		
100019		
100020		

Figure 72: *Overview of the sheet Classification*

Most of the parameters in this sheet are updated automatically, with exception of the ABC-classification. The ABC-classification has to be updated by sorting the sales from largest-to-smallest (Z-to-A). Thereafter, the whole classification (ABCXYZ) is updated automatically leading to values for either the target cycle service level and the safety factor. The output of the safety factor and the determination on whether the product is MTO or MTS will then automatically be updated in other sheets, leading to a different output of the model. Therefore, the only step for a user of the model to actually use the model is to sort the sales and update the hidden sheets.

Hidden sheets

As said before, there are hidden sheets containing data that is relevant to make a workable model. An overview of the hidden sheets is given below.

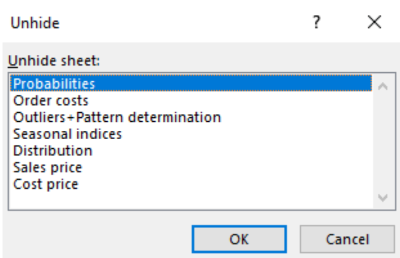


Figure 73: *Overview of the hidden sheets available in the proposed model*

To unhide the hidden sheets, the user has to right-click on the sheet bar and choose the option *Unhide.* An overview as given in the figure above appears. The user has to select the sheet that he or she wants to unhide and press *OK*. As a result, the selected sheet is unhidden. If the user wants to hide the sheet again, he or she has to right-click on the specific sheet in the sheet bar and choose the option *Hide*.

There are three sheets which purely consist of a data table. Therefore, they will not be discussed separately and a short summary of these sheets is given below:

- The *Probabilities* sheet consist of a data table that gives an overview of the probabilities for a product to have inventory for over a year or the probability to have products in inventory for over two years. These probabilities are used to determine the additional costs to take obsolescence into account.
- The *Sales price* sheet consists of a data table that states the selling price per product. The selling price is purely used to execute the classification of products.
- The *Cost price* sheet consists of a data table with the most up-to-date cost prices. This list can easily be updated by gaining data from the ERP system. The cost prices are used to execute the classification and with inclusion of obsolescence it is also used to determine the economic order quantity.

Each of the three sheets can be updated when the user thinks that the data is not representative for the current situation.

The remainder of the hidden sheets do not purely consist of data and are discussed in this manual.

Order costs

The first hidden sheet that will be discussed is the sheet of the *Order costs.* An overview of the sheet is given below.

Input data	
Die change	
Colour + Material	
Colour	
Material	

	Probability die change	Probability colour change	Probability material change
Rib-Rectangle	0.55	0.95	0.94
Diamond	0.21	0.85	0.75
Mini Rib-Diamond	0.5	0.97	0.76
Trilobal	0.63	1	0.8
Splash	0.67	1	0.81
Rib-Diamond	0.35	0.9	0.63
MS-Pro	0.78	1	0.93
Epsilon	1	1	1
Large-Rib-C	1	1	1
Komma	0.8	1	0.92
Omega	0.5	0.92	1
Wave	1	1	1
Polar	0.67	0.92	0.92
Average	0.66	0.96	0.88

Item No	Shape	P(die)	P(colour)	P(material)	Order costs
100001					
100002					
100003					
100004					
100005					
100006					
100007					
100008					
100009					
100010					
100011					
100012					
100013					
100014					
100015					
100016					
100017					
100018					
100019					
100020					

Figure 74: *Overview of the hidden sheet Order costs*

As one can see, there is some data that has to be filled in manually. Namely, the cost of a die change and the cost of a colour and material change. The costs of a colour or material change individually are automatically updated when the costs for a colour and material change are entered.

When the user thinks that the costs of a die change and the cost of a colour and material change do not correspond with reality, he or she can adjust the costs manually. The order costs automatically update as a result of changing input data.

Furthermore, a table with the probabilities of facing a certain changeover is given for several shapes. If the item has a shape that is not part of the table, average probabilities are taken. The probabilities are based on data of 2018. If the user wants to update the probabilities, they first have to be determined.

The probabilities are determined by defining the number of orders produced during one die and the ratio of colour and material changes related to the found number. By taking the average of all results related to a shape, the probability per shape is found. The average probabilities is the average of all shapes available.

The last aspect that has to be updated to have reliable order costs is that of the shape in the right table. The shape has to be written in the same way as it is stated in the probabilities table. If the shape is not available in the table, the box representing the shape could be left blank, such that the average probabilities are taken.

If all these aspects, the costs, the probabilities and the shape are filled in, the order costs will automatically be updated and implemented in the actual inventory control policy. The order costs are used to determine the economic order quantity.

Outliers + Pattern determination

Another hidden sheet that will be discussed is the *Outliers + Pattern determination* sheet. This sheet is not essential to have a workable model, but is gives a global overview of the demand. A representation of the sheet is given below.

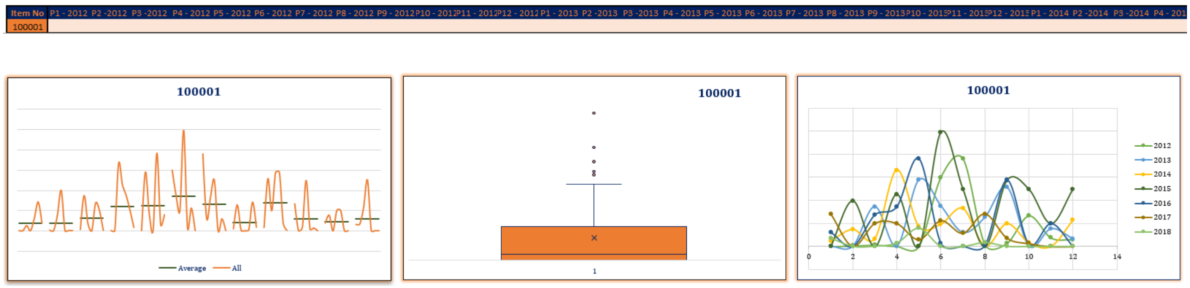


Figure 75: *Overview of the hidden sheet Outliers + Pattern determination*

The demand will automatically be updated, so the user only has to determine for which product graphs are wanted. The first graph represents a seasonal subseries plot, which indicates whether the product is following a clear season. The second graphs represents a box plot, which indicates whether there are some outliers in the demand that could be removed in order to calculate the parameters. The last graph compares the demand of the different years to see whether the product is following a general pattern.

As a result, the sheet is helpful in gaining some understanding about the product but it is not required to have a workable inventory control policy.

Seasonal indices

A sheet that is required to have a working inventory control policy is that of the *Seasonal indices*. An overview of the sheet is given below.

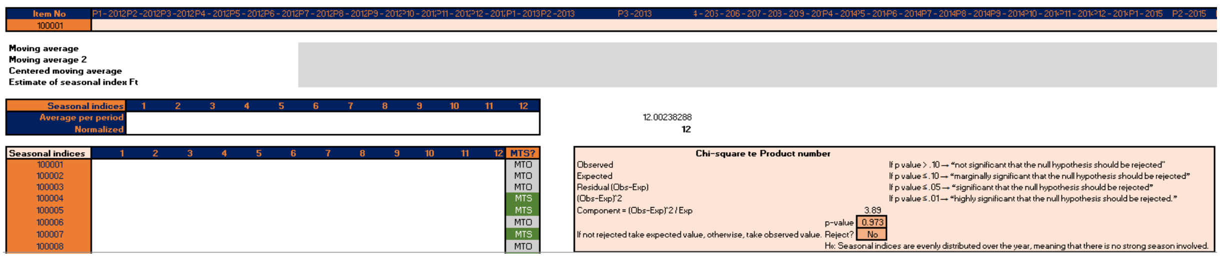


Figure 76: *Overview of the hidden sheet Seasonal indices*

This sheet is quite a challenging one, since the seasonal indices will not automatically be updated when new demand is retrieved.

The first step in updating the seasonal indices is to extend the formulas of the moving average, moving average 2, centred moving average and estimate of seasonal index F_t to the month which is six months before the last period for which the demand is available. The formulas for the last six months are not yet updated since we work with moving averages.

The second step is to choose the product for which the seasonal indices are required and copy and paste the normalized indices to the data table in the bottom of the sheet if the Chi-Square test concludes that the null-hypothesis could be rejected, otherwise take the expected values, which means that every seasonal index of a product should equal 1. The model will retrieve data from this data table, therefore, it is essential to update this table.

It takes a lot of work to update the seasonal indices for all products, therefore, it is suggested to only update the seasonal indices for the products that are considered to be MTS. The reason is that only these products make use of the seasonal indices to determine the parameters of the inventory control policy. For that reason, a column is added to the data table, stating which products are considered to be MTS based on the model.

Distribution

The final sheet of the model is that of the *Distribution*. This sheet is not required to have a workable model, but it gives an indication whether a Normal distribution can be assumed. It can be assumed that a Normal distribution is reasonable if the mean demand during lead time is higher than ten. This sheet will be updated automatically and does not require any actions from the user. It serves to give an indication about the distribution. If a Normal distribution cannot be assumed, we look at the months for which there was sale. If this number is rather small compared to the number of months for which there is data available, it can be assumed that the product is MTO. In that case, it is not really necessary to determine a distribution. However, when a product is classified as MTS and it appears that a Normal distribution cannot be assumed, the inventory control policy may not be used to determine the reorder point, safety stock and economic order quantity. If that is the case, the user has to find a fitting distribution and another way to determine the relevant parameters. An overview of the sheet is given below.

Based on a yearly basis

Item N	Mean demand (last yea	Mean demand per we	Lead tim	Mean demand during lead tin	Distribution	Months of sale
100001			4		Normal distributed	
100002			4		Normal distributed	
100003			4		MTO	0
100004			4		Normal distributed	
100005			4		Normal distributed	

