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INCREASING DELIVERY RELIABILITY BY INVENTORY AND NON-INVENTORY MANAGEMENT

MASTER THESIS

JAROLA CENTRAL SERVICES B.V. | UNIVERSITY OF TWENTE

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INCREASING DELIVERY RELIABILITY BY INVENTORY AND NON-INVENTORY MANAGEMENT

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Preface

I would like to present to you my thesis, which is the final assignment before I finish the educational program Industrial Engineering & Management (MSc) at the University of Twente. After a period of almost half a year, this thesis concludes a period of hard working with many teachable moments.

This preface is meant to thank the people that were involved in the research and helped me finish this thesis. First, I want to thank my primary supervisor from the University of Twente, Matthieu van der Heijden. Thanks to his extensive feedback, guidance, constructive criticism and helpful insights, I was able to conduct my research and be of help to Jarola. I have experienced the guidance as very positive. I would also like to thank my second supervisor, Leo van der Wegen, for his feedback and help.

Secondly, I want to thank my colleagues from Jarola, who were all very helpful and enthusiastic about this project. Thanks to all colleagues, I learned a lot during my graduation period. I want to thank Rene Makkinga in particular, who was my supervisor at Jarola and was always available to help and answer questions. The guidance and feedback are much appreciated.

I hope you enjoy reading my Master Thesis.

Jethro Kiers

Management Summary

This project is executed at Jarola as graduation assignment for the Master study Industrial Engineering and Management at University of Twente. Jarola is a knowledge and trading platform for the technical market, with the biggest and most well-known subsidiary Wildkamp, a technical wholesaler. Jarola has a broad assortment of over 200,000 items. A relatively small part of the items are held in inventory (SKUs, around 20,000 items) in the distribution centre. The other part of the assortment is not held in inventory, which means that items are only ordered at the supplier if a customer has placed a sales order at Jarola. These items are called non-SKUs, items that are not stocked on purpose. The goal of the research is to increase the delivery reliability through inventory and non-inventory management (non-inventory management is the management of non-SKUs; inventory management is the management of SKUs).

Current Situation and Problem description

The goal of Jarola is to deliver orders to the customer on time. Unfortunately, it is seen in practice that the delivery to the customer does not take place as on time as wished in too many cases. The current delivery reliability (percentage of orders delivered on time) is measured as 93.6% over 2021 on average; however, there is reason to doubt the current way of measuring. Therefore, the overall problem statement given by the organisation is that the delivery reliability is found to be too low, but that there are no insights into how low this reliability actually is and that there is no insight in the causes of low delivery reliability. Since the current measurements are doubted, a new definition is presented and data analysis is performed on the resulting KPI: the shipment reliability. The data analysis shows that the shipment reliability was 89.7% over the order lines and 87.5% over the orders, which is significantly lower than the given 93.6%. For non-SKU order lines, the shipment reliability was 71.6% and for SKU order lines, this was 90.7%.

The shipment reliability is mainly low for non-SKUs, for which the promised lead time to the customer is the replenishment lead time plus two working days. The process of ordering and delivering a non-SKU order line is given in Figure i, from which it can be concluded that there are many possibilities of delays in the process, without having a safety net such as safety stock. Due to a lack of data, the realised replenishment lead time can only be measured from the moment the order is placed until the order is booked and processed (Lead time and Booking and processing time in Figure i), which means that the internal uncertainties of booking and processing time are included in this measurements. Using this method, it is found that there is a significant delay in the replenishment lead times of on average 7.1 days over 2021, compared to the average replenishment lead time that is stored in the system. The first focus of this research is therefore on the uncertainty of the replenishment lead times. Another focus is to avoid the uncertainties in the process of ordering and delivering non-SKUs, by finding a method to have the right items in stock and the right items not in stock.

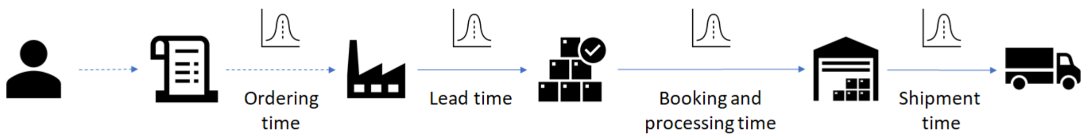

Figure i: Visualisation of ordering and shipping process of a non-SKU

Since the stocked items do not perform as expected as well, analysis is done on the inventory management at Jarola. The classification method of SKUs is analysed: SKUs are classified according to a double ABC-classification based on expected revenue and on historical order lines, using 70/20/10% and 65/20/15% distributions, respectively. Then, a final classification is created based on the combination of the classifications (Table i). A target service level (volume fill rate) is assigned to the final classification.

