Improving the inventory management of components for product X in a shifting assembly environment at Thales

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Preface

Dear reader,

You are about to read the bachelor thesis 'Improving the inventory management of components for product X in a shifting assembly environment at Thales' which marks the end of my bachelor Industrial Engineering & Management at the University of Twente.

First of all, I would like to thank my supervisors at Thales, Henk Gerritsen & Harald Luijten, for producing an interesting and challenging graduation assignment at Thales allowing me to exploit my knowledge concerning inventory management in a very specialized and exceptionally fascinating business environment. During my time at Thales, I experienced a lot of interactions with colleagues who helped me gain helpful insights regarding performing and managing research. Therefore, I would also like to thank my colleagues for always making me feel welcome and being able to answer my questions quickly.

I would also like to express my gratitude toward my supervisor at the University of Twente, Dennis Prak. A special thanks for the many and long discussions we have had on how to tackle this research while always being patient and responsive. Even though meetings were always longer than initially planned, they helped me guide my research in the right direction. I would also like to thank my second supervisor, Matthieu van der Heijden, for his help, feedback, and insights in the final stages of this research. His neutral and fresh perspective on my research gave me useful hints toward finalizing my thesis.

Finally, I want to thank my family and friends for their support during the research and the writing of this bachelor thesis. Thanks for being able to get my mind off the research when things got 'twisted' such that I could start with a fresh view when needed.

I hope you enjoy reading this bachelor's thesis.

Chiel Rietman

July 3, 2024

Management summary

The research performed for this graduation assignment has been conducted at Thales Nederland B.V. in Hengelo, Netherlands. Thales Group, a world leader in the market of defense radar systems, is currently experiencing high inventory levels in Hengelo for its *product x* for which they are demanding an inventory management policy to control the inventory levels of its components. While Thales wants to lower these inventory levels, it is also demanded that the assembly line of *product x* does not experience idle times for waiting on components that are out of stock. As the output of *product x* is going to increase significantly, Thales suggested improving the KPI 'days of inventory on hand' as this states the efficiency of inventory by dividing the average inventory levels by the cost of sales which incorporates the increase in output, making it fairer to compare the results of this research with the current situation.

Currently, Thales is operating in an engineer-to-order environment where component procurement is customer-order driven. However, soon, Thales is shifting to a make-to-stock strategy by replacing the customer order decoupling point in the final stages of the assembly process, making it possible to produce a standard product and making component procurement forecast-driven such that customer lead times are reduced significantly. To analyze possibilities to lower the inventory levels while maintaining component availability, the main research question addressed in this thesis is as follows:

'How can the inventory levels, and therefore, the current number of days of inventory on hand for product x be optimized through a new material inventory policy for Thales Nederland B.V. while maintaining material availability?'

Performing the ABC analysis, it was found that 130 out of 1385 components make out 95% of *product x´s* value and therefore 95% of the annual usage. Through this analysis, the scope of this research was defined. Currently, in the engineer-to-order strategy, components are meant to be procured after a customer places an order leading to a customer lead time of up to two years. In reality, to ensure that components are delivered in time for the assembly process, component orders are pre-released leading to high possibilities of excess inventories as is currently the case. When shifting to a make-to-stock, to prevent the assembly process from idling when components are out of stock, safety stocks need to be determined.

In the case of Thales, the demand for components is deterministic while a fixed production rate of one *product x* each month means that every component should be in stock and, according to the product's BOM, in the right quantities when a new product is needed to be assembled. Due to this deterministic demand, safety stocks are solely responsible for uncertainties in supply. To determine these uncertainties, each supplier's delivery delays are being revised to determine a standard deviation of the lead times per supplier. For simplicity of this research, the lead times and respective delays are assumed to follow a normal distribution. Throughout a simulation model, component lead times that follow a different distribution are evaluated to depict the robustness of this assumption.

While Thales is using ORACLE's ERP software, continuously reviewing inventory positions is possible. Because of this, continuous review policies are utilized to determine safety stocks and, therefore, order quantities. As demanded by the research question, we want to optimize inventory levels while maintaining a relevant customer service level in the order fill rate. To determine a reasonable service level, this research has recommended determining safety stocks according to a target fill rate as this depicts the percentage of stock available on hand when needed. A target fill rate can be defined for each component by determining an optimal ratio between holding costs and backorder costs, similar to the newsvendor problem, which

determines the risks one wants to take for stocking out each independent component. Here, expensive components may stock out more frequently than cheap ones.

Through an inventory management tool designed for Thales, safety stocks and order quantities are being configured. To visualize and analyze the dependencies of all the different components with different lead time uncertainties, target fill rates, and order quantities on the inventory levels and the order fill rate of *product x*, a simulation has been built that demands each component in the right quantities every month. Through this simulation, we can depict the performance of the inventory management tool's output, concerning the components' safety stocks and order quantities, on the days of inventory on hand to understand to what extent the policy improves the research' main KPI while maintaining a reasonable order fill rate. Where, currently, the days of inventory on hand for *product x's* components is 283 days it should be possible to lower this to 122 days utilizing the proposed inventory management policy.

When performing a sensitivity analysis through the simulation to determine the robustness of the tool's output concerning lowering safety stocks for individual components and all safety stocks, it was found that lowering safety stocks led to lower order fill rates and longer waiting times, while initially lowering the inventory levels which eventually increase again due to excess inventory of components that are waiting to be used.

Next to the inventory management policy that requires safety stock to be kept in-house at Thales, supply chain coordination possibilities have been analyzed to show possibilities to decouple safety stocks and distribute them over suppliers in finished components and/or separate subcomponents. To determine a distribution of safety stocks over the supply chain that is economically more optimal, one can conduct internal research on the suppliers to review each subcomponent's supply uncertainties. For time's sake, we have modeled a mathematical model to estimate an optimal distribution of safety stocks to perform an analysis on possible holding cost savings. When keeping safety stocks in finished components at suppliers, it is possible to lower inventory holding costs by up to 30%, which is mainly because of the margin from the supplier to Thales that has not been applied to the component's price yet. Next, it could be possible that one subcomponent contains all the risks and uncertainties of the supply of a component that Thales needs. In this scenario, only the subcomponent needs to be kept in safety stock along with additional safety stock to hedge against any uncertainties that may arise in the lead time from the supplier to Thales. After building an example of the latter scenario, a 40% decrease should be possible based entirely on the proportion of the risky subcomponent's price upon the whole component's price.

Based on the research performed at Thales, the main recommendations are as follows:

- Implement the inventory management tool's output concerning safety stocks and order quantities.
- Keep track of the delays per order per supplier to update the standard deviations of lead times in the future. This is important since it is expected that suppliers and their lead times become more reliable due to better coordination and communication with the suppliers which should lead to lower safety stocks.
- Further investigate possibilities to place safety stocks at suppliers as this can significantly decrease overall inventory costs while maintaining a high customer service level.

Table of Contents

Readers guide

The research conducted at Thales Nederland B.V. is described in seven chapters throughout this thesis. A brief description per chapter is given in this guide for readers.

Chapter 1: Introduction

In Chapter 1, the research is introduced by describing the company and the problems it is facing. After visualizing a problem cluster, the core problem is identified after which a research design is produced and explained. This research design defines the scope of this research as well as the relevant research questions.

Chapter 2: Current Situation

The second chapter performs an analysis of the current situation concerning Thales' procurement strategies to understand where opportunities lie to develop an inventory management control policy for Thales' components. Through the current situation, we also define the exact scope of components to review in this research. Here we gather all relevant SKU characteristics such as their prices and supply uncertainties after which we can determine inventory management parameters in order quantities and safety stocks.

Chapter 3: Literature Review

In Chapter 3, a literature review has been performed to state the importance of switching to an inventory management policy where the use of an MRP system is not justified anymore. Through this review, we want to determine how we can solve this multi-item inventory management problem. Here we also want to describe what the impact of the made assumptions can be. The possibilities to review multi-echelon inventory management policies are described shortly to analyze possibilities to place safety stock in other installations in the supply chain if it is economically beneficial.

Chapter 4: Solution Design

Chapter 4 describes how the inventory policies reviewed in Chapter 3 can be made applicable for Thales through means of a simple tool utilizing input parameters as the SKUs' characteristics. Here, we also depict a simulation model that is used in the results and sensitivity analysis to understand the severity of the inventory management tool's output on the performance of KPIs concerning inventory costs and service levels. At last, a methodology to analyze the supply chain inventory coordination possibilities is presented.

Chapter 5: Results & Sensitivity Analysis

In Chapter 5, the results from the tool are depicted and evaluated through a simulation in Siemens' Plant Simulation to visualize expected inventory levels and respective costs and service levels. The tools' output robustness is evaluated by altering the statistical distribution of some components' lead times to analyze the impact of the normal assumption on inventory and service levels. Here we also want to depict what happens when safety stocks are held in lower quantities. Further in this chapter, we also depict a couple of examples concerning the analysis of decoupling safety stocks in the supply chain.

Chapter 6: Solution Implementation

This chapter presents an approach based on literature to understand the severity of change management in the environment of Thales.

Chapter 7: Conclusions, Recommendations, and Further Research

Finally, Chapter 7 presents the conclusions and recommendations through the conduction of this research. Here, the limitations of this research are described and mentioned on what to look out for when conducting further research on this topic at Thales.

Acronyms

ADU	Annual Dollar Usage
BOM	Bill Of Materials
CODP	Customer Order Decoupling Point
CSL	Cycle Service Level
CV	Coefficient of Variation
DBV	Distribution By Value
DOI	Days of inventory on hand
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
ESC	Expected Shortage per Replenishment Cycle
ETO	Engineer-To-Order
FR	Fill rate
IP	Inventory Position
KPI	Key Performance Indicator
LTD	Lead time demand
MOQ	Minimal Order Quantity
MRP	Material Requirements Planning
MTS	Make-To-Stock
OTD	On-Time Delivery (rate)
SKU	Stock Keeping Unit
SS	Safety stock
VBA	Visual Basic for Applications
VEX	Valeur d'Exploitation
WIP	Work in process

1 Introduction

Throughout the second semester of the academic year 23/24, Thales Nederland B.V. offered an opportunity to conduct this research to complete the Bachelor of Industrial Engineering & Management. Since Thales Nederland B.V. is shifting to serial production for a selection of its products, this research aims to determine the safety stocks and order quantities of components of *product x* to optimize inventory management and inventory costs while maintaining component availability. The company is introduced in Section 1.1 while the problem is identified throughout Sections 1.2 and 1.3. The research design of this graduation assignment is described in Section 1.4.

1.1 Company introduction

In today's world, conflicts between countries are occurring more often. During such times, the demand for maintaining security, tactical superiority, and strategic independence is increasing rapidly. Thales Hengelo provides solutions and helps to fulfill these demands by offering various products (radars and software) but also knowledge of its products and specializations.

In 1922, 'NV Hazemeijers Fabriek van Signaal apparaten' was established because of the desire of the Royal Navy to provide vessels with fire control. The Dutch government decided to take over the factory after being occupied by Germany in WWII after which the company was named 'N.V. Hollandse Signaalapparaten' or 'Signaal'. Eventually, in 1990, the French company Thomson-CSF acquired a majority interest in 'Signaal' where in 2006 the group was called Thales Group. Now, after 100 years, the group has grown to 80.000 employees in 68 countries (± 2.000 employees in Hengelo) and is a major player in providing reliable technology to protect our digital safety. The field of activity has expanded from maritime safety to rail safety, public transport safety, the safety of our skies, and the safety of our planet (Thales Nederland B.V., 2024).

Thales Group is a world leader in the market of defense radar systems, for example, *product x*. The latter invention is a popular product among different military forces worldwide. Besides being multifunctional in the field, *product x* is known for its flexibility while being set up in minutes. Due to its popularity, demand for *product x* increases rapidly (Thales Nederland B.V., 2024).

1.2 Problem context

Thales Naval is currently working on a project to scale up its production to meet the increasing demand for its products in the upcoming years where the production rate of *product x* will increase by 600% to twelve pieces per year from 2025 onwards. To implement this high production rate increase in its supply chain, Thales needs to step away from its engineer-to-order project-based production where it produces 'one-of-a-kind' products specialized for certain customers and aim for a form of serial production. In this current ETO environment, components used in Thales' products are procured after the customer order is placed, resulting in high customer lead times of over two years. By moving to serial production, Thales wants to focus on producing a standard product that can be offered to its customers for which its products can be assembled based on a fixed production plan (make-to-stock) rather than customer orders to reduce customer lead times. Currently, the customer order decoupling point (CODP) is in the preliminary stages of the supply chain at the point where the customer can configure a *product x* according to their wishes. However, while Thales is going to offer a standard product with fewer configuration options to be able to "make-on-stock", the CODP will be at the software integration of the radar, where the radar's software is integrated with the customer's software, which is done in the final stages of the assembly process. Now, when stepping away from Thales' purchase-to-order strategy, Thales will face new methods and opportunities concerning economies of scale in the procurement and the management of the inventory of components.

Lately, Thales has observed higher levels of inventory of components. The main reasons for this are on one side the request for pre-releases of component orders to ensure timely deliveries, which could lead to excess inventory when a customer order is not placed or placed much later. Conversely, Thales does not optimize its inventory management parameters such as the order quantities and the safety stocks of its components. Trade-offs concerning warehousing costs are not considered over the last few years, leading to high warehousing costs and less cash flows. Also, the product-engineering phase of *product x* has not been qualified yet, leading to long idle times because the components need to be redesigned, leading to excess inventory of the components waiting to be used. Since the qualification of *product x* is soon to be finalized, this problem is not considered in this research. The main focus of this research for Thales, where production is scaling up and shifting to an MTS environment, lies in a revision of the purchasing strategy and inventory management of the components needed for the production of Thales' *product x*. Important objectives are:

- Find out what the components' order quantities have to be.
- Find out what the components' safety stocks have to be to account for uncertainties in the supply of the components for *product x*.
    - Since the demand for the components is deterministic through the fixed production plan, there is no uncertainty in demand for the components of *product x*.
    - To account for material availability against supplier shipment delays, we want to keep extra component inventories in multiples of *product x's* needed quantities through its BOM. Therefore, it is most important that the ROPs are determined and rounded in multiples of *product x*. A further explanation is described in Section 4.1.3.

After these objectives have been reached, through this research, an extra analysis will be performed depicting the possibilities and advantages of coordinating safety stocks in the supply chain as demanded by Thales. Throughout this analysis, we want to find out whether placing safety stocks at suppliers of Thales can improve total inventory holding costs while maintaining a similar customer service level. Thales has some expensive and critical SKUs that they, on one hand, would like to keep on stock, but on the other hand, would not like to keep on stock in-house to avoid expensive inventory holding costs. This analysis will compare three different scenarios to find out what is economically most beneficial.

- Scenario 0: place all component safety stock at Thales.
- Scenario 1: place all component safety stock at the component's supplier.
- Scenario 2: place a combination of raw materials/subcomponents and components in safety stock at the supplier and Thales respectively.

The focus of this research lies in the production scale-up by optimizing inventory levels for components of *product x* without compromising component availability for *product x* since the demand for this product will increase rapidly in the near future. Thales Nederland B.V.'s profitability was, over the fiscal year 2023, significantly below its target and a reason for this was the significant increase in inventory. Parameters such as order quantities and safety stocks are therefore key parameters to be determined and considered in the new inventory management policy while the extra analysis in this research depicts cost-optimizing possibilities concerning supply chain coordination.

1.3 Problem identification

To find out which problem to solve, Thales' management is asked what key performance indicators need to be improved. Through Section 1.3.1, the action problem and main KPI are explored after which, in Section 1.3.2, the core problems of the action problems are visualized through a problem cluster. At last, in Section 1.3.3, the current value of the KPI and its desired norm are described.

1.3.1 Action problem

Currently, Thales is observing an extremely high 'days of inventory on hand' for the components for its *product x* (283 days). Thales wants to improve this KPI as it determines how quickly a company utilizes the average inventory available at its disposal (CFI, 2024). The formula of the days of inventory on hand (DOI), depicted in (1.1), indicates that the KPI measures the relative efficiency of inventory to the number of goods sold in a specific time window (in this case one year). At Thales, the average inventory is depicted by the so-called Valeur d'Exploitation (VEX) which also incorporates the work in process (WIP) next to the average inventory in the warehouse. Since Thales is going to scale up its production, it is not strange if the inventory will remain as high as it is now or if it even increases, however, the most important is that the relative level of the inventory will decrease compared to recent numbers implying an increase in profit. Therefore, the days of inventory on hand is an adequate measure and appointed by Thales as the main action problem. Important here is that while lowering the inventory, component availability has to be maintained to a certain service level. This service level is yet to be determined.

$$DOI = \frac{Average\ Inventory}{Cost\ of\ Sales} \times 365\ days \qquad (1.1)$$

1.3.2 Problem cluster & core problem

To analyze the root causes of the action problem mentioned in Section 1.3.1, a problem cluster has been constructed in consultation with several problem owners at Thales. Now, while the procurement strategy will become based on the fixed production plan and thus different from the current situation, we also have to incorporate (core)problems that are expected to affect the action problem. Figure 1.1 depicts the problem cluster.

When analyzing potential causes and root causes of the high days of inventory on hand for *product x*, two potential core problems can be identified:

1. The design of *product x* is not finalized yet. While currently, the configuration of *product x* is not finished, some components need to be redesigned leading to longer order lead times (components OOS) and, therefore, a warehouse full of *product x's* components waiting to be used.

2. Inventory management parameters (order quantities and safety stocks) need to be revised. While Thales is scaling up its production and implementing a new production strategy (ETO to MTS) where supplier lead times are variable and uncertain, safety stocks need to be determined. On the other hand, order quantities need revision while component prices and, therefore, holding costs have increased due to inflations and component scarcity. Currently, safety stocks are determined based on expectations and feelings, rather than data-driven calculations, resulting in either high stocks or idle times in the production process which

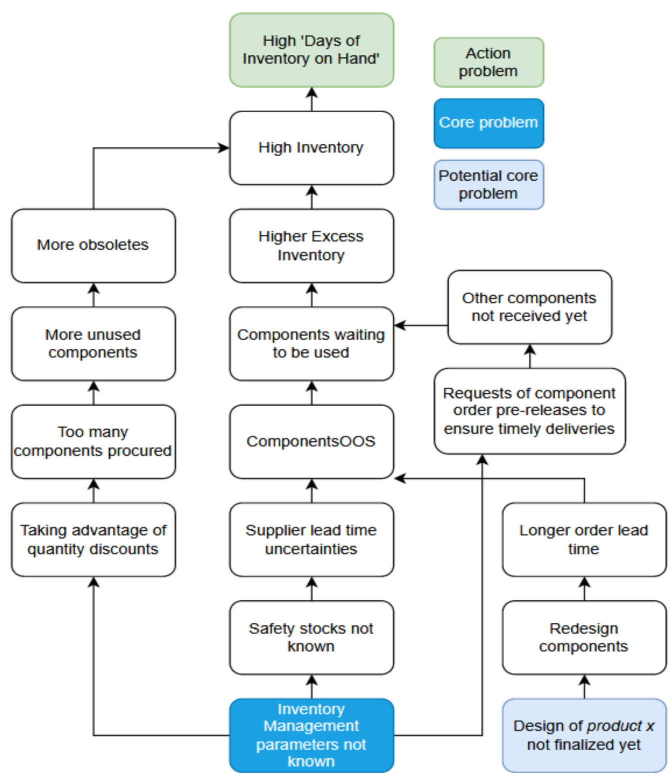

Figure 1.1 - Problem cluster DOI

drive the high excess inventory and, therefore, high DOI. Further, while it is known that suppliers are not reliable, customer orders are pre-released to ensure timely delivery leading to high possibilities of excess inventory and therefore a higher DOI.

The latter root cause for the high DOI is taken as the core problem. A new procurement strategy is demanded to have materials available for production in time. Thales explicitly mentioned optimizing the procurement strategy and inventory costs while focusing on keeping inventory high enough without materials being out of stock. This signals a trade-off between inventory costs, ordering costs, and backorder costs. While the main objective is to lower the DOI for the components of *product x*, we do not want safety stocks to be insufficient such that component stockouts take place and extra holding costs of the excess inventory as well as additional penalties for delivering too late occur. As described in Chapters 3 & 4, each component's target fill rate has been determined similarly to the newsvendor problem. When doing so, an optimal order fill rate for *product x* is assumed to follow, which is simulated utilizing a simulation model that visualizes the performance of the individual components' safety stock/ROP configurations on the order fill rate of *product x*.

1.3.3 Norm & reality

To find the reality of the action problem concerning a high number of days of inventory on hand for *product x*, we must observe how inventory levels and cost of sales develop over time according to equation 1.1 since historical data is scarce. To compute the DOI for *product x*, we look at the forecasts for both inventory levels and cost of sales for *product x*. When doing so, the estimated value for the DOI of *product x's* components is 283 days. It is difficult to decide what the norm has to be since the objective is to simply improve this high DOI. However, the current value is high since Thales has yet to implement a new procurement strategy and since the output of *product x* (and thus the cost of sales) is low as of now. To implement this strategy, it is important to keep an eye on variability in suppliers' lead times to build some form of buffer for the materials. When doing so, Thales must be able to lower their DOI to below 150 days. For example, Tesla has a DOI of 27 days (StockDividendScreener, 2023) while they are also manufacturing products with intricate components that may require longer lead times. On the other hand, Pfizer has a DOI of 144 (GuruFocus, 2023) days (while they have to work with strict regulations and long development cycles (as does Thales). A substantial difference is the output that Thales realizes compared to these two companies, which is much lower. When combining these two reasonings, A DOI of below 150 days is a reasonable norm for now and accepted by Thales as a benchmark for this research. Table 1.1 depicts the norm & reality of the DOI and the action problem statement.

Variable	**Norm**	**Reality**	**Problem owner(s)**
Days of inventory on hand for *product x's* components	150 days	283 days	- Purchasing department - Master planning department
Action problem statement:	"The days of inventory on hand for the components of *product x* should be decreased from 283 days to 150 days employing a new procurement strategy for the purchasing and master planning departments."		

Table 1.1 - Norm, reality & action problem statement

1.4 Research design

To conduct this research and find answers to solve the core problem such that the action problem is improved, a research design is necessary. In Section 1.4.1, the problem-solving approach with respective research questions is stated. Next, in Sections 1.4.2 & 1.4.3, the scope and deliverables of this research are described.

1.4.1 Problem-solving approach & research questions

Since Thales is observing high levels of inventory, a solution needs to be found for optimizing inventory management without compromising the increase in production rate of *product x* of 600%. To account for the gap between the norm and reality stated in Section 1.3.3, a material inventory policy is needed. This raises the main research question:

How can the inventory levels, and therefore, the current number of days of inventory on hand for product x be optimized through a new material inventory policy for Thales Nederland B.V. while maintaining material availability?

A problem-solving approach is needed to answer this research question systematically (Heerkens, 2017), therefore, this approach is divided into six stages. First, the current situation is analyzed after which useful theories regarding inventory management policies are reviewed through a literature study. Next, a solution is designed according to the theory and data made available by Thales. This solution, a material inventory tool, that configures order quantities and safety stocks, is then also in need of being communicated such that it can be implemented rightfully. The tool's output concerning components' order quantities, safety stocks, and ROPs is evaluated through a simulation to draw conclusions about the stated norm in Section 1.3.3 and to analyze the performance of the inventory management tool´s output on several KPIs relevant to inventory management. During this research, a tool is created, according to a material inventory policy, to determine the optimized order quantities and more importantly, to exploit possibilities to lower inventories through safety stocks while maintaining material availability. Through the subsections of this research accompanied by sub-questions, possibilities, and assumptions to design such a tool will be discussed.

1. What is the current procurement strategy of Thales Nederland B.V.?

To find solutions to implement a material inventory policy, the current situation is revised to find opportunities for optimization. The function of this descriptive analysis was to gather both qualitative data (list of relevant SKUs) and quantitative data (SKU parameters such as prices and supplier lead times). Since, at Thales, safety stocks depend on uncertainties in the suppliers' lead times for the components of *product x*, these uncertainties are examined from existing data and assumptions made for these existing data. Data are gathered through archival research and small interviews. This research question is answered in Chapter 2 ("Current Situation") through the following sub-questions:

1.1. What SKUs are relevant to analyze with respect to product x?
1.2. What is the current inventory policy regarding these SKUs?
1.3. How does the production plan of product x lead to demand requirements and which uncertainties play a role here?
1.4. What further data are available on these SKUs? (supplier lead times + variance, price, distribution, backorder costs)
1.5. To what extent are these data reliable?