Figure 77: *Overview of the hidden sheet Distribution*

Appendix N: Overview of the dashboard of the Monte Carlo simulation

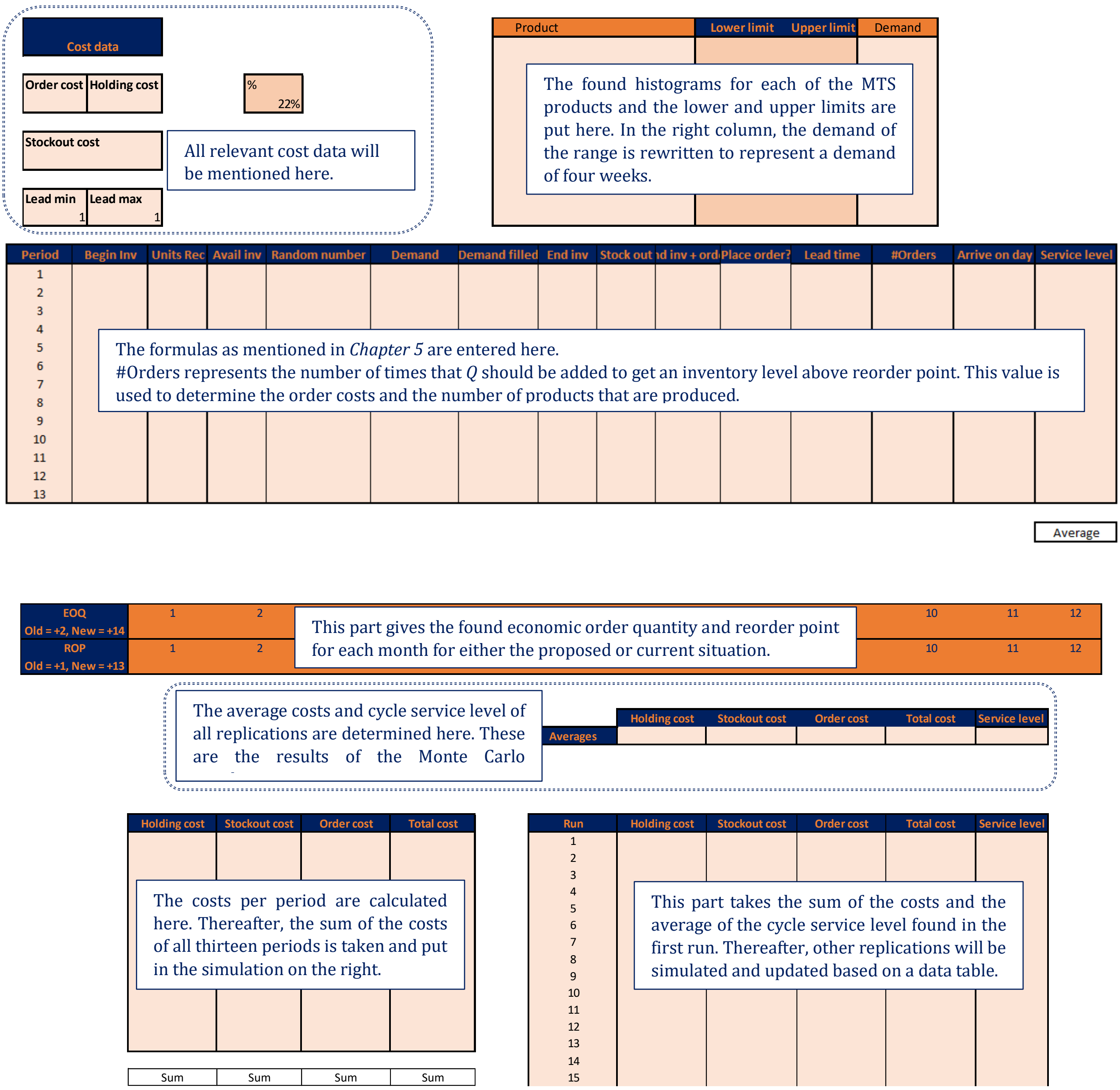


Figure 78: *Overview of the dashboard of the Monte Carlo simulation*

Appendix O: Results of the Monte Carlo simulation

The values are multiplied with a random factor for confidentiality reasons.

Current model — € 864,554,197.81 | 0.89

Item	Holding cost	Stockout costs	Order cost	Totals costs	Service level
100004	€ 7,560,616.95	€ 28,376.90	€ 1,909,156.83	€ 9,498,150.68	1.00
100005	€ 5,206,412.29	€ 10,024.34	€ 1,214,083.56	€ 6,430,520.19	1.00
100007	€ 4,992,892.94	€ 952,434.19	€ 2,125,550.19	€ 8,070,877.33	0.89
100009	€ 955,550.95	€ 16,669.93	€ 538,758.27	€ 1,510,979.16	0.98
100021	€ 10,633,992.25	€ 691,922.55	€ 4,476,950.52	€ 15,802,865.32	0.97
100022	€ 9,359,444.81	€ 903,469.00	€ 4,084,772.32	€ 14,347,686.13	0.95
100023	€ 1,009,772.34	€ 3,243.82	€ 771,283.78	€ 1,784,299.94	1.00
100024	€ 4,108,283.60	€ 196,636.07	€ 1,999,830.66	€ 6,304,750.32	0.97
100025	€ 2,573,378.56	€ 206.44	€ 786,581.51	€ 3,360,166.51	1.00
100026	€ 1,370,753.11	€ 13,963.65	€ 506,493.97	€ 1,891,210.73	0.98
100027	€ 7,920,322.35	€ 37,112.10	€ 2,194,529.05	€ 10,151,963.50	1.00
100040	€ 5,824,932.93	€ 93,126.76	€ 1,624,897.17	€ 7,542,956.87	0.99
100099	€ 5,546,678.40	€ 124,956.25	€ 1,911,938.24	€ 7,583,572.88	0.96
100104	€ 3,274,011.97	€ 238,939.68	€ 1,969,513.33	€ 5,482,464.98	0.95
100122	€ -	€ 2,513,825.28	€ 9,762,733.80	€ 12,276,559.07	0.00
100124	€ 5,729,430.87	€ 3,373,846.74	€ 1,905,819.14	€ 11,009,096.76	0.54
110002	€ 10,963,287.54	€ 1,156,075.56	€ 17,798,704.83	€ 29,918,067.92	0.89
110007	€ 18,211,555.93	€ 4,987,625.14	€ 21,642,245.16	€ 44,841,426.24	0.85
110008	€ 151,161.07	€ 9,826,895.46	€ 68,995,713.47	€ 78,973,770.00	0.05
110009	€ 4,441,851.41	€ 127,333.82	€ 12,674,526.95	€ 17,243,712.19	0.97
110010	€ 7,124,625.63	€ 179,844.39	€ 6,500,536.31	€ 13,805,006.33	0.97
110011	€ 5,146,996.11	€ 280,200.94	€ 17,412,080.62	€ 22,839,277.67	0.97
110018	€ 12,329,341.04	€ 2,551.43	€ 7,093,185.90	€ 19,425,078.37	1.00
110019	€ 2,451,825.39	€ 1,831.58	€ 1,585,525.24	€ 4,039,182.22	1.00
110020	€ 8,262,306.85	€ 1,109,380.60	€ 12,983,039.73	€ 22,354,727.18	0.96
110028	€ 15,962,517.79	€ 401,936.89	€ 5,291,291.45	€ 21,655,746.13	0.97
110030	€ 6,033,375.46	€ 142,247.25	€ 3,701,332.41	€ 9,876,955.12	0.98
110036	€ 10,934,291.95	€ 1,769,972.03	€ 45,309,552.75	€ 58,013,816.73	0.95
110047	€ 5,835,105.99	€ 872,330.58	€ 24,363,344.79	€ 31,070,781.36	0.97
110110	€ 3,690,228.30	€ 555,937.91	€ 15,061,115.57	€ 19,307,281.78	0.89
110117	€ 25,791,355.31	€ 747,410.88	€ 16,814,614.18	€ 43,353,380.37	0.97
110176	€ 2,585,217.42	€ 41,796.71	€ 10,256,719.78	€ 12,883,733.91	0.98
110208	€ 11,342.34	€ 28,448.53	€ 67,428,435.59	€ 67,468,226.47	0.31
110211	€ 4,813,153.75	€ -	€ 3,593,770.27	€ 8,406,924.02	1.00
110224	€ 25,555,779.29	€ 23,710.88	€ 4,813,328.30	€ 30,392,818.47	1.00
110225	€ 6,206,454.91	€ 13,142.67	€ 4,694,502.58	€ 10,914,100.16	1.00
110239	€ 8,626,427.25	€ 1,774,408.03	€ 18,672,087.81	€ 29,072,923.10	0.90
110242	€ 861,742.89	€ 15,584.06	€ 5,958,210.42	€ 6,835,537.37	0.97
110244	€ 8,112,379.94	€ 628,589.69	€ 16,221,400.67	€ 24,962,370.30	0.88
110245	€ 5,211,056.74	€ 8,588.54	€ 14,964,319.49	€ 20,183,964.76	1.00
110323	€ 10,315,123.29	€ 137,082.80	€ 28,414,467.67	€ 38,866,673.76	0.99
110324	€ 2,602,647.90	€ 835,141.80	€ 19,585,243.21	€ 23,023,032.91	0.88
110326	€ 5,488,193.50	€ 324,909.94	€ 14,766,262.10	€ 20,579,365.53	0.95
110332	€ 2,229,366.60	€ 70,627.70	€ 8,898,202.78	€ 11,198,197.08	0.93
Total	€ 296,015,185.91	€ 35,262,359.50	€ 533,276,652.41	€ 864,554,197.81	0.89

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Cheaper option	*Difference in costs*
NEW	€ 285,726.57
NEW	€ 926,629.07
NEW	€ 127,215.66
OLD	€ -68,608.26
NEW	€ 6,320,426.03
NEW	€ 2,757,599.84
OLD	€ -43,677.47
OLD	€ -390,588.85
OLD	€ -1,741,138.97
OLD	€ -74,507.46
OLD	€ -88,335.56
NEW	€ 338,932.10
NEW	€ 669,574.42
OLD	€ -241,361.36
NEW	€ 5,958,485.65
OLD	€ -3,638,321.20
NEW	€ 9,439,503.25
NEW	€ 8,482,461.63
NEW	€ 68,734,201.67
NEW	€ 3,173,988.86
NEW	€ 852,109.98
NEW	€ 7,323,710.56
NEW	€ 418,085.74
NEW	€ 934,837.27
NEW	€ 1,847,464.18
NEW	€ 1,166,519.66
NEW	€ 372,820.89
NEW	€ 30,047,452.29
NEW	€ 17,882,170.62
NEW	€ 6,281,263.69
NEW	€ 14,058,820.15
NEW	€ 3,647,256.02
NEW	€ 66,030,619.32
OLD	€ -10,503,631.62
NEW	€ 2,993,353.25
NEW	€ 2,080,933.35
NEW	€ 6,213,297.50
OLD	€ -3,941,632.16
OLD	€ -11,382,398.65
NEW	€ 6,322,317.20
NEW	€ 9,066,494.06
NEW	€ 1,484,080.56
OLD	€ -11,885,798.04
NEW	€ 1,871,958.90