A remarkable finding is that one category of items that are classified as A-items only has a target service level of 85% (orange in Table i) and a B and C-item can have a target service level of 90% and 85% (red in Table i). So, the target service levels per classification have to be examined. Overall, the classification focuses on having higher service levels for items with higher revenue instead of items with higher order lines, while focusing on order lines has influence on the shipment reliability.

Table i: Double digit classification and target service levels (Volume Fill rate)

		Order lines		
		A	B	C
Rev	A	A (97%)	A (97%)	A (97%)
	B	A (97%)	B (90%)	C (90%)
	C	A (85%)	B (85%)	C (85%)

Replenishment Lead Times

Simulations are performed using the realised replenishment lead times from the moment of ordering until the moment of booking and processing (Figure i). Doing so resulted in significant increases in inventory of 12.0% (items) and 9.9% (value). From this, it can be concluded that the inventory is currently being underestimated, which can have significant effects on the realised service levels and therefore on the shipment reliability. Using the realised replenishment lead times on the shipment reliability over 2021 (only non-SKUs, since the expected shipment date of non-SKUs depends directly on the replenishment lead time), an increase is found of 12.4% over the non-stocked order lines, which also results in an overall increase of 0.9% over the order lines and an increase of 1.6% over the orders. Therefore, the replenishment lead times are recommended to be updated as soon as possible and to be kept up to date by creating a dashboard where the information of realised replenishment lead times should be displayed. When updating the replenishment lead times, fixed order and delivery days should be considered as well, such that these correspond with each other. Having clear communication lines between the purchasing, commercial, and logistics department is important to deal with this problem.

Model SKU versus Non-SKU

Since there are many uncertainties in the order and delivery process of non-SKUs, it is of high importance for Jarola to have the right items in stock. Currently, this decision is not done optimally, but mainly based on gut feeling, experience, and sales. Using existing models from literature, a profit optimisation model is determined that calculates the expected profit for an item under stocking and under non-stocking. The profit optimisation is based on the revenue minus the purchasing, holding, ordering, shortage, and partial delivery cost. The shortage cost under non-stocking includes the replenishment lead time, to incorporate that a longer lead time should tend to the decision to stock or discontinue the item. Using the expected profit, an advice is generated either to stock, to non-stock or to discontinue the item (discontinue advice is given if the profits are smaller than zero under stocking and under non-stocking). If the advice is to change the status of the item, a dashboard is created with other information on it for the decision maker to base its decision on. Other criteria that are not modelled but should be considered for the decision are substitutability, complementarity, possible purchasing agreements such as right to return, risk of obsolescence, and strategic criticality. To cope with these non-analytical criteria, decision trees are created.

Using the developed model and simulation over 2021 data an increase of 0.5% is found for the shipment reliability over the order lines and an increase of 1.0% over the orders (while only considering 3.3% of the order lines). Furthermore, the profit increases significantly (at least 6.7%) and the cost decrease significantly (at least 26.7%). The advised changes are mainly in low-valued items with low margins. These items should therefore be checked with more care.

Implementing the model should be done by periodic reviews. A schedule should be made such that every supplier is checked at least twice per year. By doing checks on weekly basis the workload is spread over the year. Furthermore, clear communication lines should be created between the purchasing, the commercial, and the logistics department to cope with the problems together.

Inventory Optimisation
It is found that the current classification and assigned target service levels are not performing as they should. Using simulations in Slim4 (inventory management software), it is found that using a double ABC-classification on revenue and order lines (same as current) with distributions 70/20/10% and 65/20/15%, respectively, but with a symmetric crossing method and consistent assigning of target service levels, the weighted average service levels increase with 0.2% (revenue), 1.7% (order lines), and 1.0% (demand). However, the inventory also increases with 2.0% (units) and 0.3% (value). The realised distributions indeed result in a better prioritised classification: 79/15/6% on revenue and 68/20/12% on order lines. Using these settings over the shipment reliability over 2021, this results is an overall increase of 1.3% over the order lines and an increase of 0.6% over the orders, which is significant, since only 15.2% of the total order lines are affected.