For the extra analysis concerning placing safety stocks at suppliers in the supply chain, we also want to determine what the possibilities are and what agreements need to be made.

1.6. *What possibilities do suppliers offer concerning the coordination of safety stocks over the supply chain?*
1.7. *What agreements are needed to be made concerning such coordination?*

2. ***What is a suitable material inventory policy for Thales Nederland B.V. and the SKUs of its product x?***

The second research question of this research is answered through a literature review. During this phase, possibilities to determine the material's buffers and order quantities utilizing the available data that Thales provides are reviewed. Here, inventory policies and means to determine safety stocks using individual SKU target fill rates (similar to the newsvendor problem), are exploited such that an optimal order fill rate for *product x* follows. To maintain the scrupulousness of this research, only academic sources and study books from the University of Twente were used while the sources must be reliable to create reliable outcomes later in the research. This research question is answered in Chapter 3 ("Literature Review") through the following sub-questions:

2.1. *Which inventory management theories are of interest with the available data at Thales to determine safety stocks for the components of product x?*
2.2. *What could be the impact of made assumptions?*

Next to finding solutions to determine the safety stocks, we also conducted an extra analysis on the possibilities of placing safety stocks at suppliers. Alternative scenarios (Section 1.2) have to be analyzed to observe whether there is a more economical way of ensuring material availability, therefore, further sub-questions are:

2.3. *What are (dis)advantages of placing safety stock elsewhere in the supply chain?*
2.4. *What information is relevant when deciding the place of the safety stock and how can it be obtained*

3. ***What material inventory policy tool design is suitable for Thales Nederland B.V. and its product x?***

The next part of this research holds generating the solution. Here, the material inventory policy tool is designed for Thales that computes the inventory management parameters: order quantities, safety stocks, and ROPs. These parameters are determined by combining relevant input parameters from Chapter 2 and the concluded findings from Chapter 3 through Excel and its VBA. Further, to analyze the tool´s output´s performance on several inventory management KPIs, a simulation model has been built to do so. Throughout Chapter 4, we determined the most important KPIs for Thales as well as how the simulation model is programmed. This research question is answered in Chapter 4 ("Solution Design") through the following sub-questions:

3.1. *How can one let the tool determine order quantities and safety stocks?*
3.2. *Which available input data are necessary for the tool?*
3.3. *Which key performance indicators are relevant to be analyzed?*
3.4. *Which input data are needed to construct a representative simulation of the procurement and assembly process of product x?*

Now, concerning the placement of safety stock elsewhere in the supply chain, a mathematical model is designed for Thales to be able to determine whether alternative safety stock placements are economically optimal or not. A further sub-question is:

3.4 *How can we depict a good estimation of safety stock distributions at Thales and its suppliers*

4. ***What is the contribution of the tool towards lowering the inventory levels of product x?***

To evaluate the contribution of the new material inventory policy towards optimizing inventory levels and lowering the DOI, we have made use of the simulation to study the inventory levels while simulating the replenishment cycles against the rate of production (demand) in Siemens' Plant Simulation. While testing different scenarios of uncertainties for supplier lead times, the effect of the new material inventory policy has been visualized and analyzed to observe components' inventory levels as well as component availability and respective assembly idle times when components are OOS. Through the simulation, different statistical distributions of lead times are simulated to determine the fit of the inventory management policy implemented while we have assumed that all lead times follow a normal distribution. When doing so, we can analyze SKU lead times that differ too much from a normal distribution by implementing a better estimate of lead time distribution to analyze the impact on inventory management-relevant KPIs. This research question is answered in Chapter 5 ("Results and Sensitivity Analysis") through the following sub-questions which are used to build Chapter 4 ("Solution Design") and lay the foundation for the sensitivity analysis performed in Chapter 5 where different scenarios are depicted to determine the tool's robustness:

4.1. How robust is the tool´s output concerning relaxations of interpretation and constraints?
4.2. Which scenarios are in need to be reviewed?

Now that an inventory management tool is designed for Thales, we have conducted an extra analysis of alternative scenarios of safety stock placements in the supply chain. Throughout the second part of Chapter 5 ("Supply chain coordination"), we answer the next sub-research question by implementing the analysis methodology depicted in Chapter 4:

4.3 Is it useful to analyze possibilities of supply chain coordination concerning the placement of safety stocks at suppliers?

5. ***How can the material inventory tool be implemented and communicated effectively at Thales Nederland B.V.?***

Now that the tool for the new material inventory policy is designed, it has to be implemented within Thales Nederland B.V. Here it is also important that it is being communicated effectively across Thales and its stakeholders that will utilize the tool. Through a literature review, we have found critical perspectives on what to look for when implementing such an instrument in a business environment such as at Thales. Answers are described in Chapter 6 ("Solution implementation").

In Chapter 7 ("Conclusions and recommendations"), the main research question is answered. Besides drawing conclusions, recommendations and suggestions are made for further research to improve the material inventory policy. While producing recommendations, the limitations and made assumptions of this research are reflected and discussed on how these can be avoided or altered to produce more realistic outcomes.

1.4.2 Scope

In consultation with Thales Nederland B.V., this research will focus on the materials of *product x*. While Thales is scaling up production not only for this product, it is preferable to deliver a tool that could be utilized for other items as well. The list of materials for *product x* consists of around +/- 1400 components so in the first part of this research, the most critical items (analyzed in Section 2.1.2) will be selected to review and use in the tool. Items that are cheap and have a short lead time will not be reviewed since an alternative simple inventory management policy is justifiable for these items. The material inventory management tool will then implement the parameters of these components and compute accordingly after which their performance is simulated in a simple simulation model. Since for some components, demand is not entirely independent (Section 2.3.2), we assume that the components' demand only depends on the demand for *product x* for the simplicity of this research. In reality, commonalities occur for components that are used in several assemblies. This topic will be addressed when recommending future research opportunities in Chapter 7. Now, concerning the placement of safety stocks in the supply chain, Thales has appointed one critical supplier to analyze during this research. Doing more suppliers could lead to significantly more work which will not be possible within the 10 weeks.

1.4.3 Deliverables

The basis of this research is to deliver a tool that can determine the levels of safety stock accompanied by a computation of order quantities and respective ROPs to optimize inventory management for these components. Using Excel and its VBA tool, the optimal inventory management output parameters are determined after which these outputs have been analyzed and visualized through a simple simulation model made in Siemens' Plant Simulation. As demanded by Thales, one supplier is analyzed on the possibilities of alternative placement of the safety stock in the supply chain. To conclude, this research has produced:

1. A tool to determine safety stocks, order quantities, and respective ROPs.
2. A simple simulation model that can be used for:
    - analysis of product availability, customer service levels, and assembly idle times for several scenarios.
    - visualization of component's inventory levels for several scenarios to determine the DOI.
3. Methodology to estimate and analyze the placement of safety stocks in the supply chain.

Now that the design of this research has been defined, the current situation at Thales is analyzed in Chapter 2 to observe opportunities for improvement and possibilities to determine order quantities and safety stocks.

2 Current situation

Throughout this chapter, the current situation concerning Thales Nederland B.V.'s relevant components is described to answer the research question '*What is the current procurement strategy of Thales Nederland B.V.?'*. The relevant SKUs are depicted in Section 2.1 and Section 2.2 describes the policies concerning the procurement and checking inventories of these SKUs. Now, Section 2.3 depicts the SKUs' demand while Section 2.4 depicts the SKUs' lead times & uncertainties. Further SKU characteristics that are needed when determining safety stocks and order quantities such as the holding costs are depicted in Section 2.5. Next Section 2.6 describes findings of possible supply chain coordination. In the end, section 2.7 concludes the chapter.

2.1 Relevant SKUs

The purpose of this section is to gather the list of SKUs of *product x*. Here, it is also useful to already analyze the distribution by value of the SKUs to identify the most important SKUs and form the scope of this research.

2.1.1 SKUs Product x

To gather a list of all SKUs used in *product x*, Thales' MAN67 was demanded which states all necessary components to assemble *product x*. Analyzing this list of components, one can conclude that 1.385 different components are needed in the assembly process of *product x*.

To understand the need for this research and the aim to reduce inventory levels for the components of *product x*, it is computed that inventory of the components for *product x* accounts for 11% of the total inventory at Thales. While this does not necessarily imply that inventory levels are too high for *product x*, one can compare the DOI of *product x* against the total DOI of Thales Hengelo. We can conclude that the DOIs for the components for *product x* and Thales in general are 283 days and 220 days respectively. A difference of 63 days (+28,6%).

2.1.2 Distribution By Value & scope

When classifying the components according to an ABC classification and possible extensive forms of this principle, the scope of SKUs analyzed in this research is also defined. In general, items classified as A-items contribute to as much as 80% of a firm's revenue while the volume of these SKUs is typically less than 20% of the total number of components. B-items contribute to the next 15% and C-items the last 5% of sales. According to this Pareto principle, focusing on 'A' class items can yield maximum benefits (Dhoka & Choudary, 2013). The scope of SKUs analyzed throughout this research is only A-items.

Now, to determine the distribution of SKUs per class, Eraslan & Tansel (2020) recommend utilizing a classification through the Annual Dollar Usage (ADU). Using this method, first, the unit prices and annual demands are multiplied for each item based on annual monetary. Next, the items are sorted in descending order, and curves are drawn (Eraslan & Tansel, 2020). In the case of the components of *product x*, one can multiply the quantities required in one assembled product with their respective prices (Section 2.4.1) according to the product's BOM. While doing so, an overview is created of the distribution of value over the different components in one *product x*. In this case, the BOM is used rather than the annual demand of components, which is proportional to this annual demand. Annual Dollar Usage does not fit here so we shift to a Distribution By Value (DBV) also utilized by Vlaswinkel (2024). Figure 2.1 depicts the DBV for all components of *product x*.

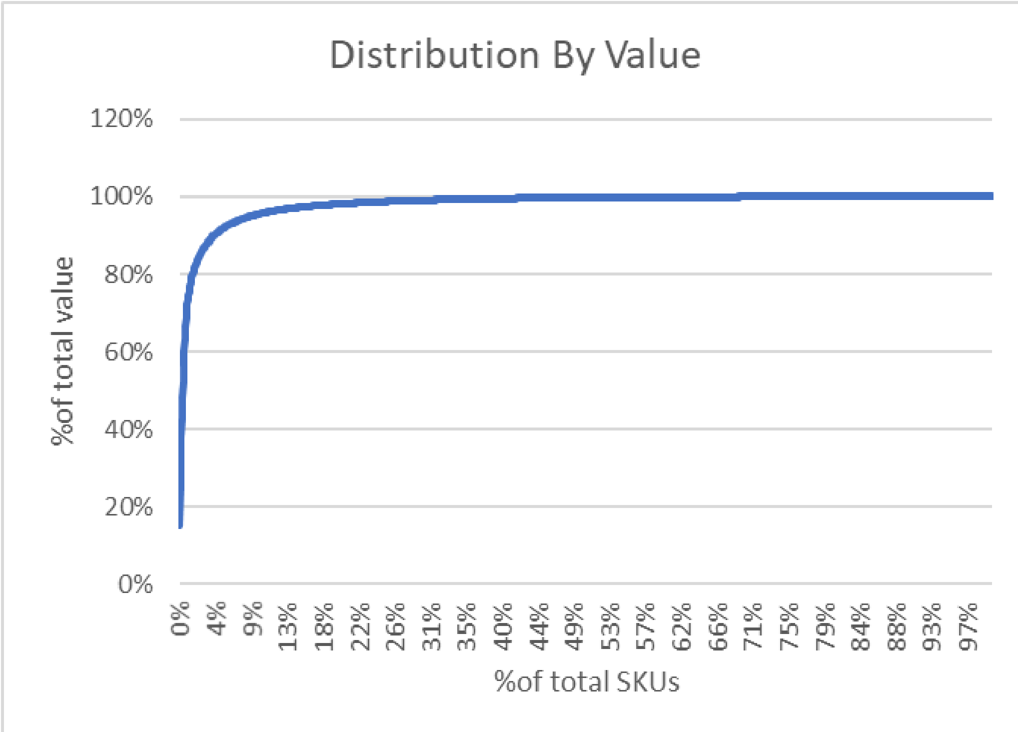

Figure 2.1 - Distribution by Value of components

According to this DBV, we observe a very steep curve suggesting that a small number of SKUs represent most of the value assembled in *product x*. While the ABC classification makes use of three classes, utilizing only two is sufficient according to Hautaniemi & Pirttilä (1999). Adding A- and B-items together yields a scope of 130 items that represent 95% of *product x's* value and offers a great opportunity to reduce overall supply chain costs in holding and backorder costs. To define the scope of SKUs to analyze during this research, Class A and B items are combined into one class. Therefore, Class A represents 9% of *product x's* components while Class C represents the other 91%. According to this distribution, when only utilizing Class A items, one can restrict to analyzing 130 'critical' SKUs. Table 2.1 depicts the distribution of components over the two classes.

Class	**#SKUs**
Class A (95% of sales)	130 (9%)
Class C (remaining 5% of sales)	1255 (91%)

Table 2.1 - Class distribution

2.2 Current inventory policies

Throughout the following sections, the current purchasing and inventory monitoring processes are explained, and how they impact the current inventory performance. Here, we also determine how these processes need to be changed when shifting from the current ETO strategy to an MTS strategy.

2.2.1 Component procurement

In the current product assembly environment at Thales Nederland B.V., most products are very specialized and project-based. In such an environment, the Customer Order Decoupling Point (CODP) lies in the early stages of the production process where the products are designed through specifications demanded by the customer. With a CODP in these early stages, Thales' component purchasing policy is completely customer order-driven, resulting in extremely long lead times between the order placement and the final delivery to the customer over two years. Currently, the component procurement process starts when the sales department at Thales draws a customer who agrees to purchase a product at Thales. The sales department places the order in the so-called 'tactical environment' after which a master planner decides when the product is going to be assembled. If an appropriate time window is found for the production process of the product, the master planning department places the order in the so-called 'operational environment'. When the order is placed in the operational environment, the purchasing department receives the order and is authorized to place the components' orders (Annonymous, 2024). As mentioned in Section 1.3.2, current inventory levels are high partly due to excess inventory of components waiting on other components such that the assembly process is started. Due to variability in supplier lead times, (expensive) components that have arrived earlier are waiting to be used. Figure 2.2 depicts the current component purchasing process and how it affects excess inventory.

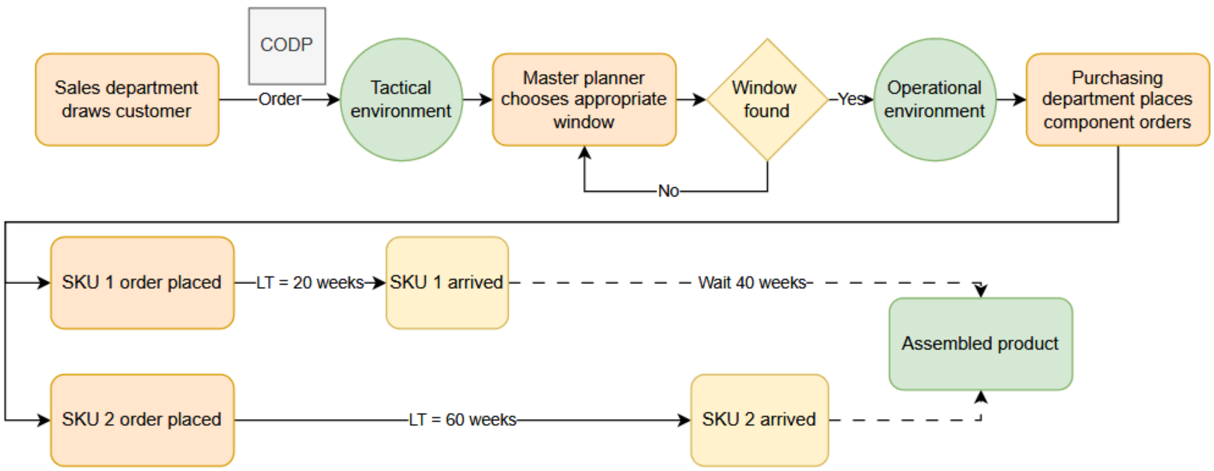

Figure 2.2 - Component purchasing process

As mentioned in Section 1.2, Thales is increasing its production rate of several products (as *product x)* to meet the increase in demand. When doing so, Thales wants to shift the CODP of these products towards the end of the production process, when integrating the customer's software with Thales' software, to be able to procure components and assemble products based on the fixed production plan rather than customer orders. Utilizing this MTS strategy, Thales will be able to lower the customer order lead times and experience opportunities to exploit alternative inventory management policies.

2.2.2 Inventory checking

A problem occurs in the process of checking component availability in both the production department and warehousing department. Due to the customer order-driven component procurement process, there is no (significant) need to keep track of the stock of the individual components. When a customer order is placed, components will be procured and assigned to the specific customer project automatically. The inventory levels of the components are not checked currently, which implies an extra obstacle that Thales needs to overcome if it wants to shift towards a production plan-driven procurement strategy with respective safety stocks and reorder points. When doing so, Thales needs to keep track of its components using, for example, its ERP system to identify situations where the reorder point is passed and a new order needs to be placed.

2.3 SKU demand through production plan

When defining safety stocks or order quantities, (forecasted) demand has to be determined. In an assembly environment, the demand for the singular components of a certain product can be translated through the Bill of Materials. If demand for a certain assembled product is known, the demand for every single component is proportional to the respective SKUs needed (through the BOM), and the demand for the product (Vlaswinkel, 2024, p.iii).

In the business environment at Thales, customers do not demand Thales' products right away and make agreements to receive the products over a longer span. While the actual demand for *product x* is as variable as in any other organization, Thales can agree with its customers to deliver its products on an agreed delivery date, making it possible to 'level' the demand for its *product x* to stabilize the production rate to twelve pieces per year (or one per month). To be able to commit to its suppliers, Thales has introduced a production plan methodology that fixes the production plan for one-and-a-half years in advance (the so-called 'frozen period'). Because some components have lead times of up to two years, Thales needs to also commit to these respective suppliers as well. After the frozen period of one-and-a-half years, Thales has introduced the 'slushy period' of one year where the production plan is fixed to a certain extent, and only some small changes are allowed to be made after approval of the industry- and procurement directors. These 'changes' do not change the annual demand for the components but rather the timing of the output. In the 'liquid period', Thales wants to leave some space for adjustments in the production plan where more or fewer products are assembled. Due to the long horizon of the frozen and slushy periods and the supplier lead times that do not exceed these cumulative time fences, we can state that the demand for all components is deterministic and proportional to the twelve *product xs* per annum. Figure 2.3 depicts the proposed planning window for *product x* by the purchasing department. Table A.1 in Appendix A.1 depicts the total demand for the relevant SKUs in the scope of this research. Through this production plan, component demand is deterministic so no standard deviations of demand are observed that may be used later in this research. As of now, safety stocks are solely necessary for uncertainties in the supply of the components for *product x*.

Figure 2.3 - Proposed planning window *product x*

2.4 SKU lead times & uncertainties

While gathering the necessary data during this research, a list was created with the SKUs needed to assemble a *product x* accompanied by all necessary data concerning these SKUs. Within this list, all components' lead times are stated. These supplier lead times are offered by the suppliers and are given in the number of weeks in which the suppliers 'guarantee' to supply their products. In reality, the 'On Time Delivery' rates (OTD) of these suppliers depict that there is a deviation from the guaranteed lead times and thus some form of uncertainty in the lead times. These uncertainties are used to determine the safety stocks later in this research.

When determining the safety stock to account for component availability, we need to determine the supplier lead time uncertainty while safety stocks are needed to account for either demand uncertainty or supplier uncertainty. Because the demand is deterministic, safety stocks at Thales solely depend on the uncertainty in the ability of the suppliers to meet the (promised) expectations demanded by Thales. Normally, lead time uncertainties are determined by concluding the standard deviations of the lead times (Chopra, 2019, p.340-341). However, since Thales makes agreements with suppliers on the delivery dates, we experience a great variation in the lead times implying a high standard deviation. According to the PUR10-list, where supplier deliveries are rated based on the delay of shipment when a delivery date is promised, we can determine the reliability of the suppliers based on the delay of their shipments.

Within the PUR10, the delay of the shipments per order is being determined (in working days). What this says is that whenever a supplier has agreed on a certain delivery date, any deviations from this are concluded as ‘delay’ (positive when late, negative when early). Basing the supplier lead time uncertainty using the delay determines the direct ability of a supplier to stick to made agreements. The delay, either positive or negative, is added to the proposed lead time by the supplier making it possible to determine the standard deviation of lead times. Analyzing the supplier lead time uncertainty as such also allows combining data of different components without looking at the, probably differing largely, lead times of these different components. The gathered standard deviations of the suppliers’ lead times can be used to determine the standard deviation of lead time demand.

A rule of thumb for the minimal sample size when determining the standard deviation is to have a sample size of 30 at minimum (Pannell, 2023). Keeping this rule of thumb in mind, we determine the standard deviation of lead times per supplier based on the orders of the critical SKUs determined in Section 2.1.2 when the historical data contains at least 30 data points. If no 30 data points can be found and data is determined to be unreliable, a supplier lead time uncertainty is determined based on all shipments made by the supplier, including other (irrelevant) SKUs as well not used in *product x*. Table 2.2 depicts the uncertainty of the supplier lead times per supplier in the scope of this research as well as the average delay per order.

Supplier	Average Delay (d)	Average Delay (y)	STD Delay (d)	STD Delay (y)
Supplier A	1	0.003846154	7.48	0.028769231
Supplier B	25	0.096153846	86.85	0.334038462
Supplier C	-3	-0.011538462	4.06	0.015615385
Supplier D	5	0.019230769	85	0.326923077
Supplier E	117	0.45	87.49	0.3365
Supplier F	-3	-0.011538462	44	0.169230769
Supplier G	-28	-0.107692308	38	0.146153846
Supplier H	-20	-0.076923077	58	0.223076923
Supplier I	11	0.042307692	36.29	0.139576923
Supplier J	-3	-0.011538462	17	0.065384615
Supplier K	42	0.161538462	90	0.346153846
Supplier L	396	1.523076923	86	0.330769231
Supplier M	-3	-0.011538462	77.61	0.2985
Supplier N	25	0.096153846	78.15	0.300576923
Supplier O	-3	-0.011538462	17.32	0.066615385
Supplier P	3	0.011538462	32.41	0.124653846
Supplier Q	-1	-0.003846154	2.06	0.007923077
Supplier R	15	0.057692308	21	0.080769231
Supplier S	46	0.176923077	57	0.219230769
Supplier T	7	0.026923077	30	0.115384615
Supplier U	-2	-0.007692308	21	0.080769231
Supplier V	-1	-0.003846154	14	0.053846154
Supplier W	3	0.011538462	63	0.242307692
Supplier X	5	0.019230769	73	0.280769231
Supplier Y	27	0.103846154	69	0.265384615
Supplier Z	-2	-0.007692308	16.13	0.062038462
Supplier AA	19	0.073076923	55	0.211538462
Supplier AB	3	0.011538462	31	0.119230769
Supplier AC	7	0.026923077	26	0.1
Supplier AD	-6	-0.023076923	16	0.061538462
Supplier AE	-1	-0.003846154	10	0.038461538
Supplier AF	1	0.003846154	38	0.146153846
Supplier AG	14	0.053846154	23	0.088461538
Supplier AH	-2	-0.007692308	12	0.046153846
Supplier AI	-2	-0.007692308	27	0.103846154
Supplier AJ	6	0.023076923	58	0.223076923
Supplier AK	15	0.057692308	40	0.153846154
Supplier AL	-3	-0.011538462	5	0.019230769
Supplier AM	3	0.011538462	66	0.253846154
Supplier AN	-3	-0.011538462	45	0.173076923
Supplier AO	11	0.042307692	64	0.246153846
Supplier AP	19	0.073076923	24	0.092307692
Supplier AQ	-1	-0.003846154	18	0.069230769
Supplier AR	38	0.146153846	67	0.257692308
Supplier AS	-13	-0.05	64	0.246153846
Supplier AT	-12	-0.046153846	40	0.153846154
Supplier AU	-4	-0.015384615	3	0.011538462
Supplier AV	-8	-0.030769231	32	0.123076923
Supplier AW	17	0.065384615	57	0.219230769

Sufficient data points relevant SKUs from supplier
Sufficient data points all SKUs from supplier
Inssufficient data points all SKUs from supplier

Table 2.2 - Average order delay & standard deviations of delay per supplier

In this table, one can distinguish three color classifications. Green means that there are more than thirty data points for the relevant SKUs of the respective supplier to determine the standard deviation of lead times and yellow means that there are less than thirty data points of the relevant SKUs but enough data points when taking all SKUs of the supplier into account. At last, red means that there are a small number of data points available concerning all orders placed at the supplier. Using the suppliers' average order delay, we can revise the promised lead time given in the MAN67 by adding these average delays on top of the promised lead times. Table A.2 in Appendix A.2 depicts the promised lead times per component as well as the revised lead times.