Proposed model — € 620,443,887.46 | 0.94

Item	Holding cost	Stockout costs	Order cost	Total costs	Service level
100004	€ 6,460,168.03	€ 30,650.66	€ 2,721,605.42	€ 9,212,424.11	1.00
100005	€ 3,740,577.16	€ 136,469.79	€ 1,626,844.16	€ 5,503,891.11	0.98
100007	€ 2,800,964.94	€ 496,080.47	€ 4,646,616.26	€ 7,943,661.67	0.95
100009	€ 961,760.11	€ 17,043.69	€ 600,783.62	€ 1,579,587.41	0.98
100021	€ 4,239,615.86	€ 635,981.27	€ 4,606,842.16	€ 9,482,439.30	0.97
100022	€ 4,455,799.26	€ 779,887.71	€ 6,354,399.33	€ 11,590,086.29	0.96
100023	€ 764,370.45	€ 9,732.36	€ 1,053,874.60	€ 1,827,977.41	0.99
100024	€ 2,941,537.62	€ 213,628.45	€ 3,540,173.10	€ 6,695,339.17	0.98
100025	€ 2,413,712.79	€ 159,573.10	€ 2,528,019.59	€ 5,101,305.48	0.98
100026	€ 1,123,595.52	€ 3,250.73	€ 838,871.94	€ 1,965,718.19	0.99
100027	€ 7,122,887.38	€ 58,143.61	€ 3,059,268.06	€ 10,240,299.06	0.99
100040	€ 3,983,706.73	€ 312,914.72	€ 2,907,403.32	€ 7,204,024.76	0.95
100099	€ 4,141,112.78	€ 148,907.60	€ 2,623,978.08	€ 6,913,998.47	0.96
100104	€ 2,119,284.02	€ 409,819.81	€ 3,194,722.52	€ 5,723,826.34	0.93
100122	€ 3,517,023.94	€ 137,019.16	€ 2,664,030.32	€ 6,318,073.42	0.78
100124	€ 4,535,567.52	€ 4,083,153.71	€ 6,028,696.72	€ 14,647,417.95	0.55
110002	€ 10,207,115.07	€ 1,460,064.42	€ 8,811,385.18	€ 20,478,564.67	0.83
110007	€ 21,858,086.76	€ 145,444.94	€ 14,355,432.92	€ 36,358,964.61	1.00
110008	€ 3,083,492.86	€ 366,582.76	€ 6,789,492.72	€ 10,239,568.33	0.91
110009	€ 5,225,477.20	€ 115,562.47	€ 8,728,683.66	€ 14,069,723.33	0.97
110010	€ 8,893,898.64	€ 7,710.95	€ 4,051,286.77	€ 12,952,896.35	1.00
110011	€ 4,190,024.99	€ 439,551.78	€ 10,885,990.35	€ 15,515,567.12	0.96
110018	€ 10,052,478.57	€ 44,358.79	€ 8,910,155.26	€ 19,006,992.62	1.00
110019	€ 1,770,501.17	€ 56,023.94	€ 1,277,819.84	€ 3,104,344.95	0.97
110020	€ 8,404,120.80	€ 1,284,681.39	€ 10,818,460.81	€ 20,507,263.00	0.95
110028	€ 10,452,161.61	€ 795,261.70	€ 9,241,803.16	€ 20,489,226.47	0.97
110030	€ 4,921,443.80	€ 634,839.00	€ 3,947,851.44	€ 9,504,134.24	0.90
110036	€ 9,937,787.61	€ 1,083,409.85	€ 16,945,166.98	€ 27,966,364.43	0.94
110047	€ 4,211,429.44	€ 351,346.39	€ 8,625,834.91	€ 13,188,610.74	0.98
110110	€ 4,072,556.06	€ 308,642.19	€ 8,644,819.85	€ 13,026,018.09	0.92
110117	€ 5,917,234.49	€ 6,586,075.66	€ 16,791,250.07	€ 29,294,560.22	0.77
110176	€ 3,028,887.80	€ 34,564.30	€ 6,173,025.79	€ 9,236,477.89	0.99
110208	€ 251,587.31	€ 3.79	€ 1,186,016.05	€ 1,437,607.15	1.00
110211	€ 4,014,347.10	€ 171,637.33	€ 14,724,571.21	€ 18,910,555.64	0.90
110224	€ 22,734,542.94	€ 16,531.16	€ 4,648,391.11	€ 27,399,465.22	1.00
110225	€ 3,418,023.27	€ 461,707.30	€ 4,953,436.24	€ 8,833,166.81	0.92
110239	€ 5,183,735.62	€ 586,182.49	€ 17,089,707.49	€ 22,859,625.60	0.97
110242	€ 1,693,550.33	€ 42,530.43	€ 9,041,088.77	€ 10,777,169.53	0.92
110244	€ 7,410,005.68	€ 727,230.54	€ 28,207,532.73	€ 36,344,768.95	0.87
110245	€ 5,552,600.30	€ 7,196.34	€ 8,301,850.92	€ 13,861,647.56	1.00
110323	€ 7,846,346.55	€ 448,693.47	€ 21,505,139.68	€ 29,800,179.70	0.98
110324	€ 9,537,244.19	€ 385,759.72	€ 11,615,948.43	€ 21,538,952.34	0.91
110326	€ 8,020,003.83	€ 1,592,049.64	€ 22,853,110.11	€ 32,465,163.57	0.81
110332	€ 2,833,170.47	€ 156,259.73	€ 6,336,807.97	€ 9,326,238.18	0.90
Total	€ 250,043,538.52	€ 25,942,159.35	€ 344,458,189.58	€ 620,443,887.46	0.94