Since a sudden increase in inventory is not wished for, the settings are recommended to be changed step-by-step, by first changing the service level of CA-items from 85% to 91% and then from 91% to 97%. Another option would be to plan more personnel when the extra inventory is expected to arrive. Furthermore, a brief analysis on the physical stock has shown that the inventory can be reduced by decreasing inventory from non-stocked items, setting the iron stock to 0 and by decreasing other stock (which can be seasonal, strategic, overstock, etc.).

Recommendations
First of all, it is recommended to create a dashboard that shows the shipment reliability to manage according to the right information and to see if improvements have influence on the KPI. To improve the shipment reliability, it is recommended to (1) start measuring the actual replenishment lead times (from the moment of ordering until the moment the order is at the DC), (2) update the replenishment lead times or make sure that suppliers deliver on time and (3) keep these up to date by creating ownership within the logistics and purchasing department. Furthermore, it is recommended to implement and use the model to give advice on whether or not to stock an item, which can have significant effect on inventory and on shipment reliability. Lastly, it is recommended to change the settings in Slim4 for the ABC-classification and target service levels to a consistent and symmetric setting where all A-items have a target service level of 97%, B-items a target service level of 90% and C-items a target service level of 85%.

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Glossary

Word or Abbreviation	Meaning / definition
DC	Distribution Centre
SKU	Stock Keeping Unit – "an item of stock that is completely specified as a function, style, size, colour, and, often, location." (Silver, Pyke, & Thomas, 2017, p. 28)
Non-SKU	Non-Stock Keeping Unit - an item that is not stocked on purpose
B2B	Business-to-Business – business makes a commercial transaction with another business.
B2C	Business-to-Consumer – business makes a commercial transaction directly to a consumer.
ERP	Enterprise Resource Planning – software
VFR	Volume Fill Rate
OLFR	Order Line Fill Rate
MOQ	Minimum Order Quantity
EOQ	Economic Order Quantity
IOQ	Increment Order Quantity
ATP	Available-To-Promise – The quantity of an item that can be promised to the customer at that specific point in time.
ABC-classification	Method to classify SKUs in terms of how high the priority of the item is.
Cross-docking	The process of receiving and almost immediately shipping an order line, without stocking the item.
Slim4	Inventory management software by SlimStock
Replenishment lead time	Lead time to replenish the inventory at the distribution centre by ordering new inventory at the supplier.
Customer lead time	Lead time to ship/deliver a sales order to the customer, from the moment the order is placed.
Non-inventory management	The management of non-SKUs
Partial Delivery	When a sales order needs multiple deliveries to fully deliver the sales order, all extra deliveries are considered as partial deliveries.
R,s,Q policy	An inventory policy with a review period, a reorder point and a fixed order quantity.
Review period	The days between reviewing whether the SKU needs replenishment.

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1 Introduction

This thesis is written as graduation assignment for the Master Industrial Engineering and Management, which is followed at the University of Twente. The assignment is executed at Jarola Group.

1.1 Jarola Group

Jarola Group is the holding of different subsidiaries, together they aim to be a knowledge and trading platform for the technical market. Jarola's headquarters is located in Lutten. The largest subsidiary is Wildkamp, which is a technical wholesaler. They sell products from more than forty different stores all over the Netherlands and use their web shop and app to enable e-commerce. The second largest subsidiary is Jarola Sales, which is focusing on customisation. Together with service and support they are delivering products to mainly retailers and smaller wholesalers. All stores and all customers of the Jarola Group are supplied by a 63.000 m^2 distribution centre located in Coevorden (NL). Jarola Central Services B.V. is a supporting subsidiary of Jarola Group, which is responsible for supporting tasks within the group such as logistics, ICT, facility management, and human resources.

The supply chain of Jarola is visualised in Figure 1. Transport from the suppliers towards the distribution centre (DC) is done by truck and is the responsibility of the suppliers; however, for some suppliers an agreement is made that Jarola handles the transport from the supplier to the DC. Transport from the DC towards the Wildkamp stores is done from Monday until Friday in the night by truck. This stream consists of replenishment for the stores and of finished orders that are picked up by customers at the store. Packages are also sent directly to the customers, if the shipment can be done by package. If the shipment is too large, the shipment is done by truck (pallets). Some stores are supplied directly by some suppliers, depending on the volume and the sales.

Strategically, Jarola aims to have the broadest and largest assortment. Also, they are focusing on knowledge directly available to the customer. To be able to deliver goods to the customer quickly, a part of the assortment of Jarola is held in inventory. Currently, there is too little space in the DC for all inventory. To overcome this, some of the inventory is stored at other (external) warehouses. If items that are stocked in these warehouses are ordered, the items are picked there and then shipped to the DC to be shipped to the customers. If items are not kept in stock, the items are only ordered at the supplier when a customer orders that item. Items that are not stocked on purpose are called *non-SKUs.* This non-SKU is then shipped to the DC to be cross docked towards the customer.