Where data scarcity is most severe is the data concerning the supplier lead times. Data concerning these performances of the suppliers (PUR10) is not only scarce but also contains a lot of flaws. Receipt dates and promised delivery dates may not be updated correctly, leading to unreliable computed delays. Now, to be able to determine safety stocks, we have to assume that the data is reliable. Recommendations will be made on what to do to acquire more reliable data concerning the supplier lead times such that safety stocks can be better determined in the future. Now, to configure such safety stocks, we will assume that the demand during lead time follows a normal distribution for the simplicity of this research. While the demand for components is deterministic, the assumptions solely rest on assuming that the lead times are normally distributed. In practice, not all suppliers' lead times are normally distributed and the literature review in Chapter 3 will discuss this matter where cases of notable deviations from a normal distribution will be analyzed in the sensitivity analysis of Chapter 5.

Further, as depicted in the problem cluster, we can observe that components are often also OOS due to redesigns of components demanded by Thales leading to longer lead times and thus delays. Now, it is not possible to determine the fraction of delays due to redesigns and due to internal problems at suppliers. Because of this, data concerning the shipment delays depicted in the PUR10 is often not representable for situations in the upcoming months where Thales will freeze its designs for *product x* such that suppliers can produce components for Thales without continuously reconfiguring their processes leading to better supply reliabilities and, hence, lower desired safety stocks. Throughout the results section in Chapter 5, we can depict two scenarios where, on one hand, the current data is used and, on the other hand, a reduction in standard deviations is used to visualize the possible reductions in safety stocks and thus the importance of freezing the designs to allow suppliers to become more reliable.

2.5 Further SKU specifications

The following sections describe the important input parameters that are necessary to compute safety stocks and order quantities for the SKUs of *product x* later in this research. To determine the order quantities for SKUs, one needs the annual demand (Section 2.3), supplier lead times & lead time uncertainty (Section 2.4), component price (Section 2.5.1), and holding & order costs (Section 2.5.2). Next, to determine the safety stocks and reorder points, one also needs the backorder costs (Section 2.5.2),

2.5.1 Component prices

While gathering the necessary data during this research, a list was created with the SKUs needed to assemble a *product x* accompanied by all necessary data concerning these SKUs. This list was created by combining a list with all SKUs of *product x* (MAN67) and a list with all specifications (prices, suppliers, lead times, etc.) concerning all SKUs at Thales (MAN65). Within this list, all component prices are stated such that computations can be made to determine order quantities and safety stocks. However, since Thales is offered a lot of quantity discounts for its components, component prices vary a lot over time. The prices gathered in the list are weighted averages of the prices that Thales has received for the respective components over time which are considered the most reliable prices to use in analysis and computations.

While component prices reflect a great part of the cost of sales per *product x*, data concerning the component prices is regarded as confidential and may not be stated in this report.

2.5.2 Order, holding & backorder costs

Order costs

When determining order quantities according to the EOQ formula, the order costs need to be determined or assumed such that an optimal ratio can be defined through this formula between the order costs and holding costs. Within Thales, order costs are not just the costs made by placing the order and are accompanied by costs made when processing the purchase orders. Therefore, order costs are considered higher than initially determined through the order placements. Since Thales does determine EOQs themselves for certain components, we make use of the same assumed order costs for simplicity of this research, which is estimated by Thales to be €200,- per order.

Holding costs (per year)

Further, we also need the holding costs for holding a component in stock for a period of time, say one year. Within Thales, holding costs account for 20% of the inventory value which is estimated through cash that cannot be used (internal interest rate of 10%), space and labor costs, and the risk of inventory becoming 'obsolete' and, therefore, not fit to be used in an assembly (Thales Nederland B.V., 2024). The 20% holding cost estimation can be used to compute both order quantities and safety stocks.

Backorder costs (per year)

Next, to determine a desired service level per SKU, the backorder costs are needed to be determined. These backorder costs (per year) are needed such that a risk assessment can be conducted per component by balancing costs for overstocking and understocking. To give an example, one may want to take more risks in stocking out expensive components in an assembly environment than stocking out inexpensive components. This is because a cheap component of a couple of cents will idle the assembly process when OOS is equally as an expensive component of a couple thousand euros. In that case, a cheap component, which is OOS, is harming the business more than an expensive component because of the higher holding costs of the expensive component. One can assume that, when a shipment of an SKU with a lot size Q is late, the backorder costs are a combination of holding the rest of the components of *product x* in inventory (holding costs) minus the value of the lot size that is too late and including additional penalties for delivering too late (Ben-Ammar *et al.*, 2020). How these backorder costs can be defined mathematically is described in Chapter 4 ("Solution generation").

Since the penalties are determined through penalty clauses with customers, any data concerning the (average) height of these penalties is highly confidential and cannot be stated publicly as in this research. While the fill rates will be determined through backorder costs including the penalties, any computations will be regarded as confidential and, therefore, not be stated.

2.6 Supply chain coordination

Throughout this Section, we want to briefly discuss opportunities to place safety stock at suppliers. In the case of this analysis, Supplier I is visited where discussions have led to the conclusion that it is possible to keep safety stock in both finished components (Scenario 1) and a combination of subcomponents or raw materials and finished components (Scenario 2). Further, Supplier I has stated that keeping safety stock in finished components will be kept against the expense of Supplier I's material costs of the finished component, which excludes any margins of profit over the prices or labour put into the process. The same holds for keeping safety stock in raw materials of Supplier I's components, where each subcomponent or raw material is kept against the expense of its material price.

Now, as depicted in Figure 2.4, scenarios 0 and 1 cover all uncertainties in the supply chain using safety stocks, where uncertainties in the transportation time from Supplier I to Thales have been assumed to be neglectable. However, when placing safety stock in sub-components/raw materials at Supplier I, one can observe remaining uncertainties in the internal process at Supplier I which need to be covered. In the case of scenario 2 at Supplier I, Supplier I has mentioned opportunities to keep fewer safety stocks in raw materials while one component is of most influence in the uncertainties of the supply chain. Let's say that one Sub-component holds all uncertainties in the supply of an SKU delivered to Thales, in that case, we can lower safety stock expenses by only keeping safety stocks for Sub-component A and remaining safety stocks at Thales to cover uncertainties in the supply from Supplier I to Thales. Throughout Chapter 3, we want to discover how we can analyze and compare the different scenarios to find out whether or not it is attractive, financially, and to further exploit possibilities to place safety stocks at the suppliers of Thales.

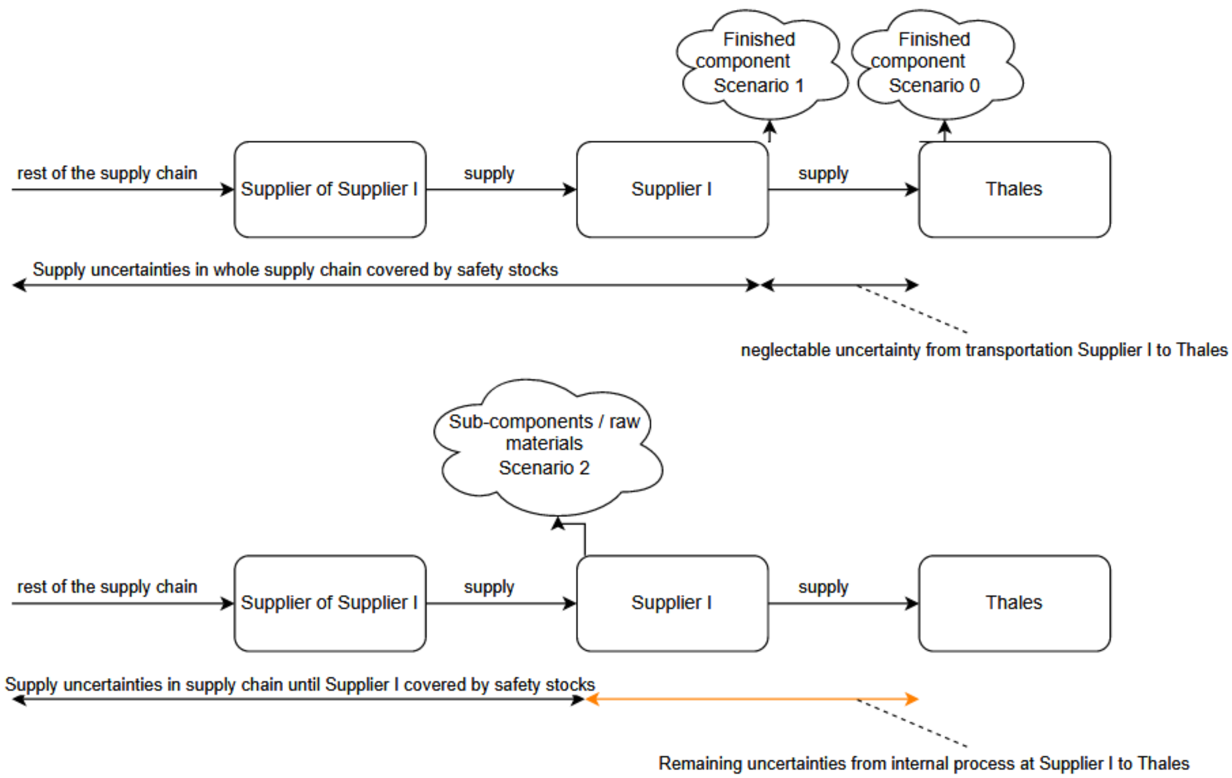

Figure 2.4 - Supply chain coordination scenarios

2.7 Chapter conclusions

Chapter 2 has been used to answer the research question '*What is the current procurement strategy of Thales Nederland B.V.?'*. To answer this question, several sub-questions have been answered to guide this research toward opportunities to determine safety stocks and the need to conduct a literature review to fill the gaps of knowledge.

Relevant SKUs – 130 SKUs have been concluded to review during this research. This follows from an ABC analysis conducted on Thales' MAN67. We have found that 9% of *product x's* components hold 95% of its total value. For these parts, we want to determine a suitable inventory management policy to control inventory levels based on the risk one wants to take with holding extra SKUs or stocking out with these

SKUs. In Chapter 3, we want to find an answer to how this multi-item problem (assembly product) can be solved.

Current inventory policy – inventory levels are currently not checked continuously since this is not necessary in the current ETO environment where customer order lead times are over two years. However, when shifting to an MTS environment in the upcoming months, component inventory levels need to be reviewed more strictly. Continuously checking inventory levels is possible through Thales' ERP system.

Demand and supply uncertainties – While the product's production plan is fixed to one product each month, demand for the components is deterministic. On the supply side, we can observe a lot of uncertainties in the sense of shipment delays. Through shipment delays (PUR10), the standard deviation of lead times can be determined such that a standard deviation of lead time demand can be determined. Further SKU characteristics such as order, holding, and backorder costs have been gathered throughout Section 2.5.

Data reliability – As mentioned in Section 2.4, data gathered through the PUR10 can be unreliable due to flaws in the updating of data. On the other side, as depicted through the problem cluster in Figure 1.1, shipment delays often also occur due to redesigns of components as demanded by Thales to its suppliers. However, it is not possible to determine the proportion of cases that a shipment delay is the fault of such a redesign or through internal problems at the suppliers. In the future, when *product x's* design is frozen, suppliers should become more reliable suggesting lower required safety stocks.

Supply chain coordination – as discussed with Supplier I, the possibilities of placing safety stocks at suppliers is an option for which holding costs, and thus expenses can become lower than keeping all components at Thales. In Chapters 3 & 4 we will discuss how we can, eventually, create a comparison between the three different scenarios depicted in the introduction of this research.

To conclude, because of a shift in production strategy (ETO → MTS), analyzing the performance of the current strategy is irrelevant to this research. Therefore, Section 2 of this report is used to gather the data concerning the demand, lead times, and more of the components in the scope of this research such that we can determine safety stocks to account for the component availability in the assembly process of *product x*. Now, since we are in the 'new product introduction' phase, data might be not representative or available yet. In the literature review in Chapter 3, we will try to find answers on how each component's safety stocks can be determined to control inventory levels in an assembly environment while maintaining a high customer service level and how certain assumptions may harm inventory management configurations. Here we want to exploit possibilities to solve this multi-item problem as well as possibilities to configure a(n estimated) distribution of safety stocks over different suppliers by decoupling the safety stock in the supply chain. Further, Chapter 3 is used to determine the impact of assuming normally distributed lead times.

3 Literature review

The next chapter is used to perform a literature study to answer the research question *'What is a suitable material inventory policy for Thales Nederland B.V. and the SKUs of its product x?'.* Section 3.1 depicts why inventory management is important and what policies hold for the business environment at Thales. Next, Section 3.2 describes how this multi-item inventory management problem can be solved such that safety stocks can be determined as well as the formulas through which the order quantities and safety stocks are determined. Section 3.3 describes what assumptions are made, whether these are justified, and what the impact of such assumptions is on the determination of the safety stocks. Section 3.4 describes how we can estimate a distribution of the safety stocks over the different installations in the supply chain such that different scenarios depicted in Chapter 1 can be compared. At last, the chapter is concluded in Section 3.5.

3.1 Inventory management

Described in this section is the importance of inventory management when shifting to an MTS strategy as well as what inventory control policies are suitable for Thales.

3.1.1 Importance of inventory management

Supply Chain Management, the control of the material flow from suppliers to final customers, is a crucial problem for most organizations. A big part of this problem is the enormous investments in inventory where tied-up capital offers potential for improvement (Axsäter, 2006, p.1). When shifting to an MTS strategy, Thales creates the opportunity to dive into production plan-driven inventory management. According to Axsäter (2006), research has resulted in new and more general methods that can reduce supply chain costs substantially. Over the years, the field of inventory control has shifted from simple decision rules to advanced decision models requiring considerable computational efforts.

Inventory management finds a balance between holding costs and customer service. Having too much inventory reduces working capital while having too little leads to a lower customer service level and potential backorder costs (Priniotakis & Argyropoulos, 2018). Currently, Thales is experiencing high inventory levels, leading to a lot of cash tied up in inventory against a high internal interest rate (10%).

In an MTS assembly environment, if one component is delayed, the entire assembly process is stopped leading to high holding costs for the other set of already delivered components. Using an MRP system, which may be justified in an ETO environment, often proves to be too limited in an MTS environment (Ben-Ammar *et al.*, 2020). Further, Ben-Ammar *et al.* (2020) discuss the importance of utilizing inventory management policies to account for supplier lead time uncertainty. Building safety stock or introducing safety lead times may account for variability in supplier lead times where an MRP system does not. After pointing out the high backorder costs for late components, individual component service levels are desired to be higher than normal to account for assembly idle times and the respective costs.

3.1.2 Inventory control policies

In supply chain management, we consider two main inventory review policies in continuous review and periodic review policies. In the continuous review policy (R, Q), the inventory position (3.1) is continuously tracked and, after the reorder point (R) is crossed, an order with a fixed size (Q) is placed. Now, with a periodic review policy (R, S), inventory status is checked at periodic intervals where an order is placed to raise the inventory level to a specific threshold (Order-up-to-level) (Chopra, 2019, p.330). When utilizing a periodic review policy with a variable lot size, safety stocks are destined to be larger than under a continuous review policy (Axsäter, 2006, p.47), which is mainly because of the extra demand during the review interval (Axsäter, 2006, p.180). If continuous review is possible, through a live ERP system, utilizing it is preferable to lower the safety stocks. Now, if demand is not continuous and inventory levels may drop too far under the reorder point (undershoot), a (R, S) policy is preferred (Axsäter, 2006, p. 49). This policy demands to order of a variable lot size such that the maximum level S is reached.

$$Inventory\ position = on\ hand + on\ order - backorders - committed \quad (3.1)$$

3.2 Inventory management parameters

Throughout this section, constraints to establish safety stocks are described in Section 3.2.1 after which the definitions and formulas of the order quantities, safety stocks, and reorder points are depicted in Section 3.2.2.

3.2.1 Service level constraints

Fill rate

Where constraining safety stocks according to a cycle service level is a widely applied means, it measures the probability of replenishment cycles where on-hand stock does not reach zero. In the case of an assembly organization such as Thales, it is not necessarily a problem when a component is OOS, however, a component must be in stock when needed. A more suitable criterion, in this case, is the fill rate that counts the fraction of item demand that is available from stock. Further, a fill rate must be measured over specified amounts of demand rather than over time (Chopra, 2019, p.328). In the case of slowly moving demand such as at Thales, the fill rate is more accurate because the replenishment cycles are long due to long lead times with low quantities.

When constraining service levels to a fill rate on a single-item level, Rudi *et al.* (2009) suggests that an optimal order-up-to-level S is satisfied through a correspondent of the well-known newsvendor solution, depicted by Silver *et al* (2016) as (3.2) where the fill rate is stated as P_2, by finding an optimal ratio between backorder costs per time unit (B_3) and holding costs per time unit (h) (Rudi *et al*., 2009, p.1361). (3.2) is called the criticality ratio and depicts the balance between understocking (backorder costs B_3) and overstocking (extra holding costs h per unit). This relationship holds when all unmet demand is backlogged, (Silver *et al.,* 2016, p.249). Through (3.2), one can analyze the risk, on a single-item level, one may take on stocking out. Expensive items carrying high holding costs may suggest keeping lower safety stocks due to the higher risk one may want to take on stocking out due to the high holding costs and vice versa.

$$P_2 = \frac{B_3}{B_3 + h} \quad (3.2)$$

Order fill rate

When a customer order arrives in an ATO environment, all items required through the order are needed to be available simultaneously. The same holds in an MTS environment where all different components conclude to a final product and must therefore be available simultaneously. In this case, we are interested in finding the probability of a demand being satisfied immediately (order fill rate) or the average customer waiting times. According to Song *et al.* (1999), reliable and speedy delivery of orders is one of the most crucial factors for customer satisfaction making order-based performance measures, such as the order fill rate and the customer waiting time distribution of significant importance (Song *et al.*, 1999, p.131). Order fill rates tend to be lower than individual component fill rates because all products must be in stock for an order to be filled (Chopra, 2019, p.328).

According to Teunter *et al*. (2017), using the ABC classification to set the same service levels for each SKU in a class is a widely applied means by companies. However, Teunter *et al.* (2017) describe that targeting the service levels for each SKU simply the same as the target service level of the system (or overall product/assembly) should be far from optimal when contrasting it to revising every single item separately (Teunter *et al*, 2017, p.917). When assuming equal backorder costs, and thus equal criticality, per SKU, the fill rate at single SKU level (FR_i) can be measured where FR_i is considered to be the optimal fill rate for SKU *i*. Using the same newsvendor's formula as depicted in (3.2), equation 3.3 can be formulated per SKU *i*.

$$FR_i = \frac{B3_i}{B3_i + h_i} \tag{3.3}$$

From the definition of the total fill rate (FR_T), we can derive (3.4) where FR_T is the total fill rate of the combination of SKUs and D_i equals the annual demand for SKU *i*.

$$1 - FR_T = \frac{\sum_{i=1}(1 - FR_i)D_i}{\sum_{i=1} D_i} \tag{3.4}$$

In the research conducted by Teunter *et al*. (2017), a target fill rate for the total set of SKUs is stated after which all individual components are constrained to this total fill rate in combination with the criticality of the SKU. One could also argue that an optimal order fill rate (or total fill rate) follows from optimal individual fill rates when backorder costs B_3 are dependent on each other as is the case of the components in Thales' *product x*. In that way, a multi-item inventory problem is solved by decoupling single-item inventory problems for each SKU instead of the other way around.

3.2.2 Order quantities, safety stocks, and reorder points

Order quantities

To determine optimal order quantities such that there is an equal distribution between the holding costs of a component and the costs when a component order is placed, we can consider the economic order quantity (EOQ) model which applies to known, continuous, and constant demand over a planning horizon as is the case at Thales where demand is deterministic and constant over the production plan horizon (Godichaud & Amodeo, 2018, p.16-25). However, concerning the order quantity Q, override should always be possible to incorporate factors that are not included in the EOQ formula (e.g., MOQs) (Silver *et al*., 2017, p.147). The EOQ formula, depicted in (3.5) for SKU *i*, can be used to lower costs concerning keeping inventory and the ordering of SKUs where S equals the ordering costs, D_i equals the annual demand of SKU *i*, and h_i equals the annual holding costs of SKU *i*.

$$EOQ_i = \sqrt{\frac{2SD_i}{h_i}} \tag{3.5}$$

While the formula may suggest ordering a non-integer, rounding the determined order quantity to the nearest integer is justified according to Axsäter *et al*. (2015). As mentioned above, when a MOQ is higher than the determined EOQ (3.5), the MOQ overrides the EOQ.

Safety stocks

Since uncertainties in supply (lead times or quantities) and demand are almost inevitable in both the production and transportation of SKUs, safety stocks need to be determined to account for component availability (Axsäter, 2015, p.2). To compute safety stocks when assuming that demand during lead time is following a normal distribution, a standard deviation of lead time demand has to be determined accompanied by a target service level that the inventory performance should be constrained to. Demand and supply uncertainties lay the foundation to determine the standard deviation of lead time demand (σ_L) depicted in (3.6) which can be used to determine the SKUs' safety stocks (Chopra, 2019, p.330). Here, *L* equals the SKU's average lead time, *D* equals the SKU's average annual demand, σ_D is the standard deviation of annual demand, and s_L is the standard deviation of the SKU's lead time.

$$\sigma_L = \sqrt{L\sigma_D^2 + D^2 s_L^2} \tag{3.6}$$

Now that the standard deviation of lead time demand can be determined, a suitable service level should be appointed to constrain the inventory performance to. In the case of single-item component inventory management, the optimal service level in the sense of fill rates could be acquired through (3.3). When evaluating a target fill rate in practice, it is important to note that a stockout occurs if the demand during the lead time exceeds the ROP. Given this note, we must evaluate the average amount of demand in excess of the ROP in each replenishment cycle. The expected shortage per replenishment cycle (ESC) is the average demand that is not satisfied from stock per replenishment cycle with a given lot size Q. The FR can be determined through (3.7) (Chopra, 2019, p. 334).

$$FR = 1 - \frac{ESC}{Q} \tag{3.7}$$

Conveniently, the ESC can be expressed through (3.8) which states the relation between the safety stocks and the standard deviation of lead time demand towards the ESC. When determining a desired FR through (3.3), the desired ESC can be determined by rewriting (3.7) (see equation 3.9) such that a safety stock can be computed that accounts for an actual ESC that meets the desired value from equation 3.8. By incrementing the safety stock, starting from zero, the actual ESC should decrease until the desired ESC is met. We are left with the desired safety stock that accounts for the desired material availability determined by analyzing the risk one wants to take to allow backorders (Chopra, 2019, p. 335).

$$ESC = -ss\left[1 - F_s\left(\frac{ss}{\sigma_L}\right)\right] + \sigma_L f_s\left(\frac{ss}{\sigma_L}\right) \tag{3.8}$$

ss = safety stock

σ_L= standard deviation of lead time demand

$F_s(x)$ = standard normal cumulative distribution

$f_s(x)$ = standard normal density function

$$ESC^* = (1 - fr)Q \tag{3.9}$$

For both the standard normal distribution and the standard normal density function, a mean of zero and a standard deviation of 1 is used in any computations with the formula in (3.8) (Chopra, 2019).