Figure 79: *Results of the Monte Carlo simulation per product*

Current model															
										€ 864,554,197.81	€ 564,462,659.12	€ 1,221,404,358.99	0.89	0.73	0.97
Item	**Holding cost**	**Min**	**Max**	**Stockout costs**	**Min**	**Max**	**Order cost**	**Min**	**Max**	**Totals costs**	**Min**	**Max**	**Service level**	**Min**	**Max**
100004	€ 7,560,616.95	€ 4,789,497.87	€ 10,036,588.63	€ 28,376.90	€ -	€ 821,616.22	€ 1,909,156.83	€ 901,175.43	€ 3,454,505.80	€ 9,498,150.68	€ 8,125,459.07	€ 11,132,866.40	1.00	0.92	1.00
100005	€ 5,206,412.29	€ 3,552,587.82	€ 7,218,592.34	€ 10,024.34	€ -	€ 135,410.78	€ 1,214,083.56	€ 300,391.81	€ 2,403,134.47	€ 6,430,520.19	€ 5,557,957.13	€ 8,027,298.92	1.00	0.98	1.00
100007	€ 4,992,892.94	€ 1,761,299.58	€ 8,460,307.52	€ 952,434.19	€ -	€ 7,362,668.96	€ 2,125,550.19	€ 901,175.43	€ 3,604,701.71	€ 8,070,877.33	€ 5,975,610.42	€ 13,480,188.58	0.89	0.62	1.00
100009	€ 955,550.95	€ 317,745.50	€ 1,873,204.88	€ 16,669.93	€ -	€ 218,708.45	€ 538,758.27	€ -	€ 1,351,763.14	€ 1,510,979.16	€ 1,067,877.93	€ 2,040,862.72	0.98	0.83	1.00
100021	€ 10,633,992.25	€ 4,727,209.73	€ 14,843,942.26	€ 691,922.55	€ -	€ 4,052,926.07	€ 4,476,950.52	€ 3,003,918.09	€ 6,458,423.90	€ 15,802,865.32	€ 12,632,891.29	€ 19,053,480.32	0.97	0.87	1.00
100022	€ 9,359,444.81	€ 3,219,816.57	€ 16,567,882.13	€ 903,469.00	€ -	€ 5,401,942.80	€ 4,084,772.32	€ 1,652,154.95	€ 5,857,640.28	€ 14,347,686.13	€ 8,343,576.83	€ 19,421,604.32	0.95	0.77	1.00
100023	€ 1,009,772.34	€ 580,168.59	€ 1,394,470.33	€ 3,243.82	€ -	€ 62,983.94	€ 771,283.78	€ 300,391.81	€ 1,201,567.24	€ 1,784,299.94	€ 1,361,980.46	€ 2,171,059.42	1.00	0.95	1.00
100024	€ 4,108,283.60	€ 1,793,698.02	€ 6,100,037.23	€ 196,636.07	€ -	€ 1,465,929.58	€ 1,999,830.66	€ 901,175.43	€ 3,154,114.00	€ 6,304,750.32	€ 5,076,106.22	€ 7,497,213.56	0.97	0.84	1.00
100025	€ 2,573,378.56	€ 1,867,159.97	€ 3,628,607.43	€ 206.44	€ -	€ 27,805.59	€ 786,581.51	€ 300,391.81	€ 1,652,154.95	€ 3,360,166.51	€ 2,839,310.70	€ 3,928,999.24	1.00	0.99	1.00
100026	€ 1,370,753.11	€ 679,717.58	€ 1,985,757.59	€ 13,963.65	€ -	€ 315,110.47	€ 506,493.97	€ 150,195.90	€ 1,051,371.33	€ 1,891,210.73	€ 1,217,085.03	€ 2,373,714.05	0.98	0.77	1.00
100027	€ 7,920,322.35	€ 5,211,322.32	€ 10,789,589.15	€ 37,112.10	€ -	€ 728,091.12	€ 2,194,529.05	€ 901,175.43	€ 4,055,289.42	€ 10,151,963.50	€ 8,818,549.19	€ 11,840,960.48	1.00	0.95	1.00
100040	€ 5,824,932.93	€ 3,413,171.03	€ 8,058,743.12	€ 93,126.76	€ -	€ 874,116.19	€ 1,624,897.17	€ 450,587.71	€ 3,154,114.00	€ 7,542,956.87	€ 6,463,636.93	€ 8,684,278.58	0.99	0.90	1.00
100099	€ 5,546,678.40	€ 3,674,906.01	€ 7,609,636.95	€ 124,956.25	€ -	€ 676,481.87	€ 1,911,938.24	€ 600,783.62	€ 3,304,309.90	€ 7,583,572.88	€ 6,411,776.73	€ 8,728,746.74	0.96	0.86	1.00
100104	€ 3,274,011.97	€ 1,231,298.04	€ 4,608,003.31	€ 238,939.68	€ -	€ 2,034,590.80	€ 1,969,513.33	€ 1,051,371.33	€ 3,454,505.80	€ 5,482,464.98	€ 4,733,585.31	€ 6,666,586.58	0.95	0.80	1.00
100122	€ -	€ -	€ -	€ 2,513,825.28	€ -	€ 10,878,261.43	€ 9,762,733.80	€ 9,762,733.80	€ 9,762,733.80	€ 12,276,559.07	€ 9,762,733.80	€ 20,640,995.23	0.00	0.00	0.00
100124	€ 5,729,430.87	€ 2,525,249.87	€ 9,538,910.14	€ 3,373,846.74	€ -	€ 12,066,521.16	€ 1,905,819.14	€ 750,979.52	€ 3,003,918.09	€ 11,009,096.76	€ 6,347,380.41	€ 19,520,827.70	0.54	0.20	1.00
110002	€ 10,963,287.54	€ 6,113,285.96	€ 16,423,415.19	€ 1,156,075.56	€ -	€ 6,931,544.34	€ 17,798,704.83	€ 4,966,438.76	€ 29,798,632.55	€ 29,918,067.92	€ 18,814,655.48	€ 42,400,775.73	0.89	0.58	1.00
110007	€ 18,211,555.93	€ 10,884,688.84	€ 28,489,218.57	€ 4,987,625.14	€ -	€ 22,408,677.25	€ 21,642,245.16	€ 7,430,307.60	€ 37,151,538.02	€ 44,841,426.24	€ 32,194,152.67	€ 63,495,594.16	0.85	0.68	1.00
110008	€ 151,161.07	€ -	€ 957,600.39	€ 9,826,895.46	€ 257,126.37	€ 27,971,840.79	€ 68,995,713.47	€ 68,995,713.47	€ 68,995,713.47	€ 78,973,770.00	€ 69,539,315.18	€ 96,967,554.25	0.05	0.02	0.58
110009	€ 4,441,851.41	€ 2,957,873.53	€ 6,131,653.19	€ 127,333.82	€ -	€ 649,310.54	€ 12,674,526.95	€ 6,848,157.79	€ 21,522,781.62	€ 17,243,712.19	€ 12,636,570.05	€ 25,003,183.41	0.97	0.92	1.00
110010	€ 7,124,625.63	€ 4,090,871.69	€ 12,597,589.09	€ 179,844.39	€ -	€ 3,752,483.91	€ 6,500,536.31	€ 1,061,472.51	€ 16,983,560.24	€ 13,805,006.33	€ 9,189,113.23	€ 22,660,207.68	0.97	0.71	1.00
110011	€ 5,146,996.11	€ 2,430,400.07	€ 8,485,915.79	€ 280,200.94	€ -	€ 2,259,332.46	€ 17,412,080.62	€ 7,430,307.60	€ 28,659,757.90	€ 22,839,277.67	€ 14,376,938.32	€ 32,733,829.64	0.97	0.83	1.00
110018	€ 12,329,341.04	€ 7,213,035.65	€ 16,952,333.97	€ 2,551.43	€ -	€ 113,114.64	€ 7,093,185.90	€ 3,830,799.24	€ 12,928,947.43	€ 19,425,078.37	€ 17,014,770.15	€ 21,460,052.05	1.00	0.99	1.00
110019	€ 2,451,825.39	€ 1,646,160.51	€ 3,330,462.93	€ 1,831.58	€ -	€ 41,095.88	€ 1,585,525.24	€ -	€ 3,830,799.24	€ 4,039,182.22	€ 2,889,386.88	€ 5,818,964.34	1.00	0.98	1.00
110020	€ 8,262,306.85	€ 2,681,624.10	€ 14,036,501.22	€ 1,109,380.60	€ -	€ 6,674,342.49	€ 12,983,039.73	€ 5,267,348.95	€ 22,027,095.62	€ 22,354,727.18	€ 18,512,377.64	€ 31,016,166.05	0.96	0.80	1.00
110028	€ 15,962,517.79	€ 9,910,757.43	€ 23,275,308.77	€ 401,936.89	€ -	€ 4,416,658.69	€ 5,291,291.45	€ 1,915,399.62	€ 8,619,298.28	€ 21,655,746.13	€ 18,322,448.36	€ 25,526,762.27	0.97	0.83	1.00
110030	€ 6,033,375.46	€ 1,775,771.85	€ 13,128,488.09	€ 142,247.25	€ -	€ 1,093,273.43	€ 3,701,332.41	€ -	€ 9,576,998.09	€ 9,876,955.12	€ 7,229,612.94	€ 14,354,989.53	0.98	0.83	1.00
110036	€ 10,934,291.95	€ 3,013,944.43	€ 17,852,166.02	€ 1,769,972.03	€ -	€ 9,814,901.58	€ 45,309,552.75	€ 19,234,024.33	€ 73,977,016.65	€ 58,013,816.73	€ 36,577,270.42	€ 84,137,550.71	0.95	0.80	1.00
110047	€ 5,835,105.99	€ 304,945.45	€ 18,666,144.26	€ 872,330.58	€ -	€ 8,718,387.51	€ 24,363,344.79	€ 1,241,609.69	€ 71,017,935.98	€ 31,070,781.36	€ 1,582,190.16	€ 83,028,148.31	0.97	0.78	1.00
110110	€ 3,690,228.30	€ 585,813.45	€ 6,518,008.60	€ 555,937.91	€ -	€ 8,562,178.78	€ 15,061,115.57	€ 4,245,890.06	€ 28,659,757.90	€ 19,307,281.78	€ 9,526,387.51	€ 37,807,750.13	0.89	0.43	1.00
110117	€ 25,791,355.31	€ 13,907,912.88	€ 37,016,514.49	€ 747,410.88	€ -	€ 6,801,802.26	€ 16,814,614.18	€ 4,966,438.76	€ 37,248,290.69	€ 43,353,380.37	€ 32,598,806.67	€ 57,250,247.92	0.97	0.78	1.00
110176	€ 2,585,217.42	€ 1,424,316.37	€ 3,720,116.02	€ 41,796.71	€ -	€ 542,067.73	€ 10,256,719.78	€ 4,770,567.34	€ 16,696,985.69	€ 12,883,733.91	€ 8,128,902.28	€ 18,893,733.86	0.98	0.89	1.00
110208	€ 11,342.34	€ 547.67	€ 49,654.77	€ 28,448.53	€ -	€ 128,188.53	€ 67,428,435.59	€ -	€ 77,521,719.27	€ 67,468,226.47	€ 49,654.77	€ 77,651,301.77	0.31	0.00	1.00
110211	€ 4,813,153.75	€ 3,504,965.42	€ 6,686,153.91	€ -	€ -	€ -	€ 3,593,770.27	€ 1,241,609.69	€ 7,449,658.14	€ 8,406,924.02	€ 5,213,786.59	€ 11,295,442.30	1.00	1.00	1.00
110224	€ 25,555,779.29	€ 16,657,386.24	€ 32,243,644.68	€ 23,710.88	€ -	€ 595,801.71	€ 4,813,328.30	€ 957,699.81	€ 11,971,247.62	€ 30,392,818.47	€ 27,381,884.23	€ 34,868,615.67	1.00	0.00	1.00
110225	€ 6,206,454.91	€ 3,792,448.24	€ 8,224,371.44	€ 13,142.67	€ -	€ 178,612.54	€ 4,694,502.58	€ 478,849.90	€ 9,576,998.09	€ 10,914,100.16	€ 7,843,071.27	€ 13,550,229.20	1.00	0.97	1.00
110239	€ 8,626,427.25	€ 5,149,161.39	€ 12,604,357.02	€ 1,774,408.03	€ -	€ 6,588,571.86	€ 18,672,087.81	€ 9,553,252.63	€ 29,721,230.42	€ 29,072,923.10	€ 20,806,311.51	€ 38,749,403.54	0.90	0.74	1.00
110242	€ 861,742.89	€ 495,194.36	€ 1,245,815.47	€ 15,584.06	€ -	€ 272,491.11	€ 5,958,210.42	€ 1,259,269.52	€ 12,592,695.22	€ 6,835,537.37	€ 2,126,578.48	€ 13,277,249.80	0.97	0.74	1.00
110244	€ 8,112,379.94	€ 4,368,918.97	€ 10,680,118.51	€ 628,589.69	€ -	€ 7,236,177.92	€ 16,221,400.67	€ 7,449,658.14	€ 29,798,632.55	€ 24,962,370.30	€ 17,098,563.44	€ 40,245,323.90	0.88	0.50	1.00
110245	€ 5,211,056.74	€ 3,343,332.04	€ 7,423,118.15	€ 8,588.54	€ -	€ 306,767.27	€ 14,964,319.49	€ 5,037,078.09	€ 22,666,851.40	€ 20,183,964.76	€ 12,163,490.15	€ 26,515,108.93	1.00	0.95	1.00
110323	€ 10,315,123.29	€ 5,436,370.98	€ 15,572,870.01	€ 137,082.80	€ -	€ 1,431,448.64	€ 28,414,467.67	€ 14,899,316.27	€ 40,973,119.76	€ 38,866,673.76	€ 30,472,186.28	€ 48,760,716.03	0.99	0.95	1.00
110324	€ 2,602,647.90	€ 153,229.95	€ 4,121,621.07	€ 835,141.80	€ -	€ 6,623,035.39	€ 19,585,243.21	€ 12,416,096.90	€ 36,006,681.00	€ 23,023,032.91	€ 16,238,913.39	€ 41,541,336.65	0.88	0.50	1.00
110326	€ 5,488,193.50	€ 2,532,223.29	€ 8,561,016.33	€ 324,909.94	€ -	€ 2,133,919.17	€ 14,766,262.10	€ 6,368,835.09	€ 27,598,285.39	€ 20,579,365.53	€ 13,602,658.06	€ 31,610,025.40	0.95	0.77	1.00
110332	€ 2,229,366.60	€ 1,430,360.88	€ 2,791,217.09	€ 70,627.70	€ -	€ 239,668.74	€ 8,898,202.78	€ 4,966,438.76	€ 13,657,706.59	€ 11,198,197.08	€ 7,597,145.54	€ 15,574,412.96	0.93	0.90	1.00
Total	€ 296,015,185.91	€ 155,150,390.12	€ 450,499,668.04	€ 35,262,359.50	€ 257,126.37	€ 183,608,860.61	€ 533,276,652.41	€ 228,761,182.59	€ 864,154,182.61	€ 864,554,197.81	€ 564,462,659.12	€ 1,221,404,358.99	0.89	0.73	0.97

Figure 80: *Ranges of the results of the Monte Carlo simulation per product for the current model*