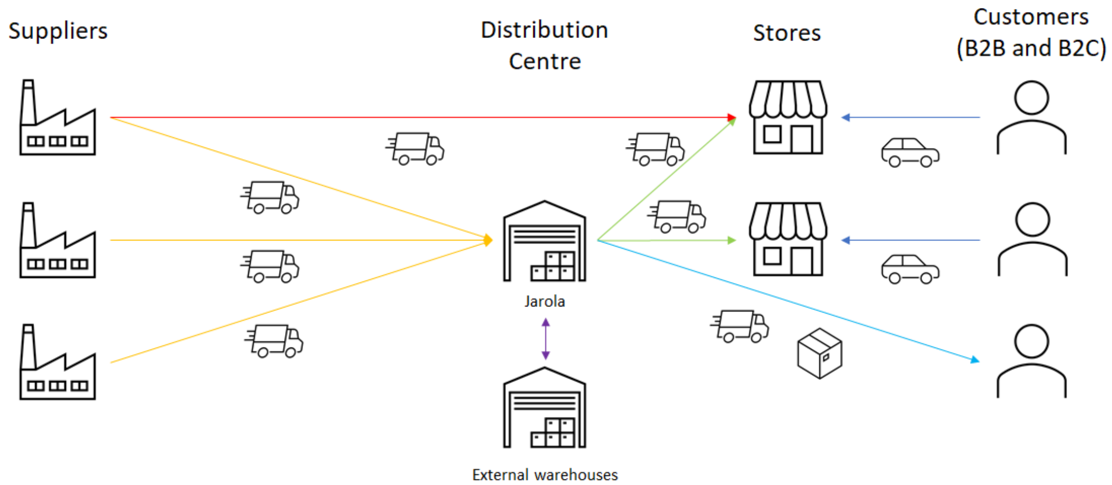

Figure 1: Visualisation of the Supply Chain

Due to the space constraints in the current DC, Jarola has almost finished building a new distribution centre. In the new DC, the picking process is largely changed towards goods-to-man instead of man-to-goods by using a robotic system. Also, space is created such that the capacity is no longer constrained by space. If this project is finished, the goal is to store the inventory that is now stored externally, internally again.

Inventory is managed using Slim4, which is inventory management software by SlimStock. This software helps Jarola creating a forecast for every SKU and to determine how many and when to order for every SKU. The inventory planning team manages the inventory and looks at outliers and exceptions and checks the ordering of items on daily basis. The inventory planning team is also responsible for ordering non-SKUs at the supplier after a customer has placed an order.

1.2 Research Motivation

Jarola's goal is to deliver *on time*. Unfortunately, it is seen in practice that the delivery does not take place as *on time* as wished in too many cases. The average percentage of sales orders delivered on time over 2021 according to the current measurements was 93.6%. However, there is reason to doubt the current way of calculating the delivery reliability towards the customer at Jarola. Currently, the delivery reliability is calculated based on whether the order is delivered on the date that was suggested by the ERP system. However, in principle Jarola promises the customer fast delivery (e.g., stocked items should be shipped the same day, provided the order is placed before 8PM). If the ERP system suggests otherwise due to e.g., a stock out, the goal of fast delivery is not met, however, the delivery reliability is not necessarily lowered. Due to this, it is expected that the actual delivery reliability is lower than the given 93.6%. Also, there is no insight in how much too late the sales orders are delivered nor is there insight in what the actual cause of delivering too late is. Delivering too late has influence on multiple departments throughout the organisation and, most importantly, on the customer, which makes the problem in the organisation important. The logistics department has extra work and costs, and the commercial department has extra work by satisfying the customer and by working ad hoc with exceptions.

To be able to reach the goal of delivering on time, Jarola holds inventory. When all items of a sales order are in stock and available, the earliest possible shipment date is the same day, provided the order is placed before 8PM on a working day. If all items are in stock and available, but a sales order is placed after 8PM, the earliest possible shipment date is the working day after. However, as mentioned before, not all items that are sold by Jarola are in stock. Jarola sells over 200,000 items, which makes it impossible to keep all items in stock. Also, a large part of the assortment are items with low demand, which makes it very expensive with respect to the revenue that is made for these items to keep all those in stock. Items that are not stocked on purpose are called non-SKUs.