Reorder points

Now that the order quantities are determined through (3.5) and safety stocks through (3.8), we need to figure out when we need to order (Reorder point). An ROP is a predetermined point where an order with lot size Q needs to be placed when the inventory position has surpassed this benchmark (Axsäter, 2006, p. 48). The ROP is nothing more than the amount of safety stock plus the expected demand during lead time. Equation 3.10 depicts the derivation of the ROP (Chopra, 2019, p. 331).

$$ROP = ss + D \times L \tag{3.10}$$

To conclude the abovementioned sections, using formulas 3.3 to 3.10, we can determine the order quantities, safety stocks, and respective reorder points.

3.3 Impact of assumptions (normally distributed demand during lead time)

Throughout this section, we are discussing how assuming a normal distribution for the components' lead times may harm the performance of the configured safety stocks. To define safety stocks in this research, it is assumed that the components' lead times are normally distributed such that a standard deviation of lead time demand can be computed, however, one may ask how robust this assumption is and when we can or cannot make such assumptions.

According to a literature review conducted by Lau & Lau (2003), one can safely assume that the lead time demand is normal as long as its coefficient of variation through (3.12) is sufficiently small (<0.5). Here, σ_{LTD} states the standard deviation of demand during the lead time and μ_{LTD} states the average demand during lead time.

$$CV_{LTD} = \sigma_{LTD}/\mu_{LTD} \tag{3.12}$$

However, Lau & Lau (2003) demonstrate that cost penalties for misrepresenting the actual LTD shape with a normal approximation can be substantial even if the coefficient of variation of the lead time demand is smaller than 0.3. Other studies from Tadikamalla (1984), Tyworth & O'Neill (1997), and Silver, Pyke & Peterson (2015) suggest that a coefficient of variation of the lead time demand below 0.5 justifies the normal assumption. Tadikamalla (1984) adds that when the coefficient of variation is large, the normal distribution may not be suitable because the probability of stocking out is too large to be ignored. For the simplicity of this research and to produce outcomes to work with, lead times are assumed to be normally distributed. In case of a coefficient of variation exceeding 0.5, we will dive deeper into the actual distribution of the lead time demand to find out the impact of assuming a normal distribution.

While penalties for delivering too late to customers are quite high for Thales, the expected desired fill rates for components are probably going to be significantly high. Tyworth & O'Neill (1997) state that the evidence gathered in their research indicates that the normal approximation of lead-time demand is robust and order-fill errors should be reasonably small, even for high service targets. While this research suggests that the normal approximation is robust even for high-service targets, it also implies that there is a risk for such service targets and thus for stocking out. The simulation model proposed in Chapter 4 may be of use to find out how robust the normal approximation is in this research. Further, according to Chopra (2019), a firm should be willing to tolerate somewhat longer lead times if there is a significant reduction in lead time uncertainty. Sharing of information and coordinated demand and supply planning can help a supply chain reduce supply uncertainty (Chopra, 2019, p.359).

3.4 Supply chain coordination

As explained in Chapter 1, an extra analysis is going to be conducted to determine whether or not it is economically beneficial to decouple safety stocks in the supply chain without harming customer service levels. Here, an alternative to keeping components in stock as a safety buffer at Thales, components can also be held in stock at suppliers upstream in the supply chain. Analyzing possibilities to execute this alternative safety stock placement is done by discussing the cost-savings one could achieve by doing this against the split in supply uncertainty that is implied when safety stock is decoupled (recall Figure 2.4). The following sections describe the advantages of alternative safety stock placement and how one can analyze whether or not it is advantageous to execute this.

3.4.1 (Dis)advantages

Where, often, the span of control for management is assigned to individual installations, single-echelon policies are utilized to optimize inventory performance results. If the relevant information is available centrally and all management objectives are aligned, multi-echelon policies can be reviewed from which the optimal solution will most likely dominate single-echelon policies. When utilizing single-echelon inventory control policies, each site has its own FR constraint/goal to satisfy, whereas, in multi-echelon inventory control policies, the overall fill rates and material costs of the whole supply chain are optimized (Hausman & Erkip, 1994, p.597). When analyzing the optimal placement of safety stocks, one wants to determine a distribution of products over the installations that lead to the lowest total material costs while limiting the increase of supply uncertainties (Axsäter, 2006, p.254).

To conclude, multi-echelon inventory control policies strive for optimized total supply chain costs by allocating safety stocks over the different installations in the chain. However, some disadvantages may occur in the sense of more supply uncertainty. When shifting safety stock from the end of the supply chain to an installation more upstream in the supply chain, one is also moving more risk to the end of the supply chain since a disruption in the assembly process may lead to idle times since the safety stock is needed to be shipped from the supplier to Thales. In this case, one wants to find the optimal component safety stock distribution that lowers total costs against a reasonable risk in supply uncertainty.

3.4.2 Clark-Scarf model

The best-known technique for determining safety stocks in a multi-echelon inventory system was presented by Clark and Scarf in 1960 (Axsäter, 2006, p.248). Utilizing the Clark-Scarf model, first, we consider the downstream installation (Thales) that is facing customer demand. This customer demand is translated to orders for components needed from suppliers upstream of the supply chain. Now, when considering safety stock placements at installations upstream of the supply chain, shortages (supply uncertainty) at the next upstream installation (supplier) lead to delays that imply certain backorder costs at the main business downstream of the supply chain (Axsäter, 2006, p.249). In the Clark-Scarf model, optimal fill rates are determined for every installation in the supply chain by analyzing the different holding costs at the supply chain's installations similar to the newsvendor formula depicted in (3.3). When holding costs at an installation upstream in the supply chain are lower than at an installation downstream in the supply chain keeping safety stock may be cheaper, however, the optimal fill rate at the supplier may be higher inducing a higher number of safety stocks and thus higher total costs. If the holding costs at an installation upstream of the supply chain are higher it is per definition worse to keep safety stock at that installation. While the Clark-Scarf model assumes a stochastic demand with deterministic lead times, the model cannot be used one-on-one with the situation depicted at Thales where demand is deterministic with stochastic lead times. However, the concept of constraining safety stocks to different target fill rates (newsvendor problem) at the different installations in the supply chain may be useful when deciding what safety stocks need to be kept to account for material availability.

3.5 Chapter conclusions

The literature review conducted in Chapter 3 has been used to answer the research question *'What is a suitable material inventory policy for Thales Nederland B.V. and the SKUs of its product x?'.* To answer this question, several sub-questions have been answered to guide this research towards methods to configure an inventory management policy for the components of *product x* and observe gaps that need to be filled in by adjusting known methodologies to suit the case of Thales.

Inventory control policies – where common review policies have been addressed, utilizing a continuous review policy should be optimal while it does not incorporate the higher safety stocks due to further lead time demand during the review period in periodic review policies. Due to Thales' ERP system, it will be possible to continuously review the inventory positions of SKUs. Now, in the spirit of Teunter's (2017) approach for assigning a target fill rate for each SKU to align with the total fill rate of an order/assembly, we can use the newsvendor formula (3.3) to depict an optimal fill rate per component. While the backorder costs are all dependent on each other due to the assembly of *product x*, targeting an individual optimal fill rate per SKU will lead to a well-determined order fill rate for the assembly of *product x*.

Assumptions – Where we assume that the components' lead times follow a normal distribution in this research, we want to find exceptional cases where this assumption is not viable. Lau & Lau (2003), suggest that when the lead time demands' coefficient of variation is below 0,5, the normal assumption is viable. However, exceeding this benchmark may lead to significant cost increases due to a higher possibility of stocking out. In Chapter 5, we describe how we can analyze how these cases harm the inventory policy's performance towards inventory KPIs.

Supply chain coordination – Multi-echelon inventory systems and decoupling safety stocks over different links in the supply chain may introduce lower supply chain costs concerning the inventory holding of SKUs. When information is available concerning uncertainties at different stations in the supply chain as well as the holding costs of keeping the SKUs in stock at these stations, coordinating and distributing safety stocks over these stations can lower inventory costs. To analyze and indicate the possible amount of cost savings, in the spirit of the well-known Clark-Scarf model, we can decouple the uncertainty (standard deviation of lead time) over the different installations such that safety stocks can be distributed over these stations according to an optimal fill rate that can be assigned to these suppliers upstream the supply chain. In Chapter 4, we will discuss this matter and explain how we can indicate a distribution of safety stocks over the different stations in the supply chain for the sake of cost-reduction analysis.

To conclude the literature review performed in this chapter to answer the research question, we can confirm that a continuous review inventory policy is preferred and justified through the means that Thales' ERP system offers. Now, concerning the desired service level constraint, we can decouple this multi-item problem into single-item problems such that each component can be constrained to its optimal fill rate. The simulation model analyzed in Chapter 5 will depict how the single-item fill rates conclude with the order fill rate of *product x.* At last, this literature review has concluded that multi-echelon inventory policies may lead to lower total material costs. For Thales, we can use the FR constraint proposed by Clark & Scarf (1960) to demand the suppliers keep a sufficient safety buffer for uncertainties upstream of the supply chain. When an optimized distribution of safety stock in the supply chain is configured, the total costs can be compared to alternative safety stock placements to identify the best scenario. Next, Chapter 4 describes how the order quantities, safety stocks, and ROPs can be determined for the assembly environment at Thales. Further, Chapter 4 also discusses how we can estimate a distribution of safety stocks over the installations in the supply chain to perform a cost analysis on the inventory holding costs of the predetermined scenarios described in Section 1.2.

4 Solution design

Throughout this chapter, the research question '*What material inventory policy tool design is suitable for Thales Nederland B.V. and its product x?*' is answered. The use of an MRP system is not justified anymore since it does not take supply uncertainties into account. Utilizing an inventory control policy is important for Thales Nederland B.V. to be able to maintain a high customer service level.

4.1 Choice of inventory control policy

In Section 4.1, we want to discuss how the inventory control policy must be reviewed (4.1.1) and how to determine the optimal order quantities (4.1.2) and safety stocks (4.1.3) in the case of Thales. While doing so, we assume that component demand is deterministic and lead times follow a normal distribution. The methodologies to determine the order quantities and safety stock that are depicted in this section are implemented in an inventory management tool for Thales that determines order quantities, safety stock, and ROPs for an arbitrary number of components. The VBA code that translates the formulas into output and the layout of the tool are depicted in Appendix B.1 & B.2 respectively.

4.1.1 Review policy

As explained by Axsäter (2006), utilizing a continuous review policy offers superior outcomes over a periodic review policy due to the extra lead time demand that occurs during each review period in periodic review policies. In the case of Thales, which makes use of the ERP software from ORACLE, it is possible to continuously review the inventory levels of the components of product x through the software. While one does not want inventory levels to radically dive below the ROP, an (R, S) policy may be a better fit when experiencing such undershoots. Now, because of the deterministic demand through the production plan that is lumpy but spread evenly over a period of time, component inventory levels can radically dive under the ROP, when simply applying the EOQ and safety stock formulas, leading to a so-called undershoot. Rather than utilizing a periodic review policy, we can revise the order quantities and safety stocks such that undershooting is not possible, and the ROP is hit exactly all the time, which will be explained throughout Sections 4.1.2 & 4.1.3. Now, utilizing a continuous review policy ((R, Q) policy) with reorder point R and fixed lot size Q is justified through the possibilities offered by Thales' ERP system. In the case of Thales, the IP consists of on-hand inventory and outstanding orders which are both monitored through ORACLE. Utilizing this continuously reviewing ERP system with revised order quantities and safety stocks, the ROP can be exactly hit, therefore, for the remainder of this research, the (R, Q) policy is further analyzed.

4.1.2 Order quantities

When utilizing the continuous (R, Q) policy, determining order quantities is optimal by utilizing the EOQ formula depicted in (3.5). When doing so, costs such as the annual holding costs and order costs are needed to determine the optimal quantities to order such that a balance can be found between the two. The third parameter of the EOQ formula holds the annual demand of the relevant SKU. While the demand for *product x* is deterministic at twelve pieces per annum, the demand for the separate components is obtained by multiplying the quantities needed through the BOM by twelve. Now, we should only be interested in buying components in multiples of *product x*, since buying other quantities leads to unnecessary component inventories. For example, *product x* needs 30 pieces of SKU1, but the EOQ formula suggests buying 40. Procuring 40 pieces will lead to a situation where the inventory position of SKU1 will radically dive below the ROP leading to undershoot and possible OOS when a shipment is delayed. Let us say that the ROP is 60 pieces, we have bought 40 pieces of SKU1 and *product x* demands 30 pieces each month. In this case, as depicted in Figure 4.1, the inventory position will radically dive under the ROP in the second month. A lot size in multiples of *product x*, let us say 30 or 60, will lead to an exact hit of the ROP of 60 pieces. To incorporate this in the inventory management tool for Thales, the optimal order quantities through the EOQ formula will be rounded to the nearest multiple of components needed in *product x*. In the case of SKU1, this could be either 30, 60, 90, etc. pieces.

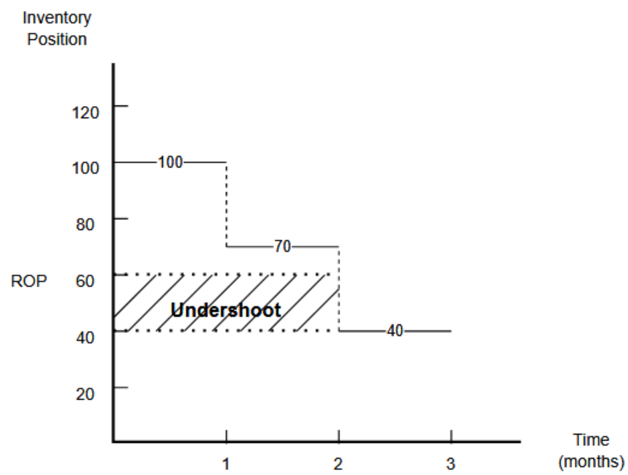

Figure 4.1 - Undershoot due to incorrect lot size

4.1.3 Safety stocks & ROPs

As explained in Section 3.4.2, safety stocks are needed to account for any uncertainties and fluctuations in the demand for a component and/or the supply of the component. In the case of Thales, safety stocks are solely kept to account for uncertainties in supply. These uncertainties are determined throughout Section 2.4. Now, through equation (3.8), we can determine the desired safety stock for the components of *product x*. For Thales to be able to determine the safety stocks, we need to determine the standard deviation of demand during the lead time as well as the desired service level Thales wants to restrict itself to account for material availability.

Standard deviation lead time demand

Since the components' demand is determined to be deterministic through the production plan at Thales, we can simplify the equation for the standard deviation of lead time demand depicted in (3.6). While the demand is deterministic, there is no standard deviation to observe concluding with a standard deviation of demand of zero. Equation 4.1 depicts the revised formula for Thales' components' standard deviation of lead time demand (σ_L) only depending on the annual demand (D) and the supplier's standard deviation of lead times (s_L).

$$\sigma_L = \sqrt{D^2 s_L^2} \tag{4.1}$$

In Section 2.4 the supplier lead time uncertainties are analyzed through the s_L, we can compute the σ_L for each component while utilizing its annual demand and its supplier's s_L depicted in Table A.1 & Table 2.2 respectively.

Desired service level

To account for material availability, one can constrain a certain inventory model to a service level. The lower the service level, the less inventory is kept but the more stockouts will occur and vice versa. As discussed in Section 3.2.1, a single-item target FR was determined to be a dominant measure for a service level in the case of Thales' components. However, an order fill rate (% of orders that can be fulfilled from inventory on hand) is an important measure in an assembly environment where the whole process is affected when a component is not in stock and, therefore, chosen to be the measure of service level performance throughout this research and visualized in the simulation model in Chapter 5. In this research, we are interested in finding each component's optimal target FR such that an optimal order FR follows from each component's target FR. While doing so, we solve this multi-item inventory problem by decoupling the problem into single-item inventory problems and solving these individually. As depicted in (3.3), a component's target FR can be determined by rationalizing the holding costs to backorder costs that occur when *product x* is delivered too late in the same manner as the newsvendor problem. The formula in (3.3) balances understocking and overstocking costs by finding a criticality ratio between backorder costs B_3 and holding costs h. Recall from Section 2.5.2 that backorder costs at Thales consist of keeping all components of *product* x in stock for a period of time (minus the shipment of an SKU with lot size Q that is too late) plus additional penalties per period of time that are included when Thales delivers a *product* x too late to its customer. (4.2) depicts the backorder costs of a late shipment of SKU_i.

$$B_3(SKU_i) = 0{,}2 \times ((\textstyle\sum_{j=1}^{130} cSKU_j) - pSKU_i \times Q_i) + penalties \qquad (4.2)$$

$$cSKU_j = total\ costs\ of\ SKU_j\ in\ product\ x\ (quantities\ in\ BOM\ \times price\ of\ SKU_j)$$

$$pSKU_i = price\ of\ one\ SKU_i$$

$$Q_i = lot\ size\ of\ SKU_i\ that\ is\ too\ late$$

In (3.3) we also want to analyze the costs of overstocking and increasing the total holding costs by one unit, however, in the case of Thales, we want to determine whether or not to keep enough pieces of an SKU such that an extra *product x* could be concluded. While each component's necessary quantity is obtained through *product x's* BOM, we can say that the costs of overstocking are the costs of holding SKUs to conclude an extra *product x*. (4.3) depicts the overstocking costs for SKU_i (h_i) where BOM_i states the amount of SKU_i needed to conclude an extra *product x*.

$$h_i = 0{,}2 \times pSKU_i \times BOM_i \qquad (4.3)$$

Now, for each of Thales' components, we can determine a target FR such that the risk of experiencing holding costs (h) is equal to the risk of backorder costs (B_3). As explained in Section 2.4.2, backorder costs consist of the holding costs of the rest of the products of *product x* and any additional penalties (per annum). (4.4) depicts a customization of (3.3) in the case of Thales.

$$Target\ FR\ SKU_i = \frac{0{,}2\times((\sum_{j=1}^{130} cSKU_j)-pSKU_i\times Q_i)+penalties}{0{,}2\times((\sum_{j=1}^{130} cSKU_j)-pSKU_i\times Q_i)+penalties+0{,}2\times pSKU_i\times BOM_i} \qquad (4.4)$$

While order quantities, lead time demand uncertainties, and target FRs can be determined through (3.5), (4.1), & (4.4) respectively, we can determine the components' safety stocks and ROPs through (3.8) & (3.10) respectively. However, (3.10) can configure ROPs that are not multiples of *product x*, leading to unnecessary safety stocks. For example, *product x* needs 30 pieces of an SKU while the SKU's ROP is 40 pieces, so a new order will be placed when the SKU's inventory position equals 40. Whenever the supply of the SKU is delayed, one extra *product x* can be assembled, leading to an inventory position of 10 pieces which is not enough to conclude another *product x*. Placing an ROP of 40 pieces is not optimal because not all components can be used efficiently. To meet the target FR, the ROP should be rounded up to the next multiple of *product x*, 60 in this case. Rounding the ROP down, in this case to 30, leads to an insufficient FR of the relevant component. To conclude Sections 4.1.2 & 4.1.3, order quantities and ROPs will be rounded to the nearest multiple and the next multiple respectively in the inventory management tool for Thales.

4.2 Simulation model

In Section 4.2, we want to discuss the simulation model that will visualize the determined component safety stocks' performance on inventory management KPIs. While this multi-item problem is solved by solving single-item problems, we want to analyze how this method leads to a suitable order FR for *product x*. In Section 4.2.1, we describe the simulation model that is programmed to visualize the rate of supply and demand of the components for *product x*. In Section 4.2.2, we discuss which KPIs are relevant to be analyzed through a simulation model in this research. Lastly, in Section 4.2.3, we discuss some flaws of the simulation model by making assumptions to best simulate reality.

4.2.1 Simulation model explained

While we are interested in programming the inventory control policy proposed through the equations described in Section 4.1 and translated by the inventory management tool, we can visualize the components' inventory levels where components arrive after a stochastic lead time and are demanded by a rate of one *product x* every month (30,42 days). By modeling this simulation in Siemens' Technomatix Plant Simulation 16.1, we can use methods to review each component's inventory position such that, when an ROP is met, new orders can be placed of lot sizes determined through the inventory management tool which arrive according to stochastic lead times (recall Section 2.4). Figure 4.2 depicts a flow diagram of the simulation model. The code for checking components' inventory positions & placing orders and the simulation model built in Siemens' Technomatix Plant Simulation 16.1 is depicted in Appendix C.

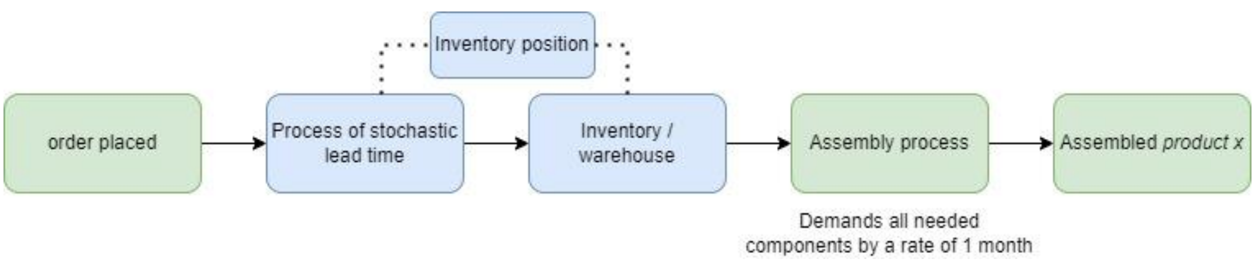

Figure 4.2 - Flow diagram simulation model (1 component)

4.2.2 Relevant KPIs

To simulate the proposed inventory management policy to analyze its performance in inventory management, several KPIs need to be defined that are relevant to review through the simulation. As described by Song *et al*. (1999), the most relevant KPIs for customer satisfaction are the order fill rate and customer waiting times. While customer service levels are important to analyze, the main aim of this research is to determine the inventory levels by utilizing the proposed inventory control policy. When doing so, we are also interested in analyzing the inventory levels with respective holding costs, VEX, and DOI. Recall that Thales determines the DOI through the VEX which is the sum of on-hand inventory and WIP. At last, while this multi-item problem is solved by solving each component's single-item problem, we are also interested in analyzing each component's fill rate. In this case, a component's fill rate is the rate of availability when the assembly process demands a new set of components.

Table 4.1 depicts the relevant KPIs to analyze through the simulation model.

Service	Cost/Cash
Order fill rate (%)	Holding costs (per year)
Waiting times (annual)	VEX (on-hand inventory + WIP)
Component fill rate (%)	Days of Inventory on Hand

Table 4.1 - Relevant KPIs

4.2.3 Flaws simulation model

Order lead times

Throughout the simulation model, because the components' lead times are stochastic, we have to assume that order lead times cannot cross. What this says is that an order of a component cannot arrive earlier than an order placed before this order. When doing so, order lead times can become dependent on each other leading to a correlation and, therefore, a smaller standard deviation of lead times such that safety stocks could be kept in smaller sizes. In reality, lead times can also become dependent on each other, for example through component scarcity. Therefore, we have to decide that this assumption holds.

Order fill rates

Where an order fill rate determines the rate of orders that are met directly from the inventory on hand, in the simulation model, the demand is dependent on each other. For example, when not all components are available when a new *product x* needs to be assembled, the order fill rate is decreased. However, when this is the case and the assembly process is idling, the components on order have extra time to arrive before the next product is needed to be assembled. This event leads to a higher order fill rate in the simulation while in reality, all customers, with whom Thales has agreed to deliver the product in time, are affected when one *product x* is delivered too late. To translate this assumption into real life, one can say that the simulation´s order fill rate can be realistic when Thales revises the promised delivery dates to the customers whenever a *product x* is delivered too late, justifying this flaw.

4.3 Supply chain coordination analysis methodology

As discussed in Section 1.2, an extra analysis is performed depicting the possibilities and advantages of coordinating safety stocks in the supply chain as demanded by Thales. Throughout this analysis, we want to find out whether placing safety stocks at suppliers of Thales can improve total inventory costs while maintaining the same customer service level. Thales has some expensive and critical SKUs that they, on one hand, would like to keep on stock, but on the other hand, would not like to keep on stock in-house to avoid expensive inventory holding costs. This analysis will compare three different scenarios to find out what is economically most beneficial.