Proposed model

Item	Holding cost	Min	Max	Stockout costs	Min	Max	Order cost	Min	Max	Total costs	Min	Max	Service level	Min	Max
										€ 620,443,887.46	€ 393,831,360.09	€ 1,034,830,854.74	0.94	0.63	1.00
100004	€ 6,460,168.03	€ 3,912,059.24	€ 9,068,649.32	€ 30,650.66	€ -	€ 586,937.47	€ 2,721,605.42	€ 1,051,371.33	€ 5,106,660.76	€ 9,212,424.11	€ 8,553,259.11	€ 10,270,216.56	1.00	0.95	1.00
100005	€ 3,740,577.16	€ 1,945,624.94	€ 9,105,932.19	€ 136,469.79	€ -	€ 1,219,036.70	€ 1,626,844.16	€ -	€ 3,304,309.90	€ 5,503,891.11	€ 4,232,226.83	€ 9,105,932.19	0.98	0.83	1.00
100007	€ 2,800,964.94	€ 269,080.00	€ 4,847,510.10	€ 496,080.47	€ -	€ 5,427,411.63	€ 4,646,616.26	€ 2,403,134.47	€ 7,659,991.13	€ 7,943,661.67	€ 6,888,898.78	€ 13,221,014.50	0.95	0.62	1.00
100009	€ 961,760.11	€ 288,974.60	€ 1,821,581.36	€ 17,043.69	€ -	€ 218,742.56	€ 600,783.62	€ -	€ 1,351,763.14	€ 1,579,587.41	€ 1,005,929.70	€ 2,040,112.03	0.98	0.81	1.00
100021	€ 4,239,615.86	€ -	€ 12,294,892.09	€ 635,981.27	€ -	€ 20,345,678.40	€ 4,606,842.16	€ -	€ 9,762,733.80	€ 9,482,439.30	€ 1,186,517.47	€ 30,108,412.20	0.97	0.51	1.00
100022	€ 4,455,799.26	€ 975,790.29	€ 8,488,137.19	€ 779,887.71	€ -	€ 4,051,439.96	€ 6,354,399.33	€ 3,454,505.80	€ 9,161,950.18	€ 11,590,086.29	€ 10,311,877.20	€ 14,467,949.18	0.96	0.81	1.00
100023	€ 764,370.45	€ 469,486.22	€ 1,092,645.55	€ 9,732.36	€ -	€ 111,634.39	€ 1,053,874.60	€ 450,587.71	€ 2,102,742.66	€ 1,827,977.41	€ 1,337,936.58	€ 2,709,943.96	0.99	0.94	1.00
100024	€ 2,941,537.62	€ 407,054.57	€ 4,940,682.28	€ 213,628.45	€ -	€ 5,432,851.57	€ 3,540,173.10	€ 1,652,154.95	€ 5,857,640.28	€ 6,695,339.17	€ 5,923,529.62	€ 11,697,546.42	0.98	0.59	1.00
100025	€ 2,413,712.79	€ 862,278.37	€ 4,414,998.25	€ 159,573.10	€ -	€ 4,143,942.27	€ 2,528,019.59	€ 150,195.90	€ 5,557,248.47	€ 5,101,305.48	€ 2,270,231.51	€ 10,140,653.58	0.98	0.67	1.00
100026	€ 1,123,595.52	€ 725,014.33	€ 1,605,299.21	€ 3,250.73	€ -	€ 44,871.89	€ 838,871.94	€ -	€ 1,652,154.95	€ 1,965,718.19	€ 1,397,934.26	€ 2,491,823.55	0.99	0.00	1.00
100027	€ 7,122,887.38	€ 4,121,399.67	€ 9,015,623.39	€ 58,143.61	€ -	€ 796,186.29	€ 3,059,268.06	€ 1,652,154.95	€ 5,557,248.47	€ 10,240,299.06	€ 9,457,414.29	€ 11,190,250.03	0.99	0.93	1.00
100040	€ 3,983,706.73	€ 1,827,165.29	€ 5,848,900.41	€ 312,914.72	€ -	€ 1,838,029.92	€ 2,907,403.32	€ 901,175.43	€ 5,707,444.37	€ 7,204,024.76	€ 6,114,013.59	€ 9,222,443.68	0.95	0.79	1.00
100099	€ 4,141,112.78	€ 2,161,630.34	€ 6,100,969.38	€ 148,907.60	€ -	€ 1,005,087.70	€ 2,623,978.08	€ 1,051,371.33	€ 4,355,681.23	€ 6,913,998.47	€ 6,172,457.05	€ 7,915,874.10	0.96	0.84	1.00
100104	€ 2,119,284.02	€ 704,270.75	€ 3,547,327.76	€ 409,819.81	€ -	€ 3,145,728.72	€ 3,194,722.52	€ 1,351,763.14	€ 5,256,856.66	€ 5,723,826.34	€ 4,672,333.30	€ 8,745,379.98	0.93	0.72	1.00
100122	€ 3,517,023.94	€ 1,629,558.83	€ 5,038,389.76	€ 137,019.16	€ -	€ 1,756,535.11	€ 2,664,030.32	€ 1,802,350.85	€ 6,308,227.99	€ 6,318,073.42	€ 4,517,864.16	€ 9,205,156.71	0.78	0.00	1.00
100124	€ 4,535,567.52	€ 107,193.44	€ 9,321,753.64	€ 4,083,153.71	€ -	€ 15,416,055.79	€ 6,028,696.72	€ 4,355,681.23	€ 9,312,146.08	€ 14,647,417.95	€ 9,395,446.60	€ 24,891,003.95	0.55	0.23	1.00
110002	€ 10,207,115.07	€ 861,158.01	€ 17,908,627.07	€ 1,460,064.42	€ -	€ 13,848,534.75	€ 8,811,385.18	€ 3,724,829.07	€ 17,382,535.65	€ 20,478,564.67	€ 10,412,052.61	€ 27,621,750.74	0.83	0.31	1.00
110007	€ 21,858,086.76	€ 12,576,680.03	€ 33,120,150.77	€ 145,444.94	€ -	€ 1,656,096.37	€ 14,355,432.92	€ 6,368,835.09	€ 24,413,867.84	€ 36,358,964.61	€ 32,068,629.90	€ 43,045,909.87	1.00	0.96	1.00
110008	€ 3,083,492.86	€ -	€ 5,749,451.38	€ 366,582.76	€ -	€ 7,335,545.06	€ 6,789,492.72	€ 1,061,472.51	€ 18,045,032.75	€ 10,239,568.33	€ 5,715,406.62	€ 25,380,577.81	0.91	0.00	1.00
110009	€ 5,225,477.20	€ 3,286,563.59	€ 7,288,597.78	€ 115,562.47	€ -	€ 583,662.81	€ 8,728,683.66	€ 4,891,541.28	€ 12,718,007.32	€ 14,069,723.33	€ 10,482,164.85	€ 16,957,346.07	0.97	0.93	1.00
110010	€ 8,893,898.64	€ 6,230,180.22	€ 12,692,646.04	€ 7,710.95	€ -	€ 267,224.89	€ 4,051,286.77	€ -	€ 8,491,780.12	€ 12,952,896.35	€ 10,246,368.69	€ 15,824,424.31	1.00	0.97	1.00
110011	€ 4,190,024.99	€ 1,539,984.04	€ 7,177,176.36	€ 439,551.78	€ -	€ 2,273,551.57	€ 10,885,990.35	€ 4,245,890.06	€ 19,106,505.27	€ 15,515,567.12	€ 10,440,078.57	€ 23,172,376.79	0.96	0.85	1.00
110018	€ 10,052,478.57	€ 5,591,250.28	€ 14,130,380.63	€ 44,358.79	€ -	€ 721,061.29	€ 8,910,155.26	€ 4,788,499.05	€ 15,802,046.86	€ 19,006,992.62	€ 17,353,017.62	€ 21,970,919.73	1.00	0.96	1.00
110019	€ 1,770,501.17	€ 598,380.21	€ 3,563,973.79	€ 56,023.94	€ -	€ 847,091.15	€ 1,277,819.84	€ -	€ 3,351,949.33	€ 3,104,344.95	€ 1,732,462.30	€ 5,116,553.56	0.97	0.73	1.00
110020	€ 8,404,120.80	€ 1,593,857.56	€ 14,110,674.30	€ 1,284,681.39	€ -	€ 14,793,589.35	€ 10,818,460.81	€ 4,788,499.05	€ 18,196,296.38	€ 20,507,263.00	€ 17,552,589.48	€ 33,509,807.73	0.95	0.66	1.00
110028	€ 10,452,161.61	€ 2,150,227.72	€ 17,340,208.72	€ 795,261.70	€ -	€ 8,067,224.85	€ 9,241,803.16	€ 3,830,799.24	€ 18,675,146.28	€ 20,489,226.47	€ 17,957,561.94	€ 26,799,942.65	0.97	0.75	1.00
110030	€ 4,921,443.80	€ 1,426,435.80	€ 12,333,997.49	€ 634,839.00	€ -	€ 6,119,488.21	€ 3,947,851.44	€ -	€ 9,098,148.19	€ 9,504,134.24	€ 4,953,663.82	€ 16,887,043.65	0.90	0.53	1.00
110036	€ 9,937,787.61	€ 1,243,117.01	€ 20,769,648.56	€ 1,083,409.85	€ -	€ 13,997,873.36	€ 16,945,166.98	€ -	€ 41,427,129.32	€ 27,966,364.43	€ 5,550,693.43	€ 55,022,592.06	0.94	0.63	1.00
110047	€ 4,211,429.44	€ 104,136.09	€ 19,685,340.48	€ 351,346.39	€ -	€ 5,393,495.66	€ 8,625,834.91	€ -	€ 39,947,588.99	€ 13,188,610.74	€ 107,685.02	€ 47,118,074.34	0.98	0.68	1.00
110110	€ 4,072,556.06	€ 108,030.63	€ 6,981,097.52	€ 308,642.19	€ -	€ 2,351,491.21	€ 8,644,819.85	€ 1,241,609.69	€ 18,045,032.75	€ 13,026,018.09	€ 1,353,285.69	€ 21,849,075.82	0.92	0.50	1.00
110117	€ 5,917,234.49	€ -	€ 18,319,438.37	€ 6,586,075.66	€ -	€ 41,787,762.70	€ 16,791,250.07	€ -	€ 36,006,681.00	€ 29,294,560.22	€ 10,156,546.56	€ 72,360,551.46	0.77	0.28	1.00
110176	€ 3,028,887.80	€ 1,823,011.55	€ 4,376,675.59	€ 34,564.30	€ -	€ 409,488.06	€ 6,173,025.79	€ 2,385,283.67	€ 10,733,776.51	€ 9,236,477.89	€ 6,149,621.23	€ 13,268,815.98	0.99	0.89	1.00
110208	€ 251,587.31	€ 46,722.68	€ 340,011.12	€ 3.79	€ -	€ 204.73	€ 1,186,016.05	€ -	€ 1,192,641.83	€ 1,437,607.15	€ 46,722.68	€ 1,532,652.95	1.00	0.00	1.00
110211	€ 4,014,347.10	€ 1,649,057.77	€ 6,762,950.75	€ 171,637.33	€ -	€ 2,124,736.10	€ 14,724,571.21	€ 1,241,609.69	€ 32,281,851.93	€ 18,910,555.64	€ 4,992,143.04	€ 35,337,746.49	0.90	0.51	1.00
110224	€ 22,734,542.94	€ 15,231,055.51	€ 28,485,569.94	€ 16,531.16	€ -	€ 897,046.65	€ 4,648,391.11	€ 1,436,549.71	€ 10,534,697.90	€ 27,399,465.22	€ 24,868,679.17	€ 30,166,578.92	1.00	0.93	1.00
110225	€ 3,418,023.27	€ 1,074,388.06	€ 6,419,478.88	€ 461,707.30	€ -	€ 4,148,678.78	€ 4,953,436.24	€ -	€ 10,534,697.90	€ 8,833,166.81	€ 4,901,937.88	€ 14,789,455.54	0.92	0.58	1.00
110239	€ 5,183,735.62	€ 2,156,716.65	€ 9,172,531.29	€ 586,182.49	€ -	€ 4,271,414.89	€ 17,089,707.49	€ 9,553,252.63	€ 26,536,812.87	€ 22,859,625.60	€ 17,961,727.64	€ 31,299,788.18	0.97	0.80	1.00
110242	€ 1,693,550.33	€ 534,769.64	€ 2,926,831.89	€ 42,530.43	€ -	€ 760,081.12	€ 9,041,088.77	€ 2,518,539.04	€ 40,296,624.70	€ 10,777,169.53	€ 4,229,771.93	€ 41,045,889.61	0.92	0.00	1.00
110244	€ 7,410,005.68	€ 462,711.62	€ 10,842,207.57	€ 727,230.54	€ -	€ 14,806,729.43	€ 28,207,532.73	€ 11,174,487.21	€ 57,114,045.72	€ 36,344,768.95	€ 19,541,858.45	€ 72,383,486.77	0.87	0.32	1.00
110245	€ 5,552,600.30	€ 3,768,360.50	€ 7,529,036.44	€ 7,196.34	€ -	€ 111,471.12	€ 8,301,850.92	€ 3,777,808.57	€ 12,592,695.22	€ 13,861,647.56	€ 10,015,508.41	€ 17,360,960.52	1.00	0.96	1.00
110323	€ 7,846,346.55	€ 1,850,771.46	€ 12,071,086.99	€ 448,693.47	€ -	€ 5,134,881.26	€ 21,505,139.68	€ 12,416,096.90	€ 33,523,461.62	€ 29,800,179.70	€ 24,125,667.17	€ 40,166,278.94	0.98	0.84	1.00
110324	€ 9,537,244.19	€ 4,810,712.04	€ 14,111,551.17	€ 385,759.72	€ -	€ 2,178,973.00	€ 11,615,948.43	€ 6,208,048.45	€ 24,832,193.79	€ 21,538,952.34	€ 15,537,905.28	€ 31,642,937.65	0.91	0.78	1.00
110326	€ 8,020,003.83	€ 3,001,248.01	€ 18,367,971.00	€ 1,592,049.64	€ -	€ 12,811,455.58	€ 22,853,110.11	€ 4,245,890.06	€ 43,520,373.11	€ 32,465,163.57	€ 15,553,635.39	€ 55,309,339.53	0.81	0.40	1.00
110332	€ 2,833,170.47	€ 873,422.31	€ 5,343,634.97	€ 156,259.73	€ -	€ 932,361.60	€ 6,336,807.97	€ 3,724,829.07	€ 18,624,145.34	€ 9,326,238.18	€ 6,386,104.69	€ 20,466,264.45	0.90	0.67	1.00
Total	€ 250,043,538.52	€ 94,999,529.89	€ 434,474,238.71	€ 25,942,159.35	€ -	€ 234,171,385.91	€ 344,458,189.58	€ 113,900,817.14	€ 711,040,566.59	€ 620,443,887.46	€ 393,831,360.09	€ 1,034,830,854.74	0.94	0.63	1.00

Figure 81: *Ranges of the results of the Monte Carlo simulation per product for the proposed model*

Appendix P: Comparison of *Q* and *s*

This *Appendix* shows the ratio between the values for *Q* and *s* for either the current as well as the proposed model. If one of the cells in the tables below show *Proposed*, this means that the value of the parameter for that specific product in that specific month is higher in the proposed model compared to the current model. The other way around, if a cell shows *Current,* then the value of the parameter in the current model is higher. The results for the ratio of *Q* between the current and the proposed model can be found in *Table 42*.