Looking at the percentage of orders delivered on time using the current measurements, the average percentage of orders with non-stocked items in it is 76.0%, while the average percentage of orders with stocked items in it is 94.8%. In 2021, 1.3% of the total order lines were non-SKUs. Since non-SKUs are ordered directly at the supplier to be cross docked to the customer, the question that arises is if the replenishment lead times are correct. It is found that Jarola does not measure the realised replenishment lead times, while, based on employees' opinions, not all suppliers deliver according to the replenishment lead time that is in the system. Another question that arises is if all non-SKUs are justifiable not in stock, or if some non-SKUs should be changed into SKUs. As mentioned before, Jarola sells over 200,000 different items and there exists a space constraint. Therefore, it is of big importance for Jarola to have the *right* items in stock and the *right* items not in stock.

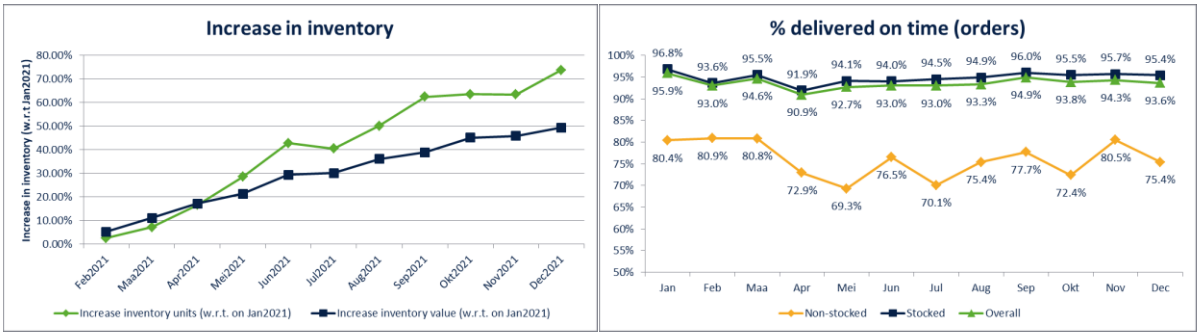

Figure 2: (a) Increase in inventory (green=units, blue=value), and (b) % of orders delivered on time (2021)

On top of the above, inventory has risen significantly in the past years. Due to raw material shortage and COVID uncertainties, Jarola has been sourcing extra inventory in the past year (2021). This has led to an increase of the total inventory of 74% (units) and 49% (value). This leads to the expectation that the delivery reliability for stocked items has risen as well; however, this is not the case. This means that the inventory management should also be analysed. In Figure 2, it can be seen that (a) the inventory has risen significantly and (b) that the percentage of orders delivered on time has not. Note that the percentage delivered on time is based on current measurements and definitions.

1.3 Problem Statement

The problem statement given by the organisation is that the delivery reliability is found to be too low, but that there is no insight into how low this reliability actually is due to currently using a definition that does not correspond with the goals/strategy/marketing of Jarola and that there is no insight in the causes of a low delivery reliability.

Firstly, there is reason to believe that the realised replenishment lead times differ from the replenishment lead times in the system; however, no measurements are done in the current situation to find the actual cause and to be able to cope with possible deviations.

Secondly, after research on the low reliability based on present data, it is found that mainly non-SKUs have a low delivery reliability. Further research shows that the process of ordering and delivering non-SKUs contains multiple possible sources of uncertainty and delays, without having a safety net such as safety stock. On top of that, interviews show that the decision to keep an item in stock or not is only based on sales or on gut feeling. Also, data analysis shows that there are both SKUs and non-SKUs that might be better off being changed to the other status. This decision is therefore not done optimally. Therefore, due to having multiple possible sources of uncertainty and delays and no safety net, it is of high importance for Jarola to have the right items in stock and the right items not in stock, however, the decision for determining whether or not to stock an item is currently not done optimally.

The third problem statement focuses on inventory management, since there has been a significant increase in inventory, while the delivery reliability has not increased. Therefore, the parameters that are used for the inventory management for SKUs must be analysed. The main direction is into the parameters such as target service levels, order quantities, and classifications.

1.4 Research Goal, Deliverables and Research Questions

The goal of this research is to improve the delivery reliability to the customer by inventory and non-inventory management (non-inventory management is the management of non-SKUs, like inventory management is the management of SKUs). Therefore, the main research question is:

How can Jarola improve the delivery reliability to the customer?