- Scenario 0: place all component safety stock at Thales.
- Scenario 1: place all component safety stock at the component's supplier.
- Scenario 2: place a combination of raw materials/subcomponents and components in safety stock at the supplier and Thales respectively.

4.3.1 Splitting supply lead time uncertainty

As depicted in Figure 2.4, in Scenarios 0 & 1 we are only keeping safety stocks for uncertainties in the rest of the supply chain until Thales, however, in Scenario 2 we will keep safety stocks for uncertainties in the rest of the supply chain until the supplier and uncertainties from the supplier until Thales. While a distribution of uncertainties is not given, we have to assume that the standard deviation of lead times is a factor of the average lead time such that we can split the standard deviation of lead times in the same proportion as a split in average lead times. The assumption is based according to the mathematical properties of calculating the standard deviation (Al-Saleh & Yousif, 2009, p.194). In reality, deviations in the average lead times may occur in either the first part of the supply chain, between the supplier and Thales, or both. Reviewing this requires internal research at the suppliers which is, due to time constraints, not possible. Therefore, assuming an equal split in standard deviations of lead times and average lead times may help us get a good estimate of the distribution of safety stocks over the different participants in the supply chain. Figure 4.3 depicts an example of this assumption.

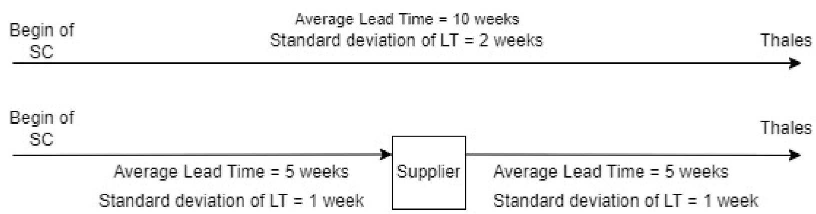

Figure 4.3 - Standard deviation of LT split proportional to LT split

Now, if we split the standard deviation of lead times according to the split in average lead times, we can assign a standard deviation of lead times to each installation in the supply chain (in this case Thales and its supplier) such that (4.1) can be used to derive the standard deviation of lead time demand at every installation. When doing so, in the spirit of the Clark-Scarf model, we can determine a target fill rate for every installation according to the newsvendor problem utilizing the installations' holding costs and the backorder costs occurring at Thales. By splitting the standard deviations of lead times equally over the installations, we assume that uncertainties are equally distributed over the supply chain, configuring a distribution of safety stocks that may not be accurate. However, when doing so, we will be able to get a good estimation concerning the cost-savings one can achieve by decoupling safety stocks to find an incentive to further investigate possibilities in multi-echelon inventory coordination.

4.3.2 Mathematical comparison model

Through the mathematical models built for scenarios 0,1, & 2, we are only interested in finding the value of safety stock that is distributed over the participants in the Supply chain (supplier (i) & Thales). When decoupling this safety stock, we are determined to find whether the holding costs for such configurations are lower than keeping all safety stock at Thales. Comparing the holding costs of safety stocks is, therefore, the main activity of this analysis. Cycle inventory and WIP are, therefore, not included.

Scenario 0

Using (4.5) we can determine the amount of safety stock to keep at Thales to meet the target FR as determined through (4.4) utilizing the holding costs at Thales. Appendix D serves as an example of the utilization of this model.

$$SS_{iT} = ROP(FR_{iT}, s_{Li})_{iT} - (LT_i \times D_i)^* \tag{4.5}$$

SS_{iT} = safety stock of SKU_i at Thales

$ROP(FR_{iT}, s_L)_{iT}$ = ROP of SKU_i at Thales according to its FR, standard deviation of lead times, and average demand during lead time

FR_{iT} = target FR of SKU_i according to holding costs at Thales

s_{Li} = Standard deviation of lead time for SKU_i

LT_i = average lead time of SKU_i

D_i = Annual demand of SKU_i

* Since we are rounding the ROP to the next multiple of *product x* (recall Section 4.1.3), we have to subtract the components that are in order by subtracting the average demand during the lead time to find the safety stock being kept at Thales. This safety stock then needs to be rounded to the nearest multiple of SKU_i needed in *product x*.

Scenario 1
Using (4.6) we can determine the amount of safety stock to keep at the supplier to meet the target FR as determined through (4.4) utilizing the holding costs at the supplier. Appendix D serves as an example of the utilization of this model.

$$SS_{iS} = ROP(FR_{iS}, s_{Li})_{iS} - (LT_i \times D_i)^* \tag{4.6}$$

SS_{iS} = safety stock of SKU_i at its supplier

$ROP(FR_{iS}, s_{Li})_{iS}$ = ROP of SKU_i at its supplier

FR_{iS} = target FR of SKU_i according to holding costs at its supplier

Scenario 2
Using (4.7) we can determine the amount of safety stock of subcomponents to keep at the supplier to meet the target FR as determined through (4.4) utilizing the holding costs at the supplier. Next, through (4.8) we can determine the extra safety stock of the finished component at Thales to account for uncertainties from the beginning of the process at the supplier until delivery at Thales. Appendix D serves as an example of the utilization of this model.

$$SS_{sub_{iS}} = ROP\left(FR_{sub_{iS}}, (s_{Li} \times \frac{LT_{sub_i}}{LT_i})\right)_{sub_{iS}} (LT_{sub_i} \times D_{sub_i}) \tag{4.7}$$

$$SS_{iT} = ROP\left(FR_{iT}, (s_{Li} \times \frac{LT_{iS}}{LT_i}\right)_{iT} - (LT_{iS} \times D_i)^* \tag{4.8}$$

$SS_{sub_{iS}}$ = safety stock of subcomponent *i* at its supplier

$FR_{sub_{iS}}$ = target FR of subcomponent *i* according to holding costs at its supplier

$(s_{Li} \times \frac{LT_{sub_i}}{LT_i})$ = splitting the standard deviation of lead times of SKU_i according to the split in average lead times where LT_{sub_i} is the lead time of the subcomponent

4.4 Chapter conclusions

In this chapter, an inventory control tool is designed for Thales by answering the research question '*What material inventory policy tool design is suitable for Thales Nederland B.V. and its product x?*'. Based on the literature from Chapter 3, we have tailored the methodologies to determine order quantities, target fill rates, and respective safety stocks & ROPs while suggesting a continuous review policy. It was found that to avoid unnecessary stocks of components that cannot conclude a *product x*, we have to order in quantities of *product x*. Here, we also want to place an ROP per component in multiples of *product x* since deviating from a multiple will lead to components not being able to fulfill an extra *product x* when shipment is late.

In Chapter 5, we want to visualize the inventory control tool's output on the performance of inventory management KPIs. The 'service' KPIs to be reviewed are the components' fill rates, average customer waiting times and the order fill rate of the assembly of *product x*. The 'cost' KPIs are the inventory's holding costs, VEX, and DOI. A simulation has been built to visualize these KPIs. The outcomes of the simulation are depicted in Chapter 5 (“Results & Sensitivity Analysis”).

To analyze the possible cost-savings for decoupling safety stocks over the installations in the supply chain, the newsvendor problem can be used by implementing each installation’s holding costs in the equation. When estimating a distribution of safety stocks over the different installations, we have assumed that uncertainties in supply are equally distributed over the supply chain, making it possible to split the standard deviation of lead times according to the split in average lead times for each installation. The possible cost-savings are depicted in Chapter 5 (“Results & Sensitivity Analysis”).

5 Results & Sensitivity analysis

Through Chapter 5, the proposed solution design is evaluated through a simulation model to answer the research question '*What is the contribution of the tool towards lowering the inventory levels of product x?*'. In Section 5.1, we discuss the output of the simulation model concerning the most relevant KPIs where we also depict the robustness of the normal distribution assumption by simulating a better estimate of the distribution of lead times for cases where the coefficient of variation in lead time demand is over 0,5. In Section 5.2, we depict the performance of the KPIs when reducing safety stocks of components. At last, in Section 5.3, we analyze the possible cost-savings that may be possible when decoupling safety stocks in the supply chain after which the chapter is concluded in Section 5.4.

5.1 Performance of inventory control policy

After simulating the proposed inventory control policy, we depict the performance of the KPIs in Section 5.1.1. In Section 5.1.2, we revise the distribution of lead times for cases where the CV_{LTD} is higher than 0,5 to visualize the impact of assuming normally distributed lead times for all components. In this section, we have incremented the safety stocks for these special cases to improve the inventory control model. In Section 5.1.3, we depict what happens to the relevant inventory management KPIs when every component's lead time uncertainty is halved to visualize the impact on both costs and service levels while a reduction in supply uncertainty is apparent when communication and coordination in the supply is improved.

5.1.1 Simulation output

After implementing every component's characteristics in the inventory management tool depicted in Appendix B.1, order quantities and ROPs are calculated. The components' order quantities and ROPs are depicted in Appendix E. When implementing these parameters in the simulation model, we can visualize the impact that the inventory control policy has on the relevant inventory management KPIs in both service levels and costs. Table 5.1 depicts the performance of the proposed inventory control policy on the KPIs. Where the VEX includes the WIP, we have estimated the value of components in the process by the number of working stations concluding to €11.035.915,10. This value is added to the inventory value through the simulation.

Service KPI	**Performance**
Order fill rate (%)	98,34%
Annual cumulative waiting/idle times *product x*	3 days 1,4 hours
Cost KPI	**Performance**
Annual holding costs (€)	€ 3.546.104,55
VEX (€)	€ 28.766.437,85
DOI (days)	118,24 days

Table 5.1 - KPI Performance of inventory control policy

5.1.2 Revising lead rime distributions (special cases)

Out of the 130 SKUs reviewed during this research, 13 SKUs do not meet the constraint of having a CV_{LTD} lower than 0,5. For the lead times of these 13 SKUs, we want to depict a better-fitting statistical distribution. Through the simulation model, we can alter the distribution of the lead times to visualize and understand the impact on KPIs of costs and services. Now, while data concerning the lead times is scarce, unrepresentative, and consisting of many flaws, no statistical distribution is found to fit the data set according to statistical tests conducted. However, as can be seen in a few examples in Appendix H, we can try to find a distribution that fits the data set, at least, better. When determining the best-fitting distribution of the lead times, we have made use of the Chi-Square test statistic depicted in (5.1). This Chi-Square

Statistic can help determine how well expected data (through a statistical distribution) fits the actual data. A low Chi-Square value indicates that the distribution is fitting well and vice versa.

$$Chi - Square\ Statistic\ (X^2) = \sum \frac{(observed - expected)^2}{expected} \quad (5.1)$$

When visualizing the data points, it was found that all data sets either represent a normal distribution or a gamma distribution while all sets depict a bell-shaped distribution. Table 5.2 depicts the chosen distributions with respective parameters of the components depicted as outliers.

Component	Distribution	Mean/standard deviation	Alpha/Beta
SKU50	Gamma	-	7,72/20,27 days
SKU55	Gamma	-	0,31/85,87 days
SKU74	Gamma	-	5,97/24,13 days
SKU78	Gamma	-	7,93/20,93 days
SKU79	Gamma	-	4,15/40,51 days
SKU83	Gamma	-	3,62/51,47 days
SKU86	Gamma	-	45,84/2,39 days
SKU87	Normal	187,96 days/84,63 days	-
SKU115	Gamma	-	7,20/23,57 days
SKU118	Gamma	-	4,93/38,11 days
SKU119	Gamma	-	85,44/1,75 days
SKU120	Gamma	-	93,641,67 days
SKU125	Gamma	-	85,44/1,75 days

Table 5.2 - Distribution of lead times (outliers)

The better-fitting statistical distributions have been implemented in the simulation model to produce more representative outcomes concerning the relevant KPIs. Table 5.3 depicts a comparison between the simulated outcomes in Section 5.1.1 and the simulated outcomes with revised distributions of lead times. As one can see, KPIs in costs do not differ too greatly, which is mostly because of the insignificant component prices of the revised SKUs. However, the annual waiting/idle times are increasing significantly due to more frequent OOSs of these components as well as the higher possibility of longer lead times of the revised components since the gamma distribution has a longer right-hand tail than the normal distribution in these cases.

Service KPI	Normal dist.	Revised dist.	difference
Order fill rate (%)	98,34%	97,94%	-0,4%
Annual cumulative waiting/idle times product x	3 days 1,4 hours	6 days	+96,20%
Cost KPI			
Annual holding costs (€)	€ 3.546.104,55	€ 3.586.494,86	+1,14%
VEX (€)	€ 28.766.437,85	€ 28.968.389,40	+0,70%
DOI (days)	118,24 days	119,07	+0,71%

Table 5.3 – Comparison between normally distributed lead times & revised distributions of lead times

While we are configuring an optimal inventory control policy for all 130 SKUs of *product x*, we can increment the safety stocks of the revised SKUs by concluding one extra *product x* every increment. When doing so, the optimal increase in safety stocks has been found when keeping components for two extra *product x* in inventory. Table 5.4 depicts the performances of the KPIs when incrementing safety stocks of the revised SKUs. Here we can observe that by incrementing the safety stocks by three extra products, the DOI increases compared to two extra products. Even though the service KPIs keep improving, the DOI is the main action problem of this research and, therefore, leading. This configuration is further analyzed.

Service KPI	Revised dist.	1 *prod. X*	2 *prod. x*	3 *prod. x*
Order fill rate (%)	97,94%	98,01%	98,08%	98,27%
Annual waiting/idle times	6 days	4 days 11 hours	3 days 12,7 hours	3 days 3,8 hours
Cost KPI				
Annual holding costs (€)	€ 3.586.494,86	€ 3.571.403,63	€ 3.560.658,71	€ 3.566.822,15
VEX (€)	€ 28.968.389,40	€ 28.893.403,23	€ 28.839.208,64	€ 28.870.025,83
DOI (days)	119,07 days	118,76 days	118,54 days	€ 118,67 days

Table 5.4 - Revising the inventory control policy

While 130 components contribute to 95% of *product x´s* value, we can conclude that the inventory level could increase by approximately 5% concerning the other 1.255 components leading to an inventory value of around €18.740.309,- and a VEX of €29.776.224,- such that a DOI of 122,4 days is reached.

5.1.3 Reducing uncertainties

While Thales will assemble *product x* at a fixed rate according to its production plan, suppliers are expected to become more reliable concerning their lead times when communication and coordination are improved between Thales and its suppliers. To depict the impact of reducing uncertainties and lowering safety stocks on the relevant KPIs, a simulation model is run with outputs of the inventory control tool with halved standard deviations of lead times. Table 5.5 depicts the performance of reduced uncertainties. Here we observe that inventory costs are expected to reduce by less than half in contrast to the halved standard deviations of lead times. While the service KPIs both improve, we can state the importance of reducing supply uncertainties by communicating and coordinating more effectively and freezing the component's designs.

Service KPI	Current uncertainties	Reduced uncertainties	difference
Order fill rate (%)	98,08%	98,91%	+0,83%
Annual waiting/idle times	3 days 12,7 hours	2 days 22,9 hours	-17,06%
Cost KPI			
Annual holding costs (€)	€ 3.560.658,71	€ 2.324.541,92	-34,72%
VEX (€)	€ 28.839.208,64	€ 22.658.624,68	-21,43%
DOI (days)	118,54 days	93,14 days	-21,43%

Table 5.5 - Comparison between current uncertainties & reduced uncertainties

5.2 Sensitivity analysis

Through the sensitivity analysis conducted in this section, we want to analyze what happens when one lowers the safety stocks of some individual SKUs (5.2.1) as well as reducing safety stocks for all SKUs (5.2.2). In the cases where we lower the individual SKU's safety stocks, we also want to understand their met fill rates. This KPI is analyzed through the sensitivity analysis of two SKUs.

5.2.1 Reducing single safety stocks

In this section, we depict what happens when the safety stocks of single SKUs are lowered. What is interesting to see is that the value of the total inventory levels eventually increases due to excess inventory of components that are waiting in stock on components that are OOS. First, we decrease the safety stock of SKU1 by one multiple of *product x* every step (minus 30 pieces of SKU1 each step). This component is interesting to analyze while the cumulative value of 30 SKU1s is 15,5% of *product x's* value. In this sensitivity analysis, SKU2 is also analyzed in the same manner as SKU1, which can be seen in Appendix F. Table 5.6 depicts the impact on the KPIs when decreasing the ROP of SKU1 by 30 pieces each step. While the average demand during lead time is 590 pieces, we stop at an ROP of 600 pieces.

Service KPI	ROP = 690	ROP = 660	ROP = 630	ROP = 600
Order fill rate (%)	98,08%	96,77%	95,20%	91,94%
Individual fill rate (%)	99,30%	97,87%	95,86%	92,07%
Annual waiting/idle times	3 days 12,7 hours	6 days 15,9 hours	13 days 11 hours	24 days 16,5 hours
Cost KPI				
Annual holding costs (€)	€ 3.560.658,71	€ 3.488.225,74	€ 3.555.936,57	€ 3.863.284,60
VEX (€)	€ 28.839.208,64	€ 28.477.043,81	€ 28.815.597,97	€ 30.352.338,08
DOI (days)	118,54 days	117,05 days	118,44 days	124,76 days

Table 5.6 - Safety stock reduction SKU1

As one can see in Figure 5.1, initially, the SKUs FR is quite above the order FR. However, by decreasing its safety stocks, it will move closer to the order FR. Now, as visualized in Figure 5.2, the assembly's idle times increase steadily when decreasing the safety stocks of SKU1. Eventually, both holding costs as well as DOI decrease for a short moment after which they increase heavily due to excess inventory as visualized in Figures 5.3 & 5.4 respectively.

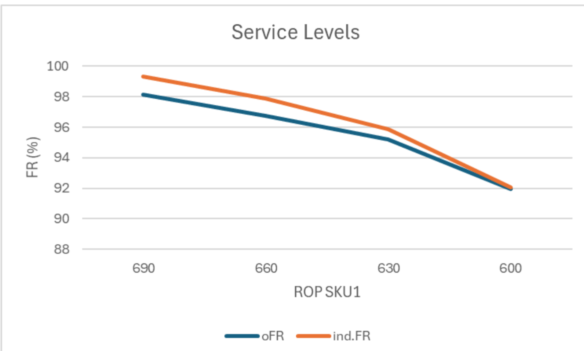

Figure 5.1 - FRs SKU1 safety stock reduction

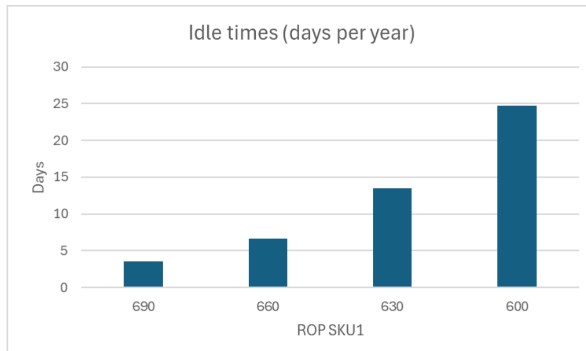

Figure 5.2 - Assembly idle times SKU1 safety stock reduction

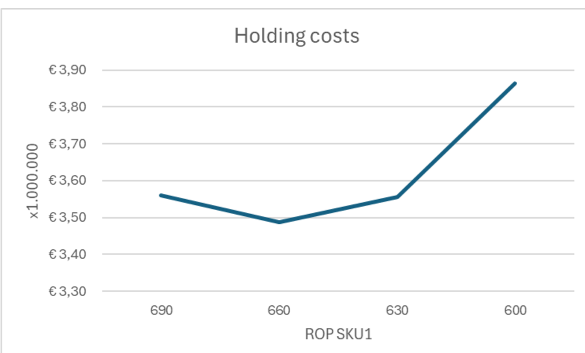

Figure 5.3 - Holding costs SKU1 safety stock reduction

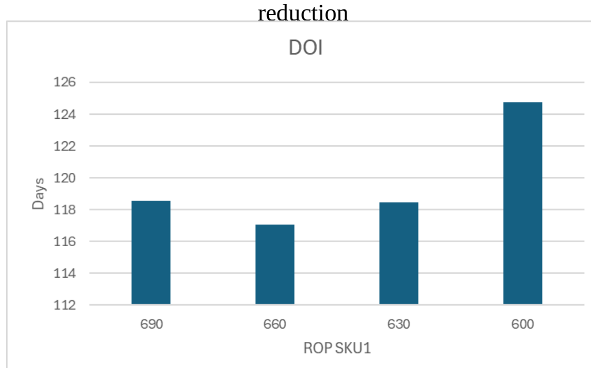

Figure 5.4 - DOI SKU1 safety stock reduction

5.2.2 Reducing all safety stocks

Where in Section 5.2.1 we have decreased the safety stock of single SKUs, we also want to depict what happens when all SKUs' safety stocks are decreased. When doing so, every SKU's safety stock is decreased by a multiple of *product x*. What we observe when we do so, is a steep initial decrease in the order FR of *product x* accompanied by long idle times and an, eventually, steep increase in inventory levels with respective costs and DOI. Table 5.7 depicts the values of the KPIs when reducing safety stocks in steps of multiples of *product x*.

Service KPI	No reduction	-1 *product x*	-2 *product x*	-3 *product x*
Order fill rate (%)	98,08%	82,11%	64,76%	58,13%
Annual idle times	3 days 12,7 hours	16 days 11,6 hours	105 days 20 hours	227 days 13 hours
Cost KPI				
Annual holding costs (€)	€ 3.560.658,71	€ 3.334.221,61	€ 4.652.696,05	€ 5.754.023,33
VEX (€)	€ 28.839.208,64	€ 27.707.023,15	€ 34.299.395,36	€ 39.806.031,76
DOI (days)	118,54 days	113,89 days	140,98	163,62

Table 5.7 - KPI Performance when safety stocks reduce

As depicted in Figure 5.5, by decreasing the safety stock, the order fill rate will drop as expected. Where the level of customer satisfaction is affected by de annual idle times of the assembly system going up to over half a year as depicted in Figure 5.6, meaning that all customers have to wait for a significant time before their products get delivered as opposed to a promised delivery date. Eventually, both holding costs as well as DOI decrease for a short moment after which they increase heavily due to excess inventory as visualized in Figures 5.7 & 5.8.

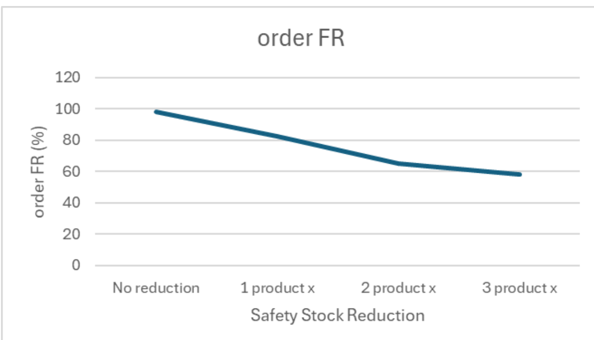

Figure 5.5 - Order FR when safety stock reduce

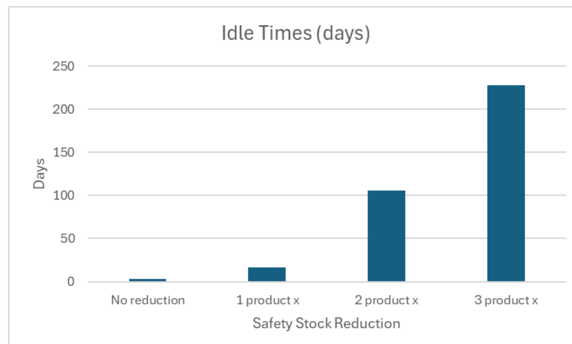

Figure 5.6 - Idle times when safety stocks reduce

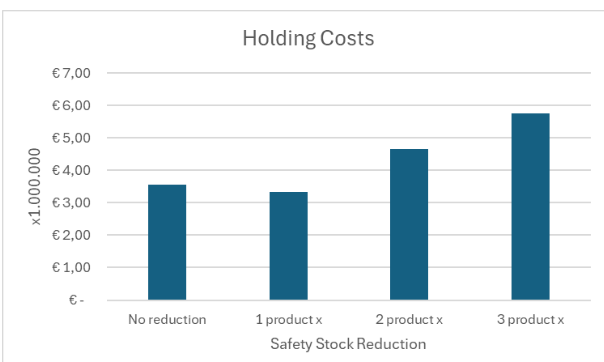

Figure 5.7 - Holding costs when safety stocks reduce

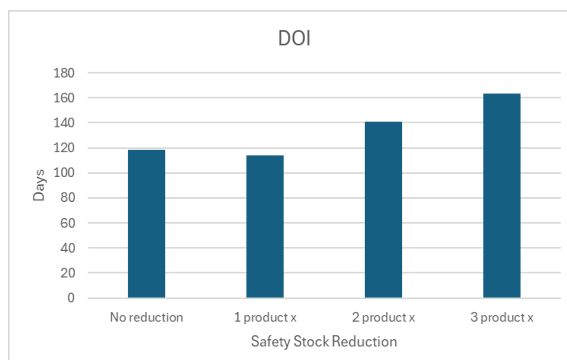

Figure 5.8 - DOI when safety stocks reduce

5.3 Supply chain coordination

In Section 5.3, we discuss what safety stock holding costs may occur when decoupling safety stocks in the supply chain. Here, we depict the three described scenarios to compare possible cost reductions when placing safety stocks at suppliers (scenario 1) or decoupling safety stocks by placing subcomponents and finished components in the supply chain (scenario 2). For each scenario, we depict the safety stocks necessary to meet the SKUs' target FR constraints after which we analyze and compare the expected costs of each scenario. For this extra analysis, Supplier I with respective components SKU1, SKU7, and SKU34 is analyzed.