Table 42: *Comparison of the economic order quantity between the current and the proposed model*

Q	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100004	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100005	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100007	Proposed	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed	Proposed
100009	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100021	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100022	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100023	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100024	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100025	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100026	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
100027	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100040	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100099	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100104	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100122	Current	Proposed	Proposed	Current	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Current	Current
100124	Current	Current	Current	Current	Current	Current	Proposed	Current	Current	Proposed	Proposed	Current
110002	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110007	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110008	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110009	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110010	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110011	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110018	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110019	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110020	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110028	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110030	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110036	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110047	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110110	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110117	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
110176	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110208	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110211	Current	Current	Current	Current	Current	Current	Proposed	Current	Proposed	Current	Current	Current
110224	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
110225	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110239	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110242	Proposed	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed
110244	Current	Current	Current	Current	Current	Proposed	Proposed	Current	Current	Proposed	Current	Proposed
110245	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110323	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110324	Proposed	Proposed	Proposed	Proposed	Current	Current	Current	Proposed	Proposed	Proposed	Current	Current
110326	Proposed	Proposed	Proposed	Proposed	Current	Proposed	Current	Current	Current	Current	Current	Current
110332	Current	Proposed	Proposed	Current	Proposed	Proposed	Current	Current	Current	Current	Current	Current

As we can see, *Q* is almost always lower in the proposed model in case of a tape product. However, for MF products, there are fluctuations. For 17 out of 28 MF products, it appears that the proposed model has higher values for the economic order quantity for at least half the year.

When we compare the ratios with the results of the Monte Carlo model as found in *Appendix O*, we see that the products with the higher order quantities normally face lower order costs. As a result, the order costs for the proposed model for the tape products are high compared to the order costs of the current model. However, this result is outweighed by the difference in order costs for the MF products, which is in favour of the proposed model.

To make some statements about the holding costs or stockout costs, we will also look at the ratio between the reorder point for both the current model as well as the proposed model. The results can be found in *Table 43.*

Table 43: *Comparison of the reorder point between the current and the proposed model*

s	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
100004	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
100005	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100007	Proposed	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed	Proposed
100009	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
100021	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
100022	Current	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
100023	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100024	Proposed	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
100025	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100026	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
100027	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100040	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100099	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100104	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
100122	Current	Current	Current	Current	Proposed	Proposed	Current	Current	Proposed	Current	Current	Current
100124	Proposed	Proposed	Proposed	Proposed	Current	Current	Proposed	Current	Current	Proposed	Proposed	Proposed
110002	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
110007	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed	Proposed
110008	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110009	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed	Proposed
110010	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110011	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110018	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110019	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110020	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110028	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110030	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110036	Proposed	Current	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110047	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110110	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110117	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110176	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110208	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110211	Current	Current	Current	Current	Current	Current	Proposed	Current	Proposed	Current	Current	Current
110224	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed
110225	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110239	Current	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed	Proposed	Proposed
110242	Current	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed
110244	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110245	Proposed	Proposed	Proposed	Current	Current	Current	Current	Current	Current	Current	Proposed	Proposed
110323	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current	Current
110324	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed	Proposed
110326	Proposed	Proposed	Proposed	Proposed	Current	Proposed	Current	Current	Current	Current	Current	Current
110332	Current	Current	Proposed	Current	Current	Current	Current	Current	Current	Current	Current	Current

We see that in general, the reorder point for the current model is higher than the reorder point of the proposed model. As a result, the holding costs should be higher for the current model, which is mostly in line with the results found in *Appendix O*. A general pattern that is found, is that the higher the holding costs, the lower the stockout costs. However, some of the products do not follow this pattern. When we dive into these products, we see that for these specific products, sometimes the proposed model has higher values for the parameters and sometimes the current model has higher values for the parameters. Besides, it appears that for some products the order quantity is higher in combination with lower reorder points or higher reorder points with lower order quantities. In general, we can conclude that lower reorder points in combination with higher order quantities are beneficial, since it reduces both the holding costs as well as the order costs. The lower holding costs may lead to higher stockout costs, however, these costs are mostly outweighed by the reduction in other costs.

Appendix Q: Histograms of all replications of the Monte Carlo simulation

Histograms of the current model

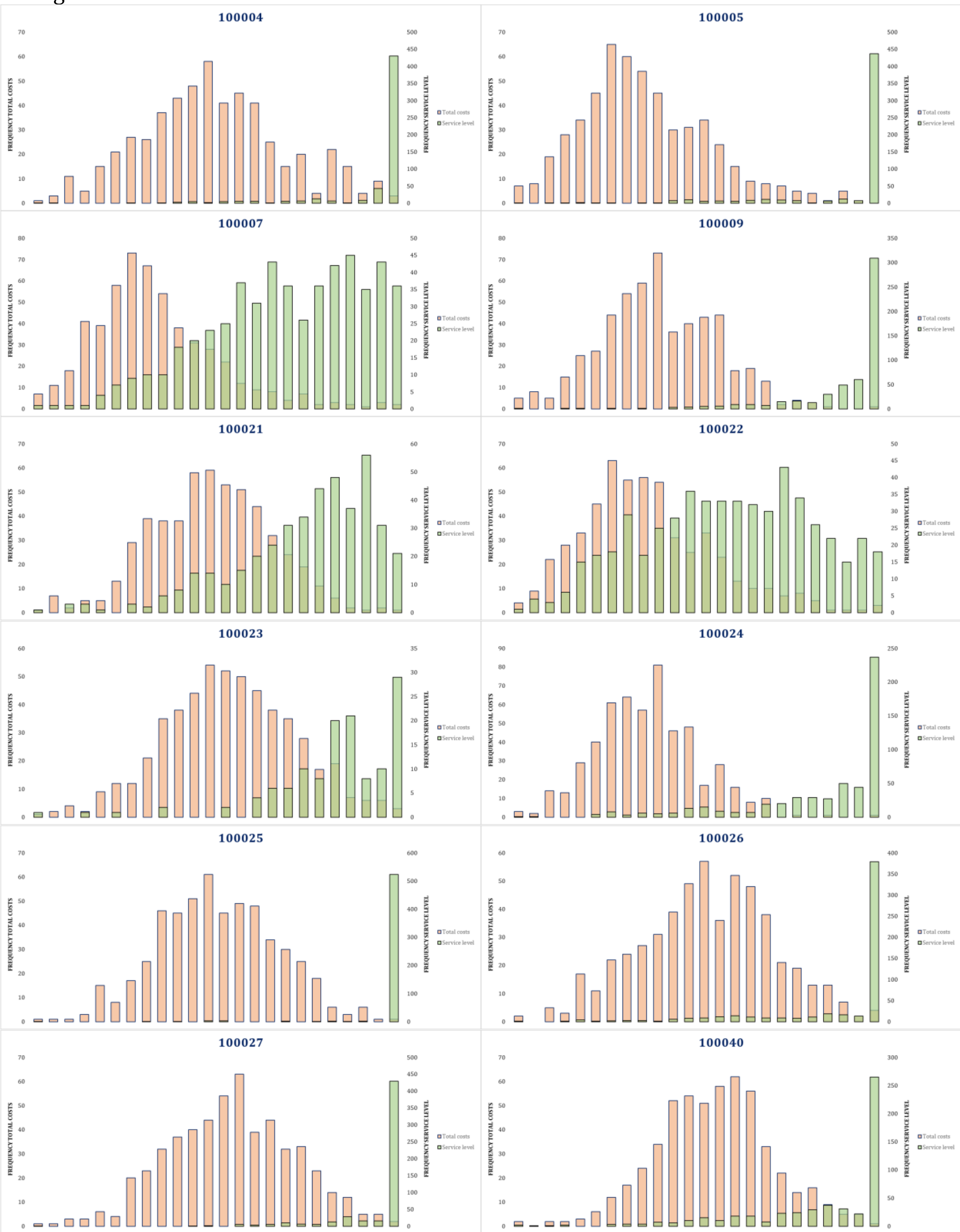

Figure 82: Histograms of the results of the 1st upon 12th MTS product for the current model

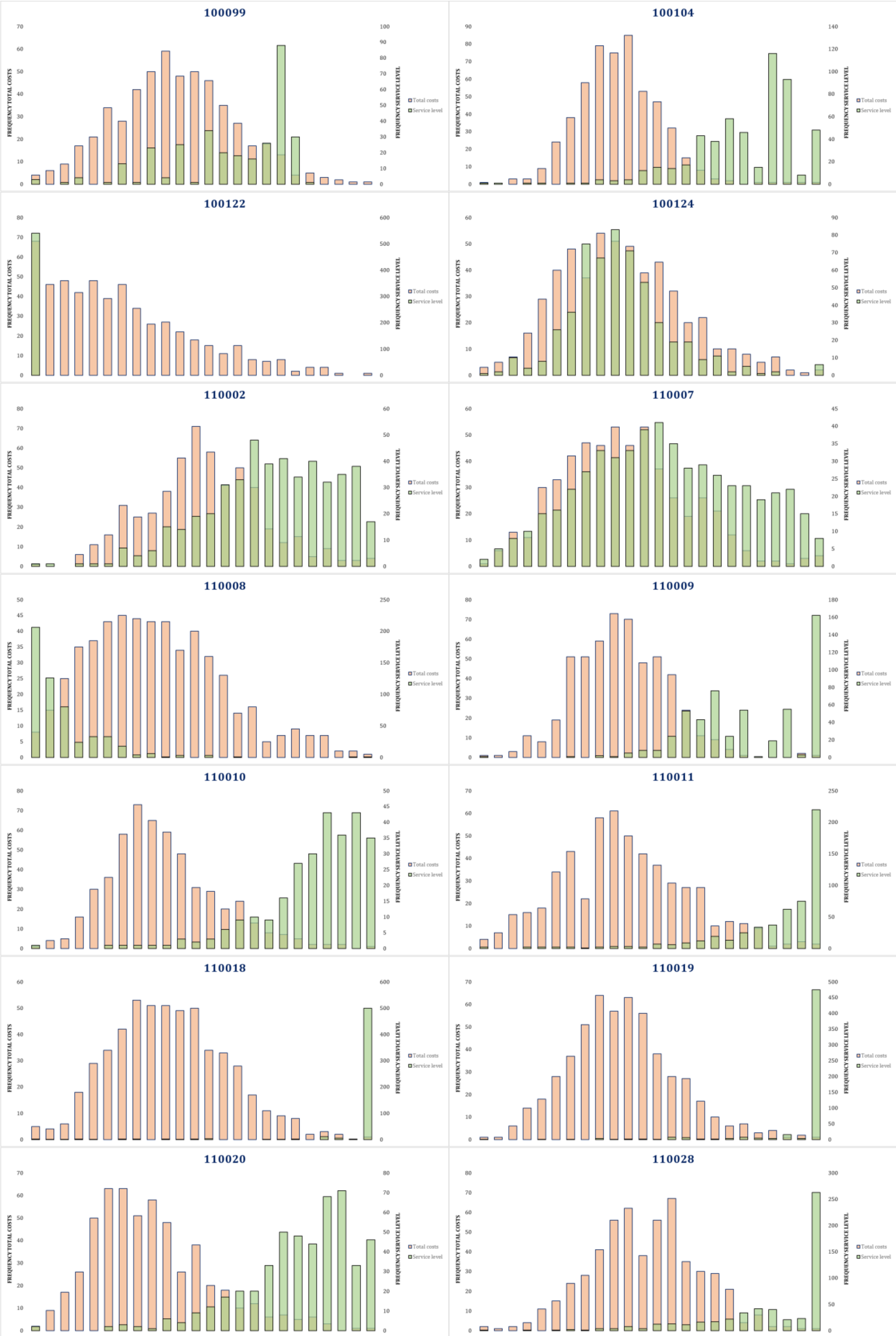

Figure 83: Histograms of the results of the 13th upon 26th MTS product for the current model