To achieve this, the following goals are determined:

1. The first goal is to clearly define delivery reliability towards the customer for Jarola. To increase delivery reliability and to measure the current performance, a clear definition needs to be present. The definition mainly consists of when an order (line) is considered to be on time. Furthermore, a concept dashboard will be delivered with the most important shipment reliability KPIs, measured over 2021.
2. The second goal is to find out how Jarola can cope with uncertainty in the replenishment lead times. This is a possible cause for the non-SKUs being too late and a possible improvement for the inventory management, which should lead to less backorders. A recommendation on how to update and keep the replenishment lead times up to date will be delivered.
3. The third goal is to define a clear process on how to determine whether an item should be kept in stock or not. This means that a model will be determined that is based on certain criteria and requirements. Having the right items in stock and the right items not in stock helps avoiding the uncertainties that are present in the process of non-SKUs and should therefore help increasing the delivery reliability. This includes providing a prototype model that gives an advice on whether or not to keep an item in stock, including an implementation plan.
4. The fourth goal is to analyse and improve Jarola's inventory management. It will be examined which parameters are not optimal/accurate. The focus will be on parameters that are input by Jarola for Slim4. The goal is to give insights on how these parameters can be improved and what influence this has on service levels, inventory levels, costs, and possibly the delivery reliability. A recommendation on what settings should be changed in Slim4 to increase service levels and the delivery reliability will be provided, including the expected influence on the inventory (costs).

To obtain the abovementioned research goals, the following research questions are formulated:

1. **Current situation/Problem analysis**

   1a. How can delivery reliability be defined at Jarola and what is the realised delivery reliability?
   The definition of delivery reliability is a management decision. Therefore, management will be given a proposition to define delivery reliability. The result will be a clear definition when an order line is considered to be delivered on time. When this definition is clear, data analysis will be performed to determine the realised delivery reliability over data from 2021.

   1b. How reliable are the replenishment lead times and is it needed to incorporate uncertainty in lead times into the (non-)inventory management models?
   Currently, it is not measured what the realised replenishment lead times are. This will be analysed to see if it is necessary to incorporate uncertainty or standard delays in replenishment lead times into the (non-)inventory management models. Since Slim4 can be used to cope with possible deviations, no literature review is needed on this topic.

   1c. How does Jarola cope with non-SKUs?
   Jarola does not hold inventory for all items. It is necessary for the remainder of the research to know how non-SKUs are coped with, or, how the non-inventory management is done.

   1d. How does Jarola determine whether or not to keep an item in stock?
   This question will be answered by conducting interviews with the responsible persons in the organisation. These persons are the commercial manager and the buyers, who are currently responsible for this decision.

   1e. How does Jarola manage their inventory?
   The Purchasing department, coordinator Inbound and the Logistics manager will be interviewed to answer this question. They are responsible for the inventory management. Slim4 is the software that is used, this software will be analysed as well to answer the question. The goal of this research question is to find which parameters in the inventory management are not optimal.

2. **Literature**
   2a. What methods are present in literature to decide whether an item is an SKU or a non-SKU?
   A literature review will be conducted on existing models for keeping an item in stock or not. This is (1) to search for decision criteria and (2) to find existing models. An overview will be given, and this will be used to answer RQ 4.
   2b. What methods are present in literature to classify SKUs?
   The focus for improving the inventory management is on the inventory classification and the target service levels. A literature review will be conducted on what methods are present in literature to classify SKUs (e.g. ABC) and an overview will be given.
3. **Coping with deviations in replenishment lead times**
   3a. What is the effect of having deviations in the lead times on the inventory and on the shipment reliability?
   The uncertainty in the lead times can be implemented using Slim4 software. Using this, simulations will be performed to see what effects uncertainties in lead times have on the inventory. Using the realised replenishment lead times, the effect on the shipment reliability will be simulated as well.
   3b. How can the shipment reliability be improved considering deviations in replenishment lead times?
   Since the goal of the research is to improve the shipment reliability, a method to cope with deviations in replenishment lead times must be determined.
4. **Model SKU vs. Non-SKU**
   4a. What criteria are there for a model for keeping an item in stock or not?
   To determine an optimal model, the criteria must be specified. This will be done by conducting interviews with the buying, commercial, and logistical department, by using the results from RQ 2a., and by data analysis.
   4b. How can the decision whether or not to keep an item in stock be improved?
   Based on RQ 2a., RQ 4a., and data analysis a model will be determined to give advice on whether or not to keep an item in stock or not. This includes creating a prototype model.
   4c. What are the correct input parameters for the model?
   The model that is determined needs the holding, ordering, shortage, and partial delivery costs. Also, it needs the probability of a partial delivery happening and the realised replenishment lead times. These parameters are determined to be able to evaluate the model.
5. **Evaluation and Implementation Decision model SKU vs. Non-SKU**
   5a. For which items should an advice be generated?
   To evaluate the model and for the implementation, a specified set of items needs to be determined.
   5b. How can the validity of the model be ensured?
   Before results can be discussed, the model needs validation. The validation will be done by comparing expert opinions with the outcomes of the model and by basing the model on models found in literature (RQ 2a.).
   5c. What are the effects of the decision model on the shipment reliability and costs?
   To know what effects the advices generated by the model have on the shipment reliability and on the costs, simulations will be performed over the 2021 dataset.
   5d. How sensitive is the decision model to the input parameters and what are the model's limitations?
   The model requires input parameters. To see what effect the input parameters have on the generated advices, a sensitivity analysis will be performed. Furthermore, the limitations of the model are discussed.