5.3.1 Scenarios

Scenario 0 – Where the prices of SKU1, SKU7, and SKU34 are €16.500,-, €9.596,-, and €425,- at Thales respectively, we can determine each component's target FR to assess their ROPs utilizing Supplier I's standard deviation of lead times. While the average lead time of Supplier I is 1,64 years, we can determine the average demand during lead time as obtained by *product x's* BOM. Utilizing the inventory control tool proposed in Chapter 4 and reassessing the safety stocks through (4.5), we can determine the optimal safety stocks in the case of scenario 0. Table 5.8 depicts the SKUs' ROPs, safety stocks, and respective holding costs at Thales.

SKU	ROP	Demand during LT	Safety stock (rounded)	Holding costs (20%)
1	690	590	90	€297.000,-
7	360	295	60	€115.152,-
34	750	590	150	€12.750,-

Table 5.8 - Safety stocks Supplier I scenario 0

Scenario 1 – It is determined that the material prices for SKU1, SKU7, and SKU34 are €11.897,88, €7.742,64, and €305,77 at Supplier I respectively. According to this, we can revise the SKUs' target FR (4.4) by means of the holding costs at the supplier (20% is assumed). When doing so, we can determine the optimal amount of safety stock per SKU according to (4.6). Table 5.9 depicts the SKUs' ROPs, safety stocks, and holding costs at Supplier I.

SKU	ROP	Demand during LT	Safety stock (rounded)	Holding costs (20%)
1	690	590	90	€214.161,84
7	360	295	60	€92.911,68
34	750	590	150	€9.173,10

Table 5.9 - Safety stocks Supplier I scenario 1

Scenario 2 – Now, for Supplier I, it is determined that the average lead time from placing an order at Supplier I to the order delivery at Supplier I is 1,23 years. This leaves a remaining lead time of 0,41 years from the Supplier to Thales (ratio 3/1). According to this, based on the assumption that the standard deviation of lead times is split in the same ratio, the standard deviation of lead times from the order placement until Supplier I is 0,10 years and 0,03 years from Supplier I to Thales. Through this assumption, we can estimate a distribution of safety stocks to keep at both installations in the supply chain. Further, Supplier I has mentioned that one subcomponent carries all uncertainties in the first part of the supply chain. For SKU1, SKU7, and SKU34, the prices of the subcomponents are €4.636,71, €3.885,97, and €300,76 respectively. Utilizing this information, we can determine the safety stocks for both the subcomponents at Supplier I and the three SKUs at Thales according to (4.7) & (4.8). The subcomponents are needed just once in every SKU making it possible to have a safety stock of every integer number. Table 5.10 depicts the subcomponents' ROPs, safety stocks, and holding costs, whereas Table 5.11 depicts the SKUs' ROPs, safety stocks, and holding costs. Here, also cumulative costs are depicted.

subcomponent	ROP	Demand during LT	Safety stock (rounded)	Holding costs (20%)
1	545	443	102	€94.588,88
7	273	221	52	€40.414,09
34	545	443	102	€6.135,50

Table 5.10 - Safety stocks (subcomponents) at Supplier I (scenario 2)

SKU	ROP	Demand during LT	Safety stock (rounded)	Holding costs	Cumulative
1	180	148	30	€99.000,-	€193.588,88
7	90	74	15	€28.788,-	€69.202,09
34	180	148	30	€2.550,-	€8.685,50

Table 5.11 - Safety stocks (SKUs) at Thales (scenario 2)

5.3.2 Possible cost-savings

While decoupling safety stocks for every SKU will generate a wide variety of different safety stock distributions over the installations with respective differences in cost-savings, we have used this analysis to depict possibilities of decoupling safety stocks and visualize possible cost-savings. According to the case of Supplier I with SKUs 1, 7, and 34, we can conclude that one can save significant holding costs when coordinating safety stocks in the supply chain. Table 5.12 depicts the comparisons of the three depicted scenarios.

	SKU1	SKU7	SKU34
Scenario 0	€297.000,-	€115.152,-	€12.750,-
Scenario 1	€214.161,84	€92.911,68	€9.173,10
Difference scenario 0	-27,9%	-19,3%	-28,1%
Scenario 2	€193.588,88	€69.202,09	€8.685,50
Difference scenario 0	-34,8%	-39,9%	-31,9%

Table 5.12 - Holding cost comparisons

As depicted in Table 5.12, one can save over 20% of holding costs when placing safety stocks at the suppliers if the right agreements are made and one does only account for the component prices at the supplier without added margins of labour and further handling costs. Depicting cost-savings regarding scenario 2 might be deceiving since the possible holding costs depend on whether all subcomponents are regarded as risky or not. In the case of Supplier I, one sub-supplier was regarded as a risky one carrying all uncertainties in the supply chain such that safety stocks can be lowered to the extent of only keeping the sub-supplier's components in stock.

5.4 Chapter conclusions

Through a simulation model in Siemens´ Plant Simulation, the inventory control policy configured by the tool has been simulated to analyze the performance of several inventory management KPIs to answer the research question ´ *What is the contribution of the tool towards lowering the inventory levels of product x?*´. The simulation operates by placing an order when an SKU´s inventory position has reached the ROP configured through the inventory management tool after which the order arrives after a stochastic lead time. When in stock, the components are needed at a rate of one *product x* per month so that KPIs such as order fill rates, assembly idle times, and inventory levels can be visualized.

After simulating the proposed ROPs and order quantities of the SKUs in several scenarios´ it was found that a DOI of 122,4 days could be reached with the 130 specified SKUs in this research and the remaining 1.255 components. According to these configurations, an order fill rate of 98,1% and cumulative annual idle times of 3,5 days should be possible. While the safety stocks and ROPs are determined through current data, where it is expected that suppliers will become more reliable, we also have shown that a DOI of 93,1 days is possible to target when uncertainties are halved.

Through a sensitivity analysis, where safety stocks are reduced to explore their impact on the specified KPIs, it has been visualized that lowering safety stocks results in lower order fill rates, higher assembly idle times, and higher inventory levels due to excess inventories of components that have to wait on arrivals of other components.

Now, concerning supply chain coordination, a mathematical model has been used to estimate the distributions of safety stocks over the installations in the supply chain to understand what cost reductions could occur. Here, it is found that decoupling safety stocks in the supply chain may lead to a reduction of inventory holding costs of up to 20% when simply placing finished components at suppliers, or up to 40% when safety stocks are kept on subcomponent level and finished components level. While internal research was not able to be completed at suppliers, we had to estimate a distribution of safety stocks, making this estimation unreliable for implementation.

6 Solution implementation

In this chapter an approach to answer the research question *'How can the material inventory tool be implemented and communicated effectively at Thales Nederland B.V.?'* is provided. Section 6.1 describes how the implementation of this tool and the results it generates can be conducted as well as possible in the business environment at Thales Nederland B.V. Section 6.2 describes how the tool's output can be implemented and adjusted in the future and Section 6.3 concludes the chapter.

6.1 Implementation theory

As described by Xiong *et al.* (2016), "A success of an improvement project on solving a problem in an organization is not only depending on the appropriate methodology on problem-solving but also is it important to have an appropriate methodology and process on change management". To achieve success in change, it is key to select appropriate methodologies and tools to use in an appropriate way to meet the business environment (Xiong *et al*., 2016, p.53). Xiong *et al*. also point out Kotter's widely known 8-step change model. Kotter *et al*. (2021) start by creating a sense of urgency within the company (Kotter *et al.*, 2021). While stakeholders at Thales have already mentioned that inventory levels are too high and too much cash is caught up in inventory, it is still difficult to align all stakeholders. A reason for this is that every individual stakeholder has its own performance objectives. Where some cost-driven stakeholders are aiming to drive holding costs and caught-up cash as low as possible, the sales department may want to keep more inventory such that the service level to the customers is high. A solution to this problem is to create a shared objective such that individual perspectives are aligned. A nice possibility for Thales is to focus on the DOI as it indicates and implies both inventory efficiency and sales performance as it is the ratio of average inventory and cost of sales. If all departments focus on their own objectives, the department that pushes the hardest will get the best results, however overall result is unlikely to satisfy the overall business' needs (Desmet, 2018, p.10).

When indeed implementing the tool and its outcomes, stakeholders at Thales should focus on building a guiding coalition that guides, coordinates, and communicates its activities. In the early stages of implementing safety stock, it is important to keep track of the actual inventory levels and assembly performances as well as component failure rates. As explained earlier, currently collected data might not represent the future performance of the supply and assembly processes of the components for *product x*, making it necessary to keep track of relevant changes in the data that impact the computations for either EOQs or safety stocks. Now, while Thales is a big company making changes in the procurement processes difficult to implement, it is important that the vision of the different stakeholders and problem owners are aligned and that making such changes is accepted. Kotter *et al.* (2021) explain that stakeholders who are opposing changes should not be ignored but rather be correctly informed to understand the severity of the problem and the importance of the changes. Next, it is also important to achieve small 'wins' such that the stakeholders and problem owners receive a sense of achievement when implementing the change. In this case, small wins can be identified as the material availability of the components for the assembly process. Any large wins, e.g., improved DOI will be experienced later in the process when the inventory control is fully operational according to the inventory management tool proposed in this research. In the second to last step of Kotter's 8-step change model, Kotter explains that learning in the change process is important to sustain acceleration in improving systems and policies. As explained earlier in this section, keeping track and learning from newly collected data is important to understand the new procurement strategy. In Kotter's 8-step change model's last step, the adopted change should be instituted in the business environment such as at Thales. During this step, it is mostly important to actively discuss any wins made through the change and discuss any points of improvements that could be made (Kotter, 2021).

To conclude from the latter section, for Thales it will be important to align all stakeholders' objectives such that the inventory management tool's outcomes can be accepted by all stakeholders. In reality, most stakeholders will have individual objectives that may counteract each other as will also be the case in inventory management objectives. Here, component availability and inventory holding costs will work against each other, making it important to find a balance between the two through an inventory management tool. After implementing (any of) the recommended changes through the tool it is important to visualize and communicate small wins such that stakeholders and problem owners identify the relevance of the proposed inventory control policies. Throughout the whole change process, it is also important to keep track of the data that is relevant in determining the EOQs and safety stocks, such as the average delays and the standard deviations of delays per supplier through the PUR10 list.

6.2 Implementing the tool's output

When deciding to implement (a part of) the tool's output in practice, inventory levels have to be built up to the proposed safety stock level determined by the tool. While safety stock is not considered as cycle inventory, initial component lot sizes can be as high as the determined safety stocks since the EOQs only function well for cycle stock. This also makes it possible to exploit quantity discounts. When the orders have arrived and the safety stocks are built up, new orders can be placed with lot sizes determined through the EOQ when the IP meets the ROP.

After a while, when orders have arrived and new data concerning any delays are collected, the tool's input parameters can be adjusted such that safety stocks are revised according to more representative data. If the data suggest that safety stocks can be lowered to still maintain the same component availability, one can easily adjust the ERP safety stock settings of the components in ORACLE which lowers the ROPs of the components. Now, when other components need to be analyzed to determine their safety stocks, the step-by-step approach depicted in Appendix G helps with adjusting the tool such that these alternative components outside the scope of this research can be analyzed. Further, the tool has been built such that the annual demand is required to be filled in before the configurations of the order quantities, safety stocks, and ROPs. Because of this, when the production plan changes and more products have to be assembled, the new annual demand can be filled in to reconfigure the inventory management parameters. Now, through the tool, cases of components with a coefficient of variation of demand during lead times larger than 0,5 can be identified. A suggestion is to keep an extra *product x* or two to maintain a high component availability due to the long right-hand tale of probable distribution leading to longer lead times. Here, the simulation may be of use to determine how much safety stock to keep for these cases.

6.3 Chapter conclusions

Through Chapter 6, the research question *'How can the material inventory tool be implemented and communicated effectively at Thales Nederland B.V.?'* has been answered. While Thales is a big organization, making it difficult to implement any large changes in the business environment, it is important to implement Kotter's 8-step approach concerning change management. What is most important for Thales is to align all perspectives towards the problem such that a solution can be accepted and implemented by everyone. Through the tools and software that Thales already possesses, implementing the determined safety stocks should not be difficult in practice. However, it is necessary to keep track of the real inventory levels and any stockouts or failing components such that the tool's input data can be revised, and safety stocks can be recomputed accordingly. After a significant period, when sufficient new data is collected while operating in the forecast-driven procurement environment for a while, the uncertainties in lead times (and possibly demand) need to be revised such that safety stocks can be recalculated with more representative data.

7 Conclusions, recommendations, and future research

Through this thesis, an inventory management tool has been designed and tested through a simulation model. Combining possibilities for improvement in the current situation with insights from theories through a literature review, the tool was designed to improve Thales' inventory management. Fortunately, the simulation model used for the sensitivity analysis showed some insights that can be used to improve the tool or its interpretations. This last chapter is used to answer the main research question:

How can the inventory levels, and therefore, the current number of days of inventory on hand for product x be optimized through a new material inventory policy for Thales Nederland B.V. while maintaining material availability?

Through Section 7.1, we answer the abovementioned research question. In Section 7.2, recommendations will be stated while Section 7.3 states suggestions for future research.

7.1 Conclusions

Through the problem-solving approach described in Section 1.4, various sub-research questions have been addressed and answered to build a roadmap to answer the main research question of this research. After analyzing the current situation, it was determined that safety stocks were only necessary to be kept for uncertainties on the supply side of the components while the component demand is deterministic. Next, through the literature review performed in Chapter 3, reasons and ways to determine the inventory management parameters in order quantities and safety stocks were reviewed after which a model has been developed that utilizes these theories in practice for the components of Thales.

Now that a tool has been developed, we visualized and analyzed the performance of the tool's output towards holding costs and service levels. Through a simulation model, different scenarios could be simulated to determine both the performance of the safety stocks and order quantities as well as the robustness of the tool, and the assumptions made regarding the normal distribution of lead times.

Now, using inventory management theories and respective formulas, one can define safety stocks such that material availability is reasonable and production idle times are limited while overall holding costs are tried to be kept low. Through the inventory management tool's output, the DOI for *product x* can be lowered from 283 days to 122,4 days. Where the reduction in DOI seems significant, the two numbers cannot be compared due to the significant turn in assembly and procurement strategies. While a norm of 150 days was a benchmark for the DOI, the inventory management tool can lower the relative inventory levels well enough while maintaining the preferred component availability and, therefore, answering the main research question.

Further, possibilities to place safety stocks at sub-suppliers in the supply chain have been investigated where it was found that this supply chain coordination can indeed lower inventory costs while maintaining the right component availability when research is conducted properly. Distributing safety stocks according to scenarios 1 and 2 (recall Section 1.2) may lower inventory holding costs by up to 40%.

7.2 Recommendations

where data concerning the suppliers' lead times (and delays) is scarce and unrepresentative compared to the future MTS strategy Thales will utilize, it suggests that safety stocks are determined through data that are unreliable at this point of the research. While the current data are collected in an ETO environment where communicating forecasts and production plans with suppliers is difficult and redesigns of components occur often, data show high deviations in lead times suggesting keeping higher levels of safety stock. In the future MTS environment, it is important to open up to suppliers such that these can become more reliable which leads to an incentive to keep lower levels of safety stock. Therefore, the following recommendations are in place for Thales:

- Keep track of the delays of orders per component/supplier more thoroughly such that data becomes more reliable and safety stocks can be configured more accurately.
- Communicate forecasts and production plans with suppliers regularly to help make the suppliers more reliable.
- Freeze the designs of components such that forecasts can be made for a longer timespan such that risks in the supply chain of the long lead time items are mitigated.

Further, concerning the supply chain coordination possibilities concerning safety stock decoupling, make sure that any agreements with suppliers are made carefully. Here it will be important to conduct research with the supplier to understand where the uncertainties lie in the supply chain and, more importantly, what (sub)components need to be kept in inventory or not.

7.3 Future research & limitations

The main limitation of this research was the fact that *product x* was in the New Product Introduction phase leading to a scarcity of data concerning the suppliers' lead times and abilities to deliver on time. Due to this data scarcity, safety stock configurations are unreliable as the data is unrepresentative of the future MTS environment Thales will operate in with its *product x*. After some conversations with stakeholders at Thales, it was agreed that this research should be conducted again in one or two years from now when new, more accurate, data is collected such that the safety stocks can be revised and probably be lowered. As this research has produced an inventory management tool demanding some input parameters such as the components' prices and standard deviations of lead times, one could easily gather these parameters and KPIs in the coming years to revise the order quantities and safety stocks. Without performing this research again, utilizing the tool gives a good opportunity to still determine safety stocks when more data becomes available.

Now, concerning assuming a normal distribution for the lead time which has simplified the usage of the tool for simplicity of this research, further research may be conducted to better depict the actual distributions of lead times. When doing so, other safety stock configuration methods, with respect to these other distributions, may be used to configure safety stocks accordingly. When conducting this research, it may also be interesting to exploit possibilities to make use of safety lead times, which is not done in this research while this may lead to the need for a longer frozen time frame and revised agreements with suppliers.

Where we have assumed that there are no component commonalities, and the demand for components is only dependent on *product x*, the exact demand for components has to be revised. While this only concerns a small number of components, it is still important to incorporate the demand of other Thales products in the tool as well to depict every component's exact demand. Since the production plan for other products is also fixed, leading to deterministic demand for components, revising the components' demand should not be a pitfall.

Where supply chain coordination is a viable option for Thales to reduce inventory costs, it is important to conduct research on the suppliers to understand where the uncertainties in the supply chain come from such that it is known to keep safety stock for the exact (sub)components without harming component availability and respective service levels. Here it is important to analyze the lead times from sub-suppliers to the suppliers of Thales to understand where the risks lie.

References

Al-Saleh, M. F., & Yousif, A. E. (2009). Properties of the standard deviation that are rarely mentioned in classrooms. *Austrian Journal of Statistics, 38*(3), 193-202.

Annonymous. (2024). Purchasing process map. (C. Rietman, Interviewer) Hengelo.

APICS. (2022). *APICS Certified in Planning and Inventory Management* (Vol. 7). Chicago: APICS.

Axsäter, S. (2006). Inventory position. In S. Axsäter, *Inventory Control* (2nd ed.). New York: Springer.

Ben-Ammar, O., Castagiola, P., Dolgui, A., & Hnaien, F. (2020). A hybrid genetic algorithm for a multilevel assembly replenishment planning. *Compurters & Industrial Engineering, 149*, 1.

Copra, S. (2019). *Supply Chain Management* (Vol. 7). Harlo, United Kingdom: Pearson Education Limited.

Desmet, B. (2018). Creating aligned targets. In B. Desmet, *Balancing Service, Costs and Cash in the Supply Chain Triangle* (p. 10). Solventure.

Dhoka, D., & Choudary, D. (2013). ABC Classification for Inventory Optimization. *Journal of Business and Management, 15*(1), 38-41.

Eraslan, E., & Tansel, Y. (2020). An improved decision support system for ABC inventory classification. *Evolving Systems, 11*(1), 683-696.

Godichaud, M., & Amodeo, L. (2018). Economic order quantity for multistage disassembly systems. *International Journal of Production Economics, 199*, 16-25.

Hausman, W. H., & Erkip, N. K. (1994). Multi-Echelon vs. Single-Echelon Inventory Control Policies for Low-Demand Items. *Management Science, 40*(5), 549-684.

Hautaniemi, P., & Pirttilä, T. (1999). The choice of replenishment policies in an MRP environment. *International Journal of Production Economics, 59*(1-3), 58-92.

Kotter, J. P., Akhtar, V., & Gupta, G. (2021). *Change: How Organizations Achieve Hard-to-Imagine Results in Uncertain and Volatile Times* (1 ed.). Hoboke, New Jersey: Wiley.

Lau, H.-S., & Lau, A.-L. (2003). Nonrobustness of the normal approximation of lead-time demand in a (Q, R) system. *Naval Research Logistics, 50*(2), 105-195.

Pannell, R. (2023). *The Importance of Identifying the Right Sample Size for Business Improvement*. Retrieved from Leanscape: https://leanscape.io/the-importance-of-identifying-the-right-sample-size-for-business-improvement/

Priniotakis, G., & Argyropoulos. (2018). Inventory management concepts and techniques. In G. Priniotakis, & Argyropoulos (Ed.), *Materials Science and Egineering. 459*, p. 1. Aegean: Institute of Physics Publishing.

Silver, E., Pyke, D., & J., D. (2017). *Inventory management and production planning and scheduling* (4 ed.). Boca Raton: Taylor & Francis Group.

song, J.-S., Xu, S. H., & Liu, B. (1999). Order-fulfillment performance measures in an assemble-to-order system with stochastic leadtimes. *Operations Research, 47*(1), 131-149.

Tadikamalla, P. R. (1984). A comparison of several approximations to the lead time demand distribution. *Omega*, *12*(6), 575-581.

Teunter, R. H., Syntetos, A. A., & Babai, M. Z. (2017). Stock keeping unit fill rate specification. *European Journal of Operational Research*, *259*(3), 917-925.

Thales Nederland B.V. (2024). *Governance Inventory Management.* Hengelo: Thales Group.

Thales Nederland B.V. (2024). *Our history*. Retrieved from Thalesgroup: https://www.thalesgroup.com/en/our-history

Tyworth, J. E., & O'Neill, L. (1997). Robustness of the normal approximation of lead-time demand in a distribution setting. *Naval Research Logistics*, *44*(2), 165-186.

Vlaswinke, E. A. (2024). *Improving the inventory management of parts.* Enschede: University of Twente.

Xiong, G., Zhao, A., & Nyberg, T. R. (2016). Change management of improvement project for success. *IEEE International Conference on Service Operations and Logistics, and Informatics, SOLI 2016* (pp. 53-59). Beijing: Institute of Electrical and Electronics Engineers Inc.