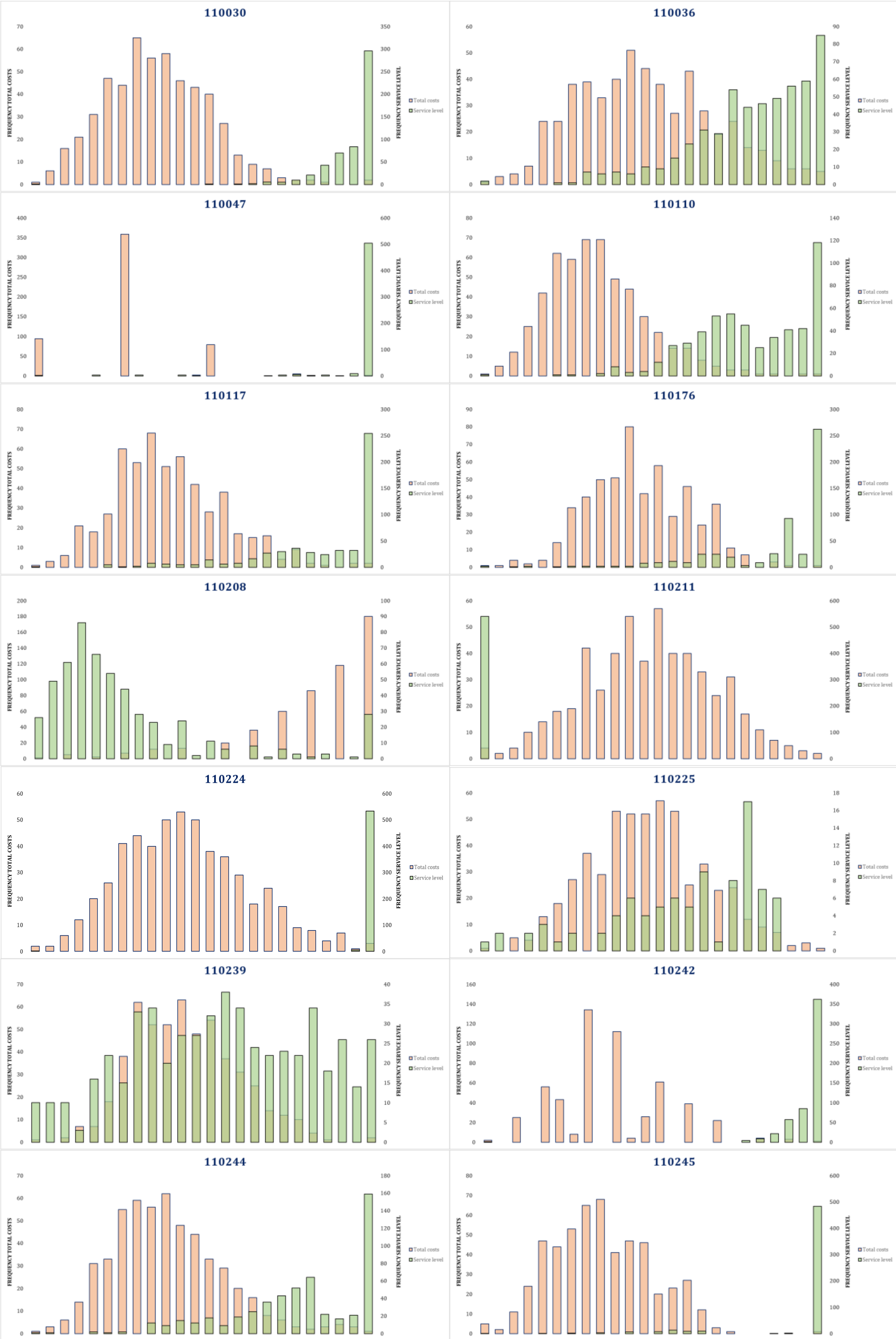

Figure 84:*Histograms of the results of the 27th upon 40th MTS product for the current model*

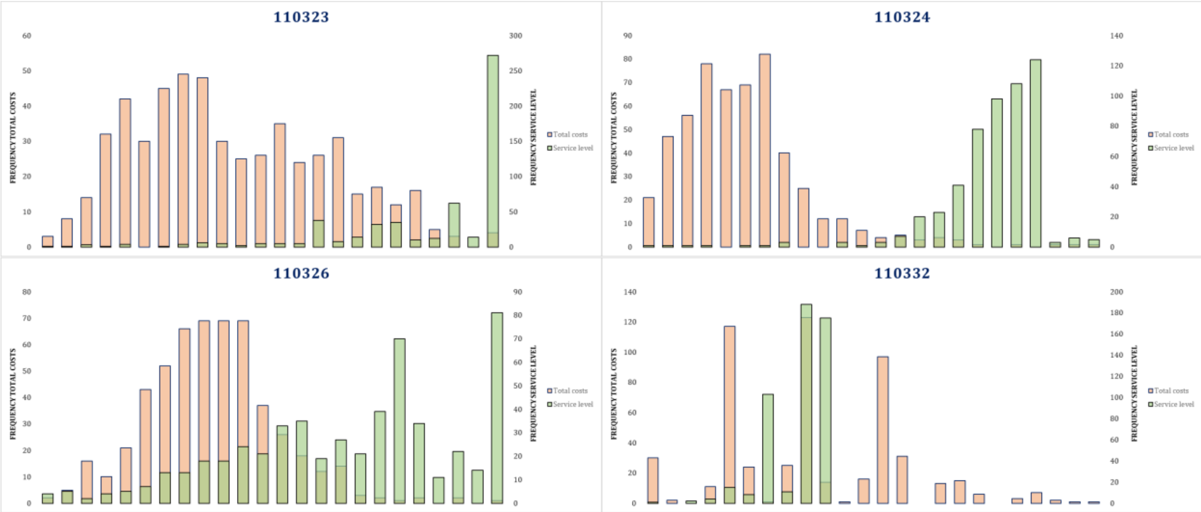

Figure 85: *Histograms of the results of the 41th upon 44th MTS product for the current model*

Histograms of the proposed model

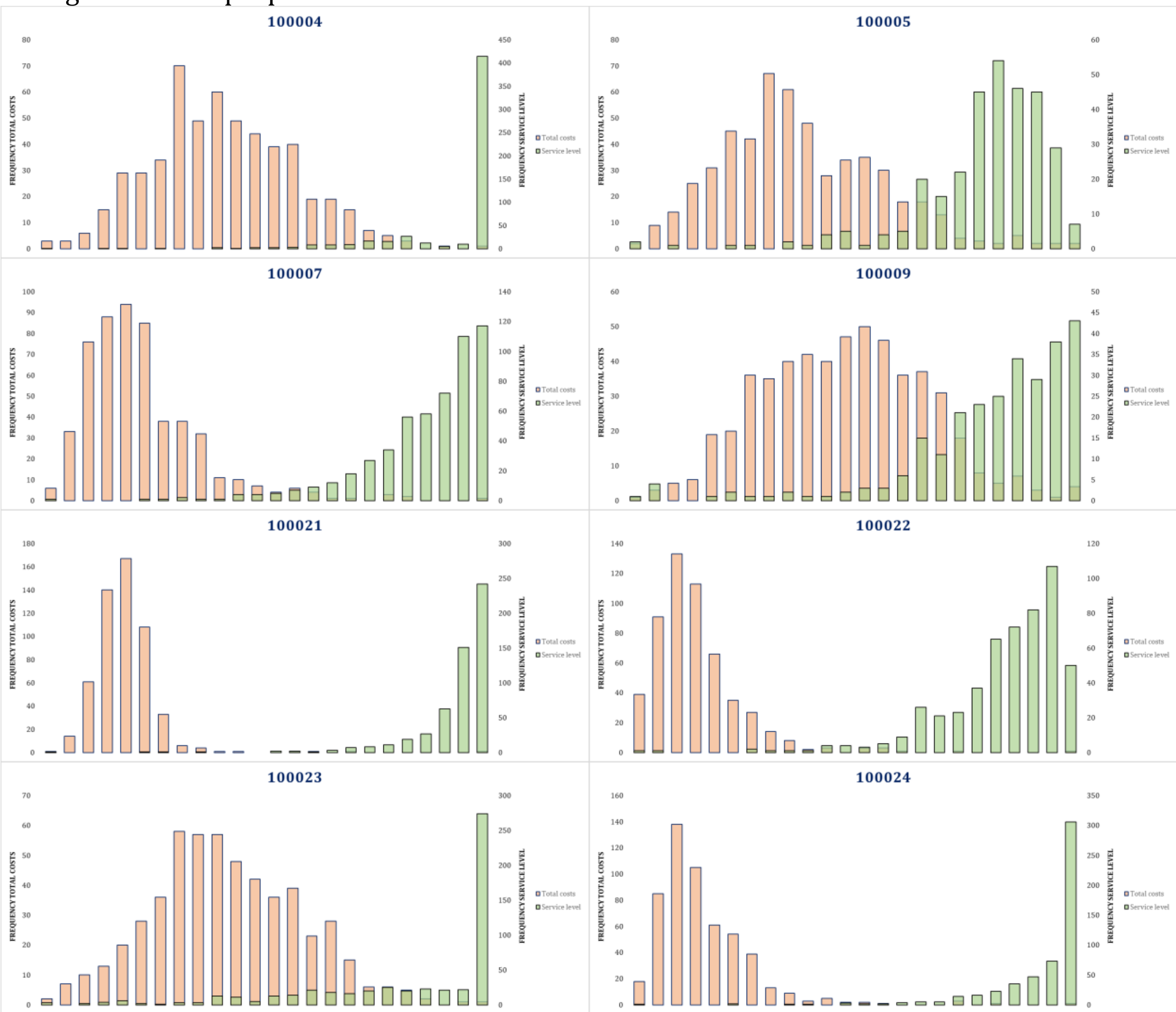

Figure 86: *Histograms of the results of the 1st upon 8th MTS product for the proposed model*