5e. How can the model to decide whether or not to keep an item in stock be implemented in the organisation?
Based on the findings and conclusions, an implementation plan will be determined.

6. **Inventory optimisation**

6a. What are the effects of changing the classification and the target service levels on the inventory (costs), the weighted average service levels, and the shipment reliability?
To improve the inventory management, settings need to be changed. Through simulations in Slim4, the effects of changing the classification and the target service levels will be simulated. Based on these effects a recommendation will be given.

6b. What is the effect of changing the holding and ordering cost on the inventory (costs)?
To improve the inventory, settings need to be changed. Through simulations in Slim4, the effects of changing the holding and the ordering costs will be simulated. Based on these effects a recommendation will be given.

6c. How can the total inventory be decreased?
The goal of this research is to increase the delivery reliability; however, the inventory of Jarola has risen significantly. To justify an increase in inventory to increase the delivery reliability, other inventory might be needed to be decreased. Analysis will be performed on how the current inventory is built up, by categorising the inventory.

1.5 Scope

- Since a new DC is currently being built, inventory locations and outbound processes are not inside the scope of this research.
- To determine whether or not an order is considered to be on time, in the optimal situation it should be known if the customer wanted his order earlier than the minimum expected shipment date. This is mainly the case for the non-SKUs, which have standard longer lead times. A customer survey could be conducted to try and estimate the customer's wish for these items; however, this will be left out of the scope of this research.
- Only the most common item statuses are considered in this research. Items that are e.g., outlet or customer-specified are left out of the scope (item statuses larger than 131 in Appendix A are left out).
- For the inventory management, only input parameters that are the responsibility of Jarola are analysed. Also, it is assumed that the forecasts are not part of the problem.
- The transportation costs are only determined for a specified set of suppliers, due to determining these is manual and time-consuming work.
- The inventory management considered in the research is solely focused on the management of the inventory at the distribution centre. Inventory kept at the stores is not included.
- For determining whether or not an item should be kept in stock, a model is developed only for existing assortment. New assortment is too dependent on human judgement to create an analytic decision rule. Also, the model for keeping an item in stock or not will be developed for and tested on slow moving stocked items and non-stocked items that are sold at least once in 2021. Furthermore, the model can only give an advice. Consequently, this will not be fully implemented, but an implementation plan will be inside the scope.

1.6 Reader's Guide

The remainder of this thesis is structured as follows.

In **Chapter 2**, the current situation is analysed, including setting a base line for possible improvements in later chapters. Furthermore, current processes are analysed to define the problem more specifically. The chapter is concluded by answering research questions 1a-1e.

In **Chapter 3,** a literature review is conducted to gain knowledge on how to decide whether or not to stock an item, since having the right items in stock is of high importance for Jarola and this is currently not done optimally. Furthermore, a literature review is conducted to gain knowledge on how to classify SKUs, since this is the focus for improving inventory management. Research questions 2a and 2b are answered in this chapter.

In **Chapter 4**, since the replenishment lead times are found to be deviating significantly, the effects of uncertainty in the replenishment lead times are simulated and an improvement plan is formulated. Research questions 3a and 3b are answered in this chapter.