Appendices

Appendix A – Component demand & lead times

Appendix A.1 – Component demand

SKU	Q(BOM)	Demand	SKU	Q(BOM)	Demand	SKU	Q(BOM)	Demand	SKU	Q(BOM)	Demand	SKU	Q(BOM)	Demand
SKU1	30	360	SKU31	15	180	SKU61	2	24	SKU91	150	1800	SKU121	15	180
SKU2	1	12	SKU32	960	11520	SKU62	15	180	SKU92	15	180	SKU122	300	3600
SKU3	30	360	SKU33	1	12	SKU63	4	48	SKU93	164.75	1977	SKU123	76	912
SKU4	1	12	SKU34	30	360	SKU64	1	12	SKU94	10	120	SKU124	2	24
SKU5	1	12	SKU35	1	12	SKU65	1	12	SKU95	3	36	SKU125	1	12
SKU6	1	12	SKU36	2	24	SKU66	1	12	SKU96	12	144	SKU126	135	1620
SKU7	15	180	SKU37	30	360	SKU67	1	12	SKU97	1	12	SKU127	30	360
SKU8	15	180	SKU38	2	24	SKU68	1	12	SKU98	1	12	SKU128	60	720
SKU9	1	12	SKU39	15	180	SKU69	1	12	SKU99	1	12	SKU129	1	12
SKU10	15	180	SKU40	4	48	SKU70	1	12	SKU100	15	180	SKU130	1	12
SKU11	1	12	SKU41	15	180	SKU71	9	108	SKU101	1	12			
SKU12	1	12	SKU42	1	12	SKU72	1	12	SKU102	4	48			
SKU13	1	12	SKU43	92	1104	SKU73	1	12	SKU103	1	12			
SKU14	9	108	SKU44	1	12	SKU74	1	12	SKU104	15	180			
SKU15	15	180	SKU45	1	12	SKU75	1	12	SKU105	1	12			
SKU16	1	12	SKU46	1	12	SKU76	1	12	SKU106	15	180			
SKU17	1920	23040	SKU47	1	12	SKU77	1	12	SKU107	30	360			
SKU18	2	24	SKU48	2	24	SKU78	1	12	SKU108	1	12			
SKU19	1	12	SKU49	1	12	SKU79	1	12	SKU109	15	180			
SKU20	1	12	SKU50	1	12	SKU80	18	216	SKU110	4	48			
SKU21	1	12	SKU51	15	180	SKU81	9	108	SKU111	4	48			
SKU22	1	12	SKU52	4	48	SKU82	6	72	SKU112	3	36			
SKU23	1	12	SKU53	3	36	SKU83	1	12	SKU113	3	36			
SKU24	20	240	SKU54	15	180	SKU84	38.4	460.8	SKU114	5	60			
SKU25	2	24	SKU55	1	12	SKU85	2	24	SKU115	2	24			
SKU26	2	24	SKU56	960	11520	SKU86	42	504	SKU116	1	12			
SKU27	15	180	SKU57	1	12	SKU87	6	72	SKU117	13	156			
SKU28	3	36	SKU58	1	12	SKU88	1	12	SKU118	21	252			
SKU29	1	12	SKU59	1	12	SKU89	5	60	SKU119	3	36			
SKU30	15	180	SKU60	1	12	SKU90	2	24	SKU120	1	12			

Table A.1 - Component demand (per annum)

Appendix A.2 – Component lead times & revised lead times

SKU	Proposed LT	Revised LT	SKU	Proposed LT	Revised LT	SKU	Proposed LT	Revised LT	SKU	Proposed LT	Revised LT	SKU	Proposed LT	Revised LT
SKU1	1.60	1.64	SKU31	0.54	0.61	SKU61	0.83	0.85	SKU91	0.62	0.66	SKU121	0.54	0.53
SKU2	1.04	1.10	SKU32	0.58	0.57	SKU62	0.52	0.51	SKU92	0.37	0.36	SKU122	0.40	0.36
SKU3	1.37	1.42	SKU33	0.65	1.10	SKU63	0.48	0.51	SKU93	0.25	0.24	SKU123	0.40	0.36
SKU4	1.33	1.28	SKU34	1.60	1.64	SKU64	0.48	0.49	SKU94	0.87	0.88	SKU124	0.19	0.19
SKU5	2.00	2.15	SKU35	0.94	0.93	SKU65	0.62	0.71	SKU95	1.12	1.16	SKU125	0.38	0.40
SKU6	2.00	2.15	SKU36	1.12	1.17	SKU66	0.58	0.57	SKU96	0.38	0.37	SKU126	0.40	0.36
SKU7	1.60	1.64	SKU37	0.40	0.36	SKU67	1.23	1.26	SKU97	0.52	0.52	SKU127	0.50	0.49
SKU8	1.37	1.42	SKU38	0.94	0.95	SKU68	0.62	0.62	SKU98	0.52	0.51	SKU128	0.19	0.19
SKU9	1.15	1.14	SKU39	0.44	0.40	SKU69	0.94	0.93	SKU99	0.52	0.53	SKU129	0.40	0.43
SKU10	1.69	1.84	SKU40	1.33	1.32	SKU70	0.58	0.57	SKU100	0.33	0.32	SKU130	1.08	1.09
SKU11	0.90	2.43	SKU41	0.69	0.73	SKU71	0.69	0.62	SKU101	0.90	0.92			
SKU12	0.40	0.30	SKU42	0.90	0.85	SKU72	0.52	0.52	SKU102	0.48	0.47			
SKU13	1.02	0.97	SKU43	0.90	0.95	SKU73	0.40	0.58	SKU103	0.31	0.30			
SKU14	1.75	1.76	SKU44	0.94	0.93	SKU74	0.38	0.37	SKU104	0.40	0.36			
SKU15	0.65	0.64	SKU45	0.52	0.52	SKU75	0.58	0.57	SKU105	0.38	0.37			
SKU16	1.08	1.24	SKU46	1.60	1.64	SKU76	0.73	0.76	SKU106	0.44	0.40			
SKU17	0.58	0.57	SKU47	0.94	0.93	SKU77	0.40	0.48	SKU107	0.52	0.51			
SKU18	1.60	1.64	SKU48	1.60	1.64	SKU78	0.44	0.43	SKU108	0.90	0.90			
SKU19	0.94	0.93	SKU49	0.94	0.93	SKU79	0.44	0.54	SKU109	0.40	0.36			
SKU20	0.94	0.93	SKU50	0.40	0.51	SKU80	0.38	0.37	SKU110	0.48	0.47			
SKU21	0.94	0.97	SKU51	0.60	0.67	SKU81	0.31	0.30	SKU111	0.90	0.92			
SKU22	0.69	0.80	SKU52	0.69	0.73	SKU82	0.58	0.57	SKU112	0.23	0.21			
SKU23	0.94	0.93	SKU53	0.52	0.53	SKU83	0.40	0.50	SKU113	0.54	0.63			
SKU24	0.85	0.89	SKU54	0.52	0.51	SKU84	0.52	0.51	SKU114	0.21	0.20			
SKU25	0.52	0.58	SKU55	0.04	0.06	SKU85	0.40	0.40	SKU115	0.38	0.43			
SKU26	1.06	1.12	SKU56	0.42	0.42	SKU86	0.27	0.29	SKU116	0.40	0.40			
SKU27	0.44	0.40	SKU57	0.23	0.22	SKU87	0.58	0.60	SKU117	0.40	0.36			
SKU28	0.94	0.95	SKU58	0.23	0.22	SKU88	0.58	0.57	SKU118	0.48	0.50			
SKU29	0.94	0.93	SKU59	0.63	0.63	SKU89	0.69	0.73	SKU119	0.38	0.40			
SKU30	0.44	0.40	SKU60	0.62	0.72	SKU90	0.85	0.82	SKU120	0.40	0.42			

Table A.2 - Revised supplier lead times (years)

Appendix B – Inventory management tool

Appendix B.1 – Tool layout

As depicted in Figure B.1, the input parameters consist of the SKUs supplier, its lead time in years, the quantities needed in one product x (Q(BOM)), the standard deviation of lead times (is predetermined and connected to the SKU's supplier by means of a lookup string in Excel), and the component's price. The annual demand is determined by multiplying the Q(BOM) with the amount of product x to review according to the userform depicted in Figure B.3.

SKU	Supplier	Lead time (y)	Q(BOM)	Demand (y)	STD Lead time	Price
SKU1	Supplier I	1.64	30	360	0.139576923	€ 16,500.00

Figure B.1 - Input parameters inventory management tool

The input parameters are used to determine the EOQs, safety stocks (SS), and ROPs as depicted in Figure B.2. This follows after the component's target FR is determined such that a target ESC is configured to determine the desired safety stocks and ROPs.

STD LTD	EOQ	Target FR	Target ESC	Actual ESC	Desired SS	Reorder Point
50.25	30	0.9709508	0.87147529	0.8508457	87	690

Figure B.2 - Output inventory management tool

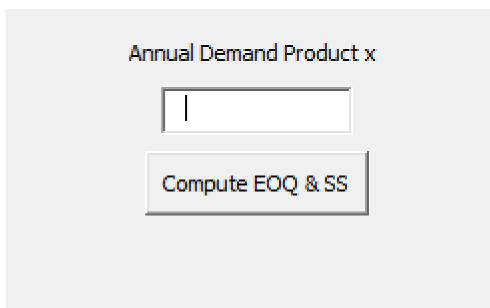

Figure B.3 - Userform inventory management tool

Appendix B.2 – VBA code

```
For i = 1 To Range("A2", Range("A2").End(xlDown)).Rows.Count 'loop over the number of relevant rows
    Cells(i + 1, 16) = 0 'initial safety stock value
    BOM = Cells(i + 1, 4) 'Quantities of SKU needed in product x
    D = BOM * UserForm1.TextBox1.Value + (Cells(i + 1, 4) * Cells(i + 1, 5) * UserForm1.TextBox1.Value)
    'demand is knowkn through BOM and demand of product x
    Cells(i + 1, 6) = D 'print demand on worksheet
    LT = Cells(i + 1, 3) 'save lead time
    STDLT = Cells(i + 1, 7) 'save standard deviation of lead time
    P = Cells(i + 1, 8) 'save price

    STDLTD = Sqr((D ^ 2) * (STDLT ^ 2)) 'formula for standard deviation of lead time demand
    Cells(i + 1, 10) = STDLTD 'print standard deviation of lead time demand

    EOQ = Sqr((2 * (D / BOM) * 200) / (0.2 * P * BOM)) 'formula for EOQ using multiples of product x
        If (D / UserForm1.TextBox1.Value) / (EOQ * BOM) > 1 Then 'EOQ needs to be enough for at least on product x
           EOQ = D / UserForm1.TextBox1.Value
        Else
            EOQ = Round(EOQ) * BOM 'multiples of product x
        End If
    Cells(i + 1, 12) = Round(EOQ) 'EOQ needs to be integer

    B3 = 0.2 * (3035070 - (P * Round(EOQ)))[redacted]'backorder costs (confidential)
    FR = B3 / (B3 + 0.2 * (P * Round(EOQ))) 'formula for desired fill rate with lot size
    Cells(i + 1, 13) = FR 'print desired fill rate

    ESC = (1 - FR) * Cells(i + 1, 12) 'formula for expected shortages per cycle
    Cells(i + 1, 14) = ESC 'print ESC

Next i 'loop to next SKU
```

Figure B.4 - VBA code EOQ & fill rate

After gathering all input parameters, the standard deviation of demand during lead time (STDLTD) can be determined by the formula depicted in (4.1). To determine the ESC, the order quantities need to be defined, which is done through the EOQ formula depicted in (3.5). The code makes sure to order at least the amount that is needed to be assembled in one final product, while also rounding the number. Utilizing the components' value and backorder costs, a target fill rate can be determined from (4.4) after which the desired ESC can be configurated through (3.8).

```
For i = 1 To Range("A2", Range("A2").End(xlDown)).Rows.Count 'loops over the total number of relevant rows
Cells(i + 1, 16) = ss 'prints initial safety stock value on worksheet
    Do Until Cells(i + 1, 15) <= Cells(i + 1, 14) 'loop until the actual ESC is less than the desired ESC
        ss = ss + 1 'incrementation of safety stock
        Cells(i + 1, 16) = ss 'print safety stock on worksheet
    Loop
    If Cells(i + 1, 16) = 0 Then
        Cells(i + 1, 16) = Cells(i + 1, 4) 'if there is no safety stock, at least keep one unit of product x
    End If
    ss = 0 'initialize next SKUs safety stock
Next i
```

Figure B.5 - VBA code safety stocks

To determine the safety stocks that meet the service level constraint, the safety stocks will be incremented until the desired ESC is met through the equation depicted in 3.8, hence the "Do Until" loop. After the safety stocks have been determined, the ROPs need to be configured while we keep in mind that an ROP can only be a multiple of components needed in product x. The ROP is rounded to the next multiple to meet the service level constraint.

```
For i = 1 To Range("A2", Range("A2").End(xlDown)).Rows.Count 'loops over total number of relevant rows
    ROP = Cells(i + 1, 16) + Cells(i + 1, 6) * Cells(i + 1, 3) 'formula for reorder point
    Cells(i + 1, 17) = Application.WorksheetFunction.RoundUp(ROP / Cells(i + 1, 4), 0) * Cells(i + 1, 4) 'print reorder point on worksheet
    'ROP is only rounded up the the next multiple of product x to meet service constraint
Next i
End Sub
```

Figure B.6 - VBA code ROPs

Appendix C – Simulation model

As mentioned in Chapter 4, we want to build a simulation model that can visualize both the inventory levels in safety stock and the WIP to conclude the components' VEXs such that the DOI can be determined. As depicted in Figure C.1, the simulation model represents 130 inventory buffers of the specified components that conclude to one *product x*. Every buffer's level is tracked to understand the components' inventory levels over time such that the VEX and holding costs can be determined.

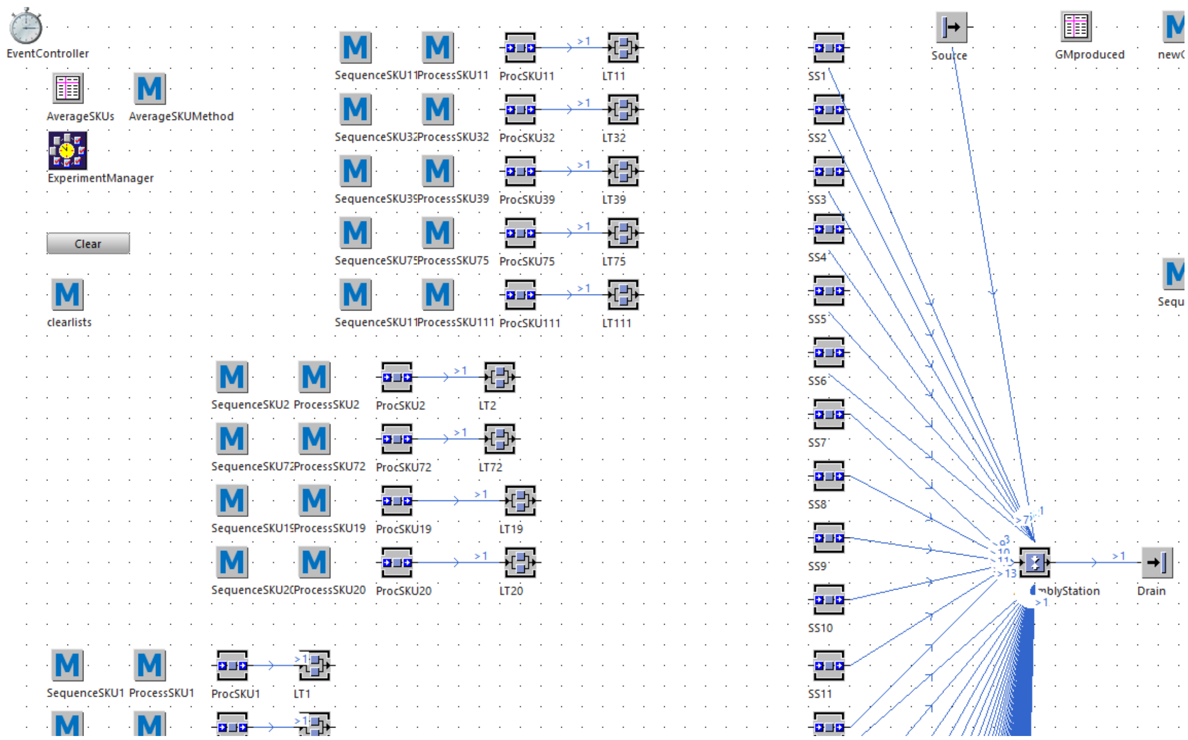

Figure C.1 - Simulation model layout

Now, to visualize and analyze the order FR and average waiting/idle times when not all components are in stock when needed, we can develop a simulation model that demands each component in their respective quantities according to the takt time of the assembly line. As the demand/production rate of *product x* is 12 per year, the takt time in this simulation is chosen to be 30 days and 10 hours such that in each takt cycle all the components are needed in the assembly station. If a component is not available from stock, the FR can be revised and the time to wait for the component can be measured to define the average waiting/idle times. Figure C.2 depicts the settings for the processing times of the assembly station, which is 30 days and 10 hours.

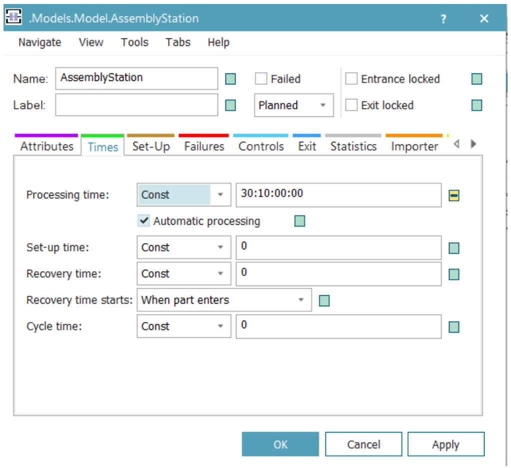

Figure C.2 - Assembly station process time configuration

Now, to represent the procurement strategy proposed through the inventory management tool, we have to purchase each component in lot sizes determined by the EOQ formula when the component's ROP is crossed. Through a method, we can check the components' inventory position (outstanding orders + on-hand stock) to determine whether or not to place a new order. Figure C.3 depicts the code in the method "ProcureSKU" for checking SKU1's inventory position. While an order consists of 30 components. The inventory during the lead time is 30 times the number of orders outstanding. Where SKU1's ROP in this example is 735, every time the number of components on hand plus the number of components in order is less than 735, a new order is placed consisting of 30 components and sent to the station "ProcSKU1" which triggers the method "SequenceSKU1".

```
var  nrSKU1, i: integer


nrSKU1 := LT1.NumMU*30 + SS1.NumMU

if nrSKU1 <= 735
    .UserObjects.OrderSKU1.create(ProcSKU1)
end
```

Figure C.3 - checking the inventory position of SKU1

After a new order is placed, the order should receive a lead time as determined through the means and standard deviations depicted in Tables A.2 & 2.2 respectively. Next, we also want to make sure that an order placed at a later point cannot be delivered earlier than an earlier placed order. Figure C.4 depicts how the method "sequenceSKU1" gives a generated lead time to every order and it makes sure that it is delivered in a given sequence since an order cannot arrive earlier than an order placed earlier. As seen in this method, the mean lead time is 598 days with a standard deviation of 50 days.

```
sequenceCountSKU1 := SequenceCountSKU1+1
@.sequenceNumber := SequenceCountSKU1
@.procTime := z_normal(598:14:24:00, 50:18:30:58, 0, 11574:01:46:40)
@.expEndtime := eventController.simtime +@.procTime
if @.ExpendTime < expectedEndTimeSKU1
    @.expEndTime := expectedEndTimeSKU1
    @.proctime := @.expEndTime-eventController.simTime
end
expectedEndTimeSKU1 := @.ExpEndTime
```

Figure C.4 - appointing a lead time and maintaining the right sequence

Next, the order has to wait for the appointed lead time after which the order, in this case, consisting of 30 SKU1s arrives at the warehouse of Thales. Figure C.5 depicts the orders' lead times and the delivery of the components in the warehouse (SS1) through the method "ProcessSKU1".

```
var i : integer
wait(@.proctime)
@.delete
    for i := 1 to 30
        .UserObjects.SKU1.create(SS1)
    next
```

Figure C.5 - lead time & delivery of SKU1

Through a simple line of code, we can depict each component´s inventory position to compute the VEX and holding costs The code is depicted in Figure C.6 counts the number of components in inventory (SS1.NumMU).

```
CountSKU1 := SS1.NumMU
```

Figure C.6 - Code to determine the holding costs and VEX

Now, to evaluate the order FR of the assembly process, the method "EndTime" has been programmed as depicted in Figure C.7. After a warm-up period of 2.000 days (172.800.000 sec), each occurrence of a processing time longer than 30 days and 10 hours (2.628.000sec) is counted (nWaiting) to determine the FR by determining the rate of assembly processes for which no waiting/idle times were observed. While the waiting times per assembly process is known, we can increment the KPI totalWaiting such that the averageWaiting (time) can be determined to understand how long each assembly process will be idling. In the end, we can use this simulation model to determine the inventory management tool's output performance on the aggregated FR and waiting times.

```
gmproduced[2,n] := eventController.simtime
gmproduced[3,n] := Gmproduced[2,n]-gmproduced[1,n]-2628000

if eventController.simtime >172800000
    i+=1
    if gmproduced[3,n] >0 then
        nwaiting += 1
        totalWaiting += gmproduced[3,n]
    end
    FillRate:=1-(nwaiting/i)
    averagewaiting := totalWaiting/i
end
```

Figure C.7 - component availability KPI computations

Appendix D – Supply chain coordination mathematical models

Appendix D.1 – Scenario 0 (safety stock at Thales)

$SS_{iT} = ROP(FR_{iT}, s_{Li})_{iT} - (LT_i \times D_i)^*$ (D.1)

SKU1
ROP = 690 pieces
LT = 1,64 years
D = 360
SS = 99,4 pieces (rounded to nearest multiple of *product x* = 90)
Price (Thales) = €16.500,-
Holding costs safety stock = 20%*€16.500,-*90 = €297.000,-

SKU7
ROP = 360 pieces
LT = 1,64 years
D = 180
SS = 64,8pieces (rounded to nearest multiple of *product x* = 60)
Price (Thales) = €9.596,-
Holding costs safety stock = 20%*€9.596,-*60 = €115.152,-

SKU34
ROP = 750 pieces
LT = 1,64 years
D = 360
SS = 159,6 pieces (rounded to nearest multiple of *product x* = 150)
Price (Thales) = €425,-
Holding costs safety stock= 20%*€425,-*150 = €12.750,-

Appendix D.2 – Scenario 1 (safety stock at supplier)

$SS_{iS} = ROP(FR_{iS}, s_{Li})_{iS} - (LT_i \times D_i)^*$ (D.2)

SKU1
ROP = 690 pieces
LT = 1,64 years
D = 360
SS = 99,4 pieces (rounded to nearest multiple of *product x* = 90)
Price (Thales) = €11.897,88
Holding costs = 20%*€ 11.897,88*90 = €214.161,84

SKU7
ROP = 360 pieces
LT = 1,64 years
D = 180
SS = 64,8pieces (rounded to nearest multiple of *product x* = 60)
Price (Thales) = €7.742,64
Holding costs = 20%*€7.742,64*60 = €92.911,68

SKU34
ROP = 750 pieces
LT = 1,64 years
D = 360
SS = 159,6 pieces (rounded to nearest multiple of *product x* = 150)
Price (Thales) = €305,77

Holding costs = 20%*€305,77*150 = €9.173,10

Appendix D.3 – Scenario 2

$$SS_{sub_{iS}} = ROP\left(FR_{sub_{iS}}, (s_{Li} \times \frac{LT_{sub_i}}{LT_i})\right)_{sub_{iS}} (LT_{sub_i} \times D_{sub_i}) \quad \text{(D.3)}$$

$$SS_{iT} = ROP\left(FR_{iT}, (s_{Li} \times \frac{LT_{iS}}{LT_i}\right)_{iT} - (LT_{iS} \times D_i)^* \quad \text{(D.4)}$$

SKU1

Subcomponent (Supplier I)
ROP = 545 pieces
LT = 1,23 years
D = 360
SS = 102,2 pieces (rounded to nearest multiple of *SKU1* = 102)
Price (Thales) = €4.636,71
Holding costs sub1= 20%*€4.636,71*102 = €94.588,88
SKU1 (Thales)
ROP = 180 pieces
LT = 0,41 years
D = 360
SS = 32,4 pieces (rounded to nearest multiple of *product x* = 30)
Price (Thales) = €16.500,-
Holding costs SKU1= 20%*€16.500,-*30 = €99.000,-
Total = €193.588,88