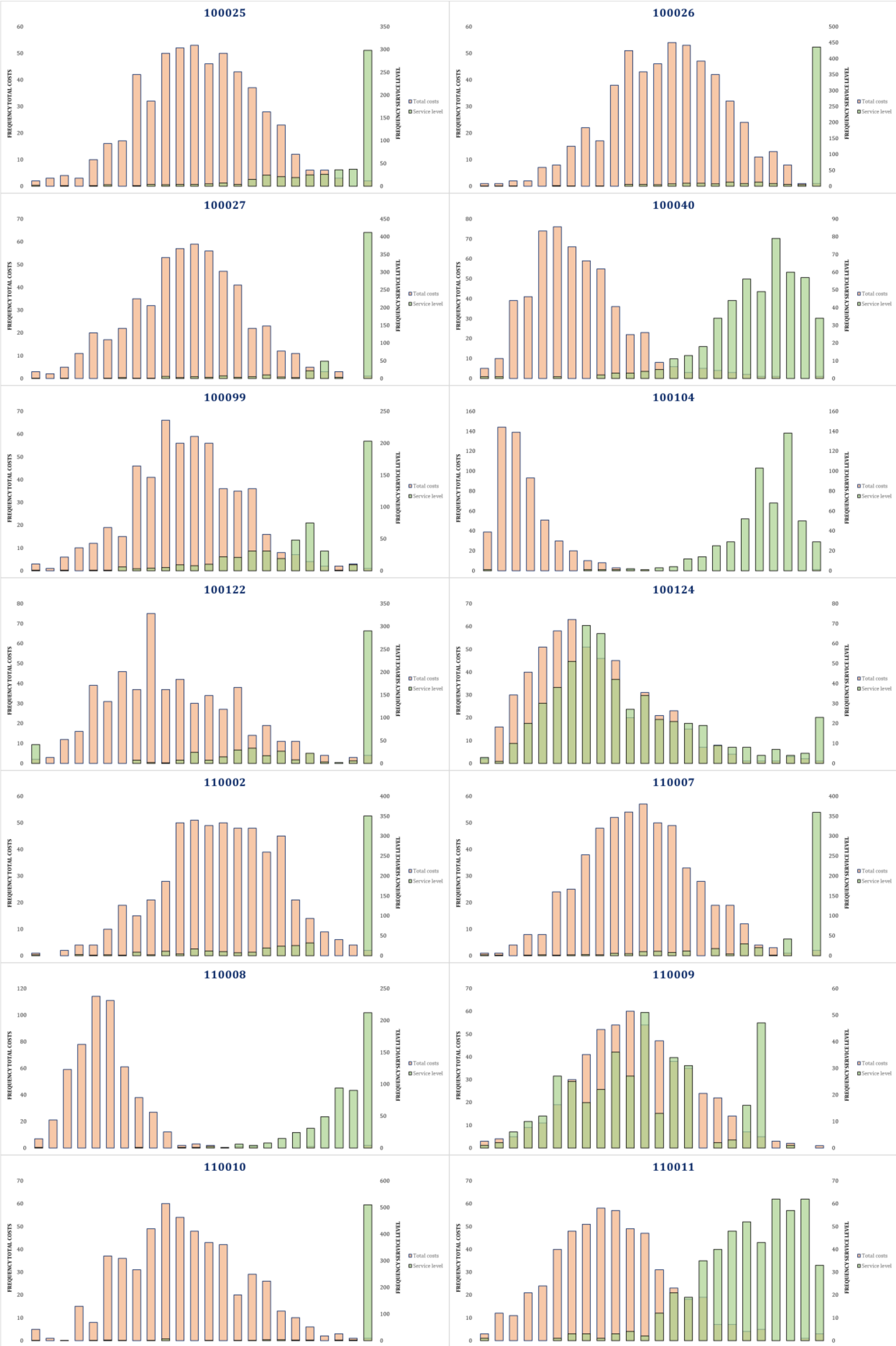

Figure 87: *Histograms of the results of the 9th upon 22th MTS product for the proposed model*

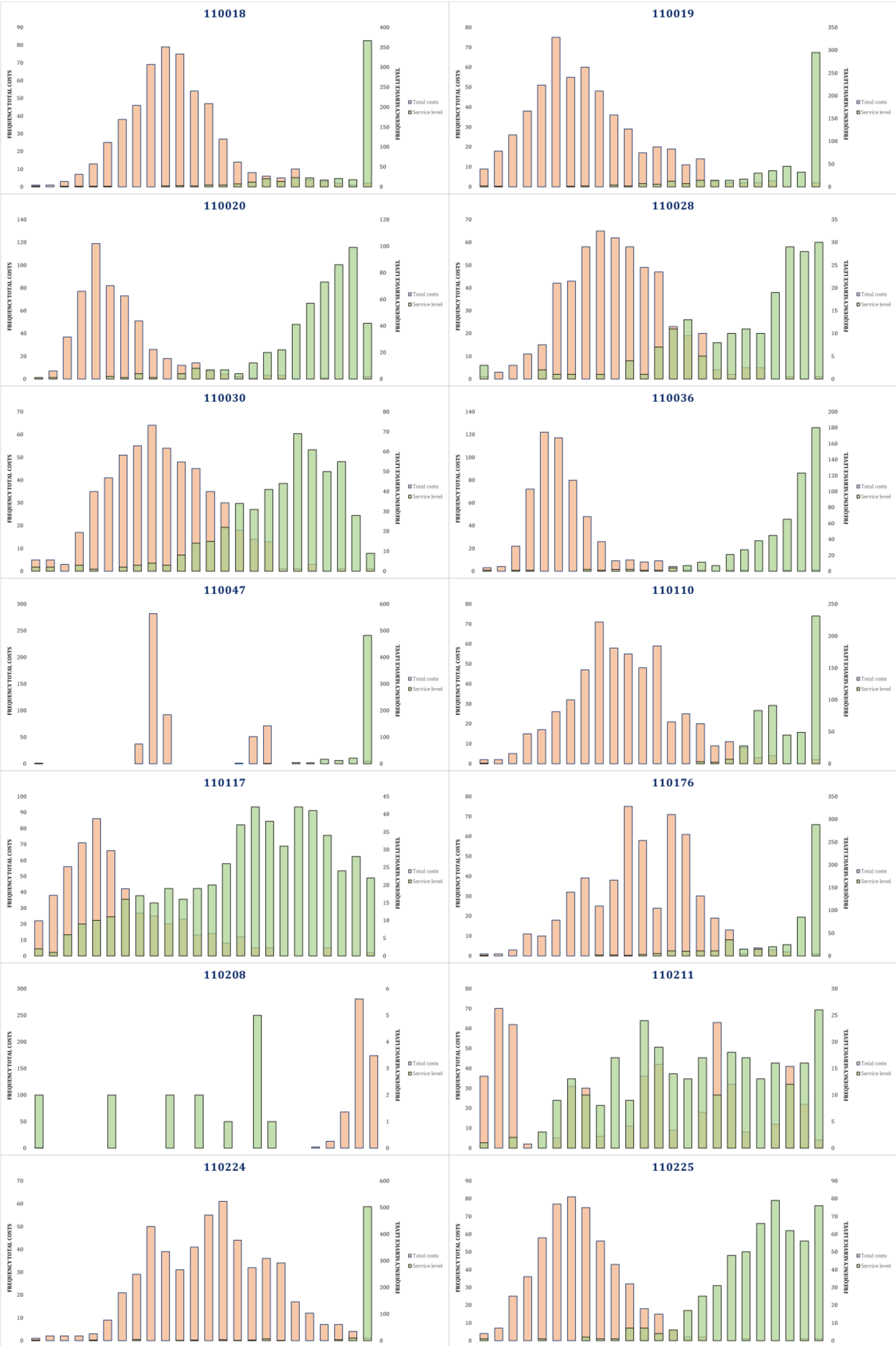

Figure 88: *Histograms of the results of the 23th upon 36th MTS product for the proposed model*

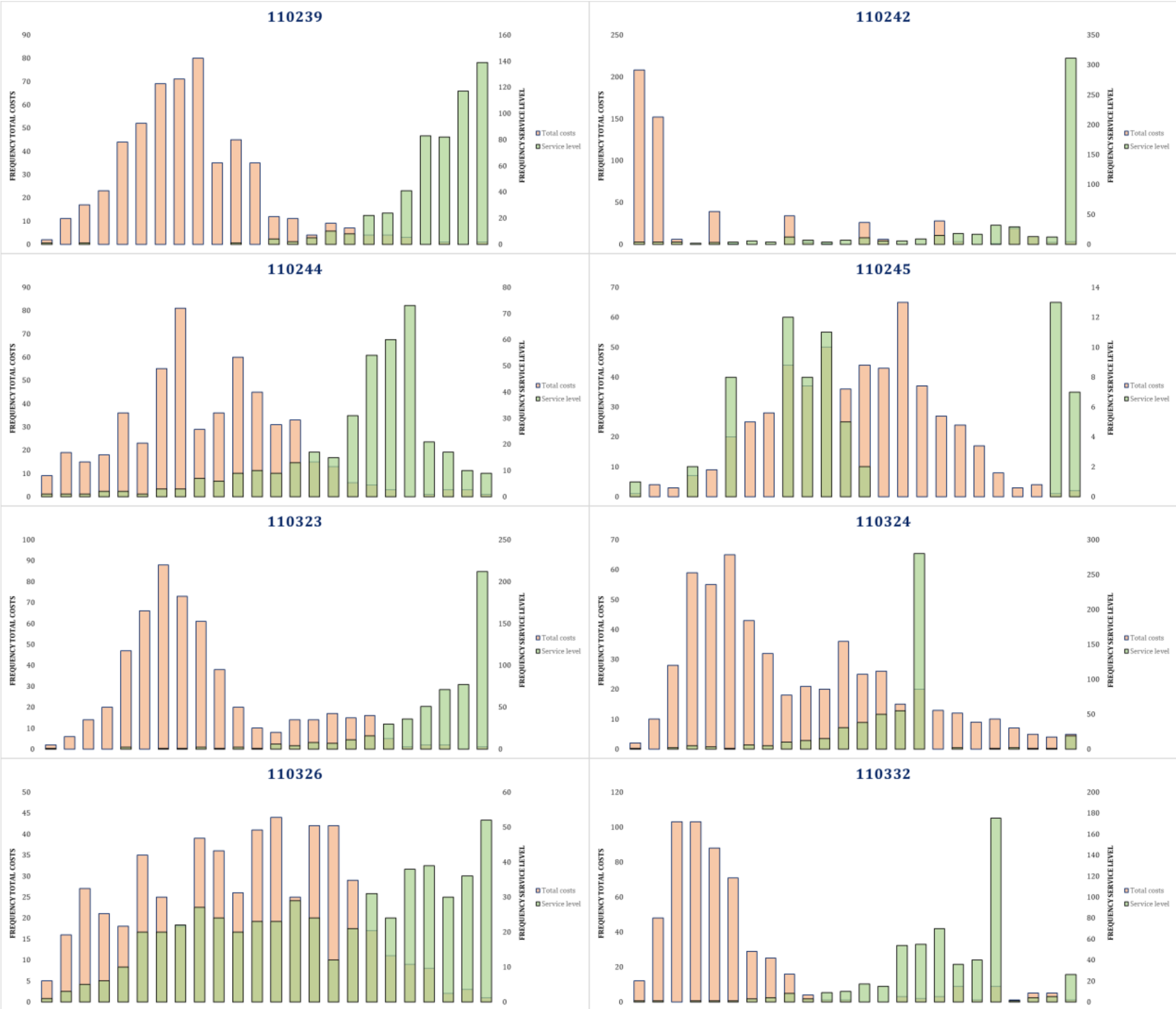

Figure 89: *Histograms of the results of the 37th upon 44th MTS product for the proposed model*