SKU7

Subcomponent (Supplier I)
ROP = 273 pieces
LT = 1,23 years
D = 180
SS = 51,6 pieces (rounded to nearest multiple of *SKU7* = 52)
Price (Thales) = €3.885,97
Holding costs sub7= 20%*€3.885,97*52 = €40.414,09
SKU7 (Thales)
ROP = 90 pieces
LT = 0,41 years
D = 180
SS = 16,2 pieces (rounded to nearest multiple of *product x* = 15)
Price (Thales) = €9.596,-
Holding costs SKU7= 20%*€9.596,-*15 = €28.788,-
Total = €69.202,09

SKU34

Subcomponent (Supplier I)
ROP = 545 pieces
LT = 1,23 years
D = 360

SS = 102,2 pieces (rounded to nearest multiple of *SKU34* = 102)
Price (Thales) = €300,76
Holding costs sub34= 20%*€300,76*102 = €6.135,50

SKU34 (Thales)

ROP = 180 pieces
LT = 0,41 years
D = 360
SS = 32,4 pieces (rounded to nearest multiple of *product x* = 30)
Price (Thales) = €425,-
Holding costs SKU34= 20%*€425,-*30 = €2.550,-
Total = €8.685,50

Appendix E – Simulation parameters determined by tool

Appendix E.1 – Order quantities

Component	EOQ	Q(BOM)	Component	EOQ	Q(BOM)	Component	EOQ	Q(BOM)	Component	EOQ	Q(BOM)	Component	EOQ	Q(BOM)
SKU1	30	30	SKU31	15	15	SKU61	4	2	SKU91	450	150	SKU121	60	15
SKU2	1	1	SKU32	960	960	SKU62	30	15	SKU92	45	15	SKU122	1200	300
SKU3	30	30	SKU33	1	1	SKU63	8	4	SKU93	494	164.75	SKU123	304	76
SKU4	1	1	SKU34	30	30	SKU64	3	1	SKU94	30	10	SKU124	8	2
SKU5	1	1	SKU35	2	1	SKU65	3	1	SKU95	9	3	SKU125	4	1
SKU6	1	1	SKU36	4	2	SKU66	3	1	SKU96	48	12	SKU126	540	135
SKU7	15	15	SKU37	60	30	SKU67	3	1	SKU97	4	1	SKU127	120	30
SKU8	15	15	SKU38	4	2	SKU68	3	1	SKU98	4	1	SKU128	240	60
SKU9	1	1	SKU39	30	15	SKU69	3	1	SKU99	4	1	SKU129	4	1
SKU10	15	15	SKU40	8	4	SKU70	3	1	SKU100	60	15	SKU130	4	1
SKU11	1	1	SKU41	30	15	SKU71	27	9	SKU101	4	1			
SKU12	1	1	SKU42	2	1	SKU72	3	1	SKU102	16	4			
SKU13	1	1	SKU43	184	92	SKU73	3	1	SKU103	4	1			
SKU14	9	9	SKU44	2	1	SKU74	3	1	SKU104	60	15			
SKU15	15	15	SKU45	2	1	SKU75	3	1	SKU105	4	1			
SKU16	1	1	SKU46	2	1	SKU76	3	1	SKU106	60	15			
SKU17	1920	1920	SKU47	2	1	SKU77	3	1	SKU107	120	30			
SKU18	2	2	SKU48	4	2	SKU78	3	1	SKU108	4	1			
SKU19	1	1	SKU49	2	1	SKU79	3	1	SKU109	60	15			
SKU20	1	1	SKU50	2	1	SKU80	54	18	SKU110	16	4			
SKU21	1	1	SKU51	30	15	SKU81	27	9	SKU111	16	4			
SKU22	1	1	SKU52	8	4	SKU82	18	6	SKU112	12	3			
SKU23	1	1	SKU53	6	3	SKU83	3	1	SKU113	12	3			
SKU24	20	20	SKU54	30	15	SKU84	115	38.4	SKU114	20	5			
SKU25	2	2	SKU55	2	1	SKU85	6	2	SKU115	8	2			
SKU26	2	2	SKU56	1920	960	SKU86	126	42	SKU116	4	1			
SKU27	15	15	SKU57	2	1	SKU87	18	6	SKU117	52	13			
SKU28	3	3	SKU58	2	1	SKU88	3	1	SKU118	84	21			
SKU29	1	1	SKU59	2	1	SKU89	15	5	SKU119	12	3			
SKU30	15	15	SKU60	2	1	SKU90	6	2	SKU120	4	1			

Table E.1 - Order quantities per SKU

Appendix E.2 – ROPs

Component	ROP	Component	ROP	Component	ROP	Component	ROP	Component	ROP
SKU1	690	SKU31	165	SKU61	42	SKU91	2550	SKU121	135
SKU2	20	SKU32	7680	SKU62	105	SKU92	90	SKU122	3000
SKU3	600	SKU33	28	SKU63	44	SKU93	659	SKU123	760
SKU4	23	SKU34	750	SKU64	10	SKU94	210	SKU124	10
SKU5	34	SKU35	14	SKU65	20	SKU95	69	SKU125	16
SKU6	34	SKU36	34	SKU66	10	SKU96	60	SKU126	1350
SKU7	360	SKU37	300	SKU67	20	SKU97	8	SKU127	240
SKU8	300	SKU38	40	SKU68	13	SKU98	9	SKU128	240
SKU9	19	SKU39	150	SKU69	14	SKU99	11	SKU129	10
SKU10	450	SKU40	88	SKU70	10	SKU100	90	SKU130	24
SKU11	41	SKU41	270	SKU71	144	SKU101	20		
SKU12	9	SKU42	20	SKU72	10	SKU102	36		
SKU13	20	SKU43	1840	SKU73	15	SKU103	7		
SKU14	270	SKU44	14	SKU74	16	SKU104	150		
SKU15	150	SKU45	10	SKU75	10	SKU105	6		
SKU16	28	SKU46	25	SKU76	14	SKU106	150		
SKU17	17280	SKU47	14	SKU77	14	SKU107	210		
SKU18	50	SKU48	50	SKU78	17	SKU108	14		
SKU19	14	SKU49	14	SKU79	20	SKU109	150		
SKU20	14	SKU50	17	SKU80	90	SKU110	36		
SKU21	20	SKU51	165	SKU81	54	SKU111	80		
SKU22	20	SKU52	72	SKU82	54	SKU112	15		
SKU23	14	SKU53	33	SKU83	17	SKU113	57		
SKU24	400	SKU54	105	SKU84	269	SKU114	25		
SKU25	32	SKU55	12	SKU85	18	SKU115	30		
SKU26	38	SKU56	6720	SKU86	588	SKU116	8		
SKU27	165	SKU57	5	SKU87	120	SKU117	130		
SKU28	63	SKU58	6	SKU88	10	SKU118	378		
SKU29	15	SKU59	11	SKU89	90	SKU119	48		
SKU30	165	SKU60	19	SKU90	30	SKU120	17		

Table E.2 - ROPs per SKU

Appendix F – Sensitivity analysis SKU2

Here, we depict what happens when the safety stocks of single SKUs are lowered. What is interesting to see is that the value of the total inventory levels eventually increases due to excess inventory of components that are waiting in stock on components that are OOS. We decrease the safety stock of SKU2 by one multiple of *product x* every step (minus 1 piece of SKU2 each step). This component is interesting to analyze while the cumulative value of SKU2 is 10% of *product x's* value. Table F.1 depicts the impact on the KPIs when decreasing the ROP of SKU2 by 1 piece each step.

Service KPI	**ROP = 20**	**ROP = 19**	**ROP = 18**	**ROP = 17**
Order fill rate (%)	98,08%	97,95%	97,30%	96,48%
Individual fill rate (%)	99,93%	99,61%	98,91%	97,59%
Annual waiting/idle times	3 days 12,7 hours	3 days 22,3 hours	5 days 14 hours	9 days 23,3 hours
Cost KPI				
Annual holding costs (€)	€ 3.560.658,71	€ 3.526.197,40	€ 3.505.693,31	€ 3.574.857,51
VEX (€)	€ 28.839.208,64	€ 28.666.902,12	€ 28.564.381,66	€ 28.910.202,64
DOI (days)	118,54 days	117,83 days	117,41 days	118.83

Table F.1 - Safety stock reduction SKU1

As one can see in Figure F.1, initially, the SKUs FR is quite above the order FR. However, by decreasing its safety stocks, it will move closer to the order FR. Now, as visualized in Figure F.2, the assembly's idle times increase steadily when decreasing the safety stocks of SKU1. Eventually, both holding costs as well as DOI decrease for a short moment after which they increase heavily due to excess inventory as visualized in Figures F.3 & F.4.

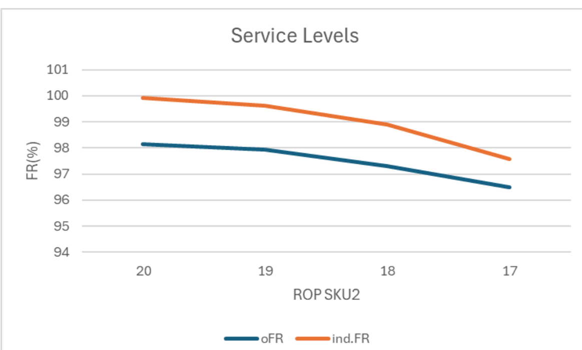

Figure F.1 - FRs SKU2 Safety Stock Reduction

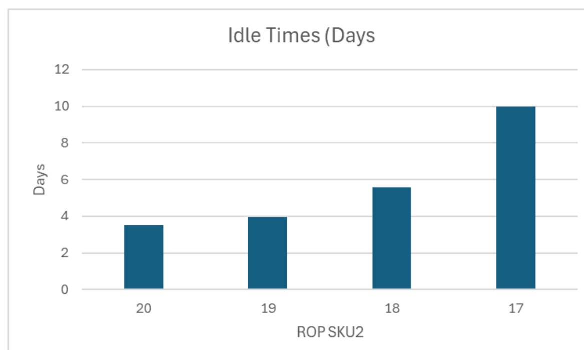

Figure F.2 - Assembly idle times SKU2 Safety Stock Reduction

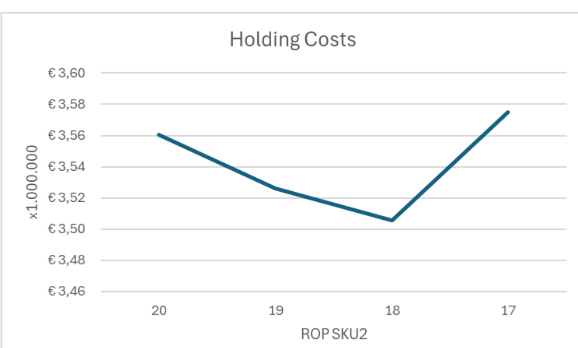

Figure F.3 - Holding Costs SKU2 Safety Stock Reduction

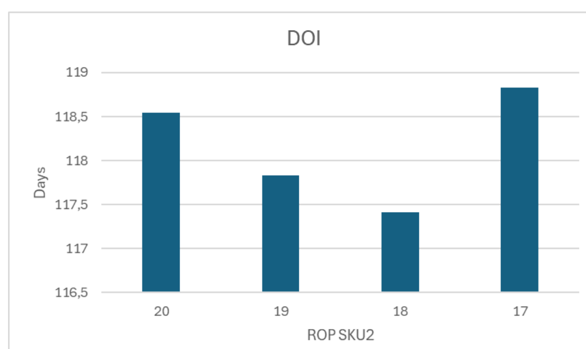

Figure F.4 - DOI SKU2 Safety Stock Reduction

Appendix G – Alternative component analysis

Step 1: Determine the supplier of the relevant SKU.

Step 2: gather the proposed lead time and needed quantities through the BOM such that the demand and demand during lead time can be determined.

Step 3: gather the component price.

Step 4: Determine the supplier's average delay and standard deviation of delay/lead times.

- If the supplier is already listed in the worksheet ‘STD LT’, this step can be skipped
- If the supplier is not yet listed in the worksheet ‘STD LT’, follow the next steps.
    - Filter the relevant supplier in PUR10
    - Filter the relevant component(s) in PUR10
    - If there are less than 30 data points, undo the filter of relevant component(s)
    - Determine the average delay through the ‘Delay (working days)’ column.
        - Add average delay to the proposed lead time from ‘step 2’. Keep in mind that the delay is in working days so compute accordingly.
    - Determine the standard deviation of delays (in years)
    - Add supplier combined with the standard deviation of delays to the sheet ‘STD LT’.

Step 5: click on the button ‘Compute EOQ & SS’ and fill in the desired demand of the relevant assembly product.

Step 6: analyze EOQs, safety stocks, and reorder points.

Appendix H – Determining the statistical distribution for outliers

To give an example of the statistical tests conducted to find a (better) fit for the statistical distributions of the outlier components, we have described the process for SKU55 (Appendix H.1) and SKU83 (Appendix H.2)

Appendix H.1 – Example SKU55

Step 1: gather the relative data points concerning the delays per order (in days) for SKU55 and add the lead time of SKU55 to these delays (16 working days). Table H.1 depicts a small sample of the data set.

Delays (d)	LT (d)
8	24
8	24
8	24
8	24
6	22
6	22
4	20
-2	14
-3	13
-4	12
-4	12
-8	8
-9	7
24	40

Table H.1 - delays SKU55

Mean	26,64894
Standard Error	4,93385
Median	15
Mode	14
Standard Deviation	47,83545
Sample Variance	2288,23
Kurtosis	37,89917
Skewness	5,914627
Range	367
Minimum	5
Maximum	372
Sum	2505
Count	94

Table H.2 - Descriptive statistics data set

Step 2: Use the Data Analysis add-in in the Data tab in Excel to depict a descriptive statistics analysis (Table H.2).

Step 3: determine an appropriate Bin range. In the case of SKU55, one can observe that the minimum LT is 5 days and a maximum of 372 days. It was chosen to have a Bin range from 0 until 380 days incrementing each bin with 20 days. Now, use the Data analysis add-in to create a histogram using the determined bins. Table H.3 depicts the histogram utilizing the abovementioned bin range. Figure H.1 depicts a graph through the histogram's output.

Bin	*Frequency*
0	0
20	70
40	15
60	2
80	3
100	2
120	0
140	0
160	0
180	0
200	0
220	0
240	0
260	0
280	0
300	1
320	0
340	0
360	0
380	1
More	0

Table H.3 - Histogram SKU55

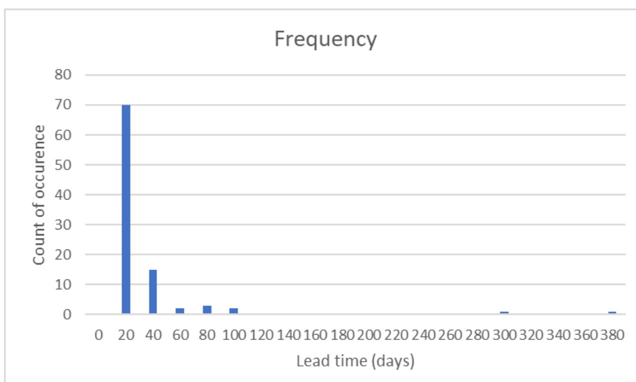

Figure H.1 - Frequencies of lead times SKU55

Step 4: test the normal distribution against the actual output by determining the probabilities of the occurrences of the bin quantities through the normal distribution using the data set's mean and standard deviation. Next, multiply the count (94) with the probabilities to visualize the expected output of the distribution. Table H.4 depicts the expected frequencies utilizing the normal distribution. Figure H.2 represents the expected output of the normal distribution against the actual output from Figure H.1. It was found that the Chi-Square test statistic´s value (equation 6.1) was equal to 6.979.677.694 while to be considered a good fit, the value has to be under 31 as this is the chi-square value of 95% with 19 degrees of freedom (20 bins -1).

Bin	*Frequency*	Normal Dist	Frequency
0	0		0
20	70	0,444726655	41,80431
40	15	0,609917481	15,52794
60	2	0,757162411	13,84102
80	3	0,867639893	10,38488
100	2	0,937411812	6,55856
120	0	0,97450143	3,486424
140	0	0,991096422	1,559929
160	0	0,997345847	0,587446
180	0	0,999326571	0,186188
200	0	0,999854905	0,049663
220	0	0,999973502	0,011148
240	0	0,999995904	0,002106
260	0	0,999999465	0,000335
280	0	0,999999941	4,48E-05
300	1	0,999999994	5,04E-06
320	0	1	4,77E-07
340	0	1	3,8E-08
360	0	1	2,54E-09
380	1	1	1,43E-10

Table H.4 - Normal distribution SKU55

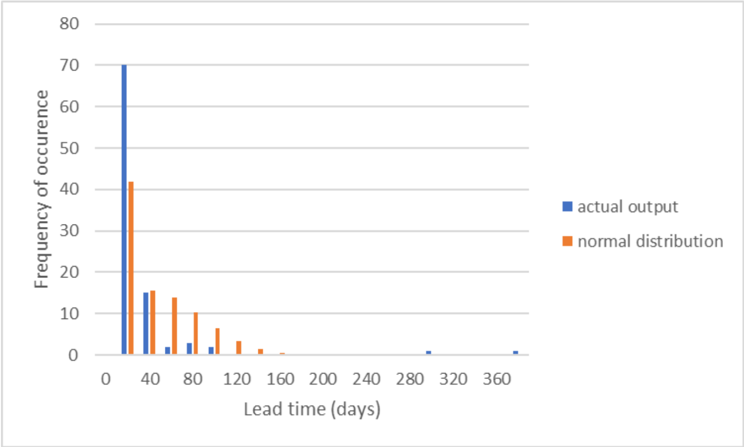

Figure H.2 - comparison of normal distribution against actual output

Step 5: pick a different statistical distribution to investigate. In this case, we will observe the gamma distributions with parameters Alpha & Beta. The value of Alpha is determined to be 0,31 through equation 6.2, while Beta's value is 85,7 days through equation 6.3. Next, determine the expected frequencies utilizing the gamma distribution. Table H.5 depicts the expected frequencies of the gamma distribution as opposed to the actual bin frequencies while Figure H.3 depicts the comparison of the gamma distribution against the actual output. It was found that the Chi-Square test statistic's value was 43. We can conclude that the gamma distribution is a better fit than the normal distribution as one can also observe when comparing Figure H.2 and Figure H.3.

Bin	*Frequency*	Gamma Dist	Frequency
0	0	0	0
20	70	0,673386542	63,29833
40	15	0,794948323	11,42681
60	2	0,861416496	6,248008
80	3	0,902941322	3,903334
100	2	0,930535522	2,593855
120	0	0,949545207	1,78691
140	0	0,962954986	1,260519
160	0	0,972574668	0,90425
180	0	0,979562492	0,656855
200	0	0,984688057	0,481803
220	0	0,988476916	0,356153
240	0	0,991295461	0,264943
260	0	0,993403263	0,198133
280	0	0,994986584	0,148832
300	1	0,996180474	0,112226
320	0	0,997083697	0,084903
340	0	0,997768996	0,064418
360	0	0,998290276	0,049
380	1	0,998687692	0,037357

Table H.5 - Gamma distribution SKU55

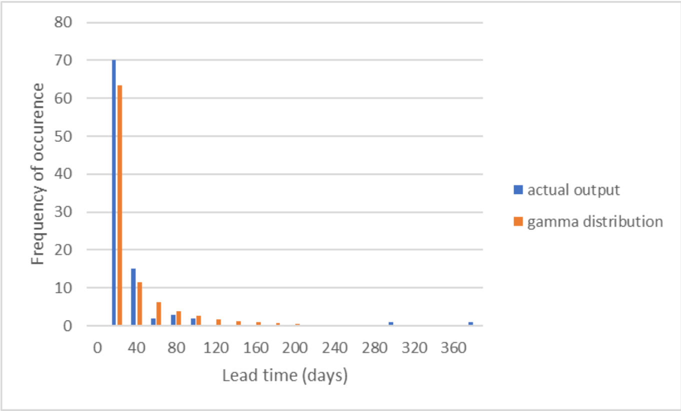

Figure H.3 - Comparison of gamma distribution against actual output

Appendix H.2 – Example SKU83

Performing Step 1 until Step 5 from Appendix H.6 for SKU83, we are able to determine a better-fitting statistical distribution for the component's lead times. Table H.6 depicts a small sample of the data set returning the delays and lead times (delay + 130 days). Next, Table H.7 depicts the descriptive statistics of the data set.

Delay (d)	LT (d)
42	172
39	169
22	152
2	132
-3	127
-3	127
-35	95
314	444
307	437
14	144
13	143
222	352
190	320

Table H.6 - small sample of data set

Column1	
Mean	186,1481
Standard Error	18,83741
Median	144
Mode	127
Standard Deviation	97,88207
Sample Variance	9580,9
Kurtosis	1,831416
Skewness	1,685153
Range	349
Minimum	95
Maximum	444
Sum	5026
Count	27

Table H.7 - descriptive statistics data set

Next, we can analyze the performance of fitting the normal distribution by comparing the frequencies of occurrences with the actual output utilizing a range of bins. In the case of SKU83, with only 27 data points, 6 bins ranging from 95 to 445 were picked to represent the frequencies of lead times. Table H.8 depicts the histogram produced with the abovementioned bin range while Figure H.4 depicts the respective graph.

Bin	*Frequency*
95	1
165	17
235	3
305	2
375	2
445	2
More	0

Table H.8 - Histogram SKU83

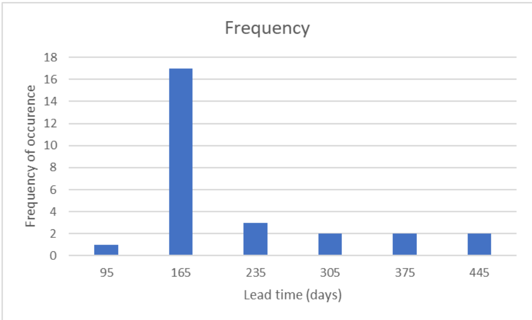

Figure H.4 - Frequencies of lead times SKU83

Now, Table H.9 depicts the expected output of the normal distribution with the parameters gathered through the descriptive statistics analysis while Figure H.5 depicts a comparison between the expected normal output and the actual output. It was found that the Chi-Square test statistic's value was 28 for the normal distribution while it has to be under 11 to be considered a good fit for the data set.

Bin	*Frequency*	Normal dist.	Frequency
95	1	0,175874104	4,74860081
165	17	0,414471495	6,44212956
235	3	0,691141605	7,470092977
305	2	0,887671025	5,306294328
375	2	0,973158235	2,308154658
445	2	0,995909749	0,614290895

Table H.9 - Normal distribution SKU83

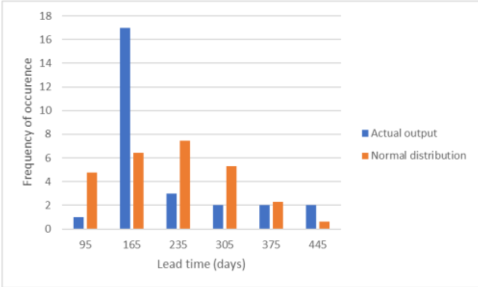

Figure H.5 - Comparison of normal distribution against actual output

Next, Table H.10 depicts the expected output of the gamma distribution with the parameters gathered through the descriptive statistics analysis while Figure H.6 depicts a comparison between the expected gamma distributed output and the actual output. It was found that the Chi-Square test statistic's value was 16 for the gamma distribution while it has to be under 11 to be considered a good fit for the data set. To conclude, the gamma distribution represents a better, however not perfect, fit for the data set of SKU83

Bin	*Frequency*	Gamma Dist	Frequency
95	1	0,166998629	4,508963
165	17	0,481302209	8,486197
235	3	0,736938155	6,902171
305	2	0,88331604	3,952203
375	2	0,952779869	1,875523
445	2	0,982112504	0,791981

Table H.10 - Gamma distribution SKU83

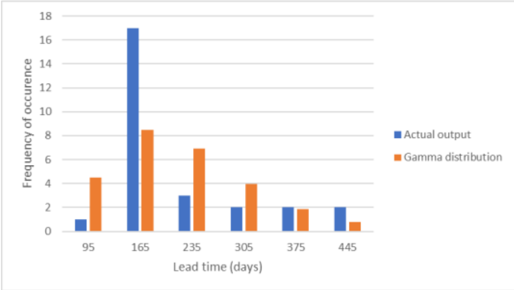

Figure F.6 - Comparison of gamma distribution against actual output