In **Chapter 5**, using the obtained knowledge from literature and the knowledge from analysing the current situation, a model is created to give advice on whether or not to stock an item. Criteria that are needed for the model are formulated. The model created needs input parameters such as ordering, holding and shortage cost to be able to evaluate the model. Therefore, these parameters are determined. Research questions 4a-4c are answered. In **Chapter 6** the model created in Chapter 5 is evaluated to check whether or not the model improves the shipment reliability. This is done by simulation over the data from 2021. Furthermore, the model is analysed on its sensitivity for costs and inventory, based on target service level. Also, an implementation plan is described.

In **Chapter 7**, the settings for the inventory management are further analysed. Simulations are done to improve the classification, target service levels, and the calculation of the EOQ, with the goal to improve the delivery reliability by reducing the number of stock outs. Furthermore, a brief analysis is done on how to decrease inventory.

Finally, in **Chapter 8**, based on the findings and on the implementation plan, conclusions and recommendations are described and presented to Jarola. Lastly, the research is discussed and suggestions for further research are presented.

2 Current situation at Jarola

In this chapter, the focus is on how Jarola manages its processes in the current situation with the goal to find the root cause of a too low delivery reliability. First, the definition of delivery reliability towards the customer is determined and measured (Section 2.1). Second, the uncertainty in replenishment lead times is analysed and it is determined whether this should be incorporated into Jarola's (non-)inventory management (Section 2.2). Third, the way Jarola copes with non-SKUs is researched (Section 2.3). Thereafter, the current way Jarola decides between keeping an item in stock or not is analysed (Section 2.4). Lastly, the way inventory is managed is analysed (Section 2.5).

2.1 Defining and measuring delivery reliability

The current way of measuring the delivery reliability does not consider the organisation's goals. To this end, the research question that will be answered in this section is *How can delivery reliability be defined at Jarola and what is the realised delivery reliability?* First, the delivery reliability is defined (Subsection 2.1.1). Second, the delivery reliability is measured based on the definition (Subsection 2.1.2). Lastly, a cause analysis on why the reliability is too low is conducted (Subsection 2.1.3).

2.1.1 Defining delivery reliability

In principle, delivery reliability is the percentage of sales orders that are delivered on time. From this, it immediately follows that the definition depends on when an order is considered to be on time and when it is considered to be too late. Currently, this is based on the expected shipment date according to the Available-To-Promise (ATP) in the ERP system. The ATP is the quantity of an item that can be promised to a customer at that point in time, considering among others incoming purchase orders, outstanding sales orders to customers and inventory on hand. The expected shipment date is then the first date that the ATP is expected to be greater than or equal to the ordered amount.

If the actual shipment date is earlier than or equal to the expected shipment date, the sales order is considered to be on time. However, using the ATP for measuring how often an order is delivered on time means not considering the strategy/goals of the organisation to e.g., ship the same working day if the order is placed before 8PM. This means that if an SKU is out of stock and the customer wishes to have the item tomorrow, it can still be considered as on time, since the ATP will create an expected shipment date at the moment that the inventory is expected to be sufficient to fulfil the sales order (which can be in e.g., three weeks). Furthermore, the current way assumes that all sales orders that are shipped today are delivered tomorrow, or in other words, it is assumed that the forwarders have a reliability of 100%. The values in Figure 2(b) are based on this definition (both using the ATP and that the forwarders have a reliability of 100%). Since the current way does not represent the real performance, a new definition needs to be determined.

Jarola outsources the distribution of the sales orders to the customers and the stores. This leads to an internal and an external part of the delivery process. To distinct between the internal and external process, the definition needs to be split into a *shipment reliability* and a *forwarder reliability*. The *delivery reliability* is then the total delivery reliability towards the customers, which includes the internal and external results. These three KPIs will be discussed separately.

Shipment reliability

Two problems arise when determining whether or not a sales order is considered to be shipped on time. First, a sales order consists out of one or more order lines, which can be either SKUs or non-SKUs. Secondly, a sales order can be delivered in parts or not. Customers can choose whether or not they wish to have the order in parts in case (a part of) one of the order lines is not available or a non-SKU is present in the order. Therefore, to determine whether or not an order is considered to be shipped on time, it needs to be determined when an order line is considered to be shipped on time.

To do so, first a distinction is made between SKUs and non-SKUs. The distinction is about the status of the item, not about whether it is actually in stock or not. So, an SKU that is out-of-stock is still an SKU for the determination of the shipment reliability. In case an order with only SKUs is placed via the web shop, the promised shipping date to the customer is the same day, if the sales order is placed before 20h on a working day. A customer can provide a later date, if that is the customer's wish. Therefore, the expected shipment date of an SKU order line is the customer's wish or the same working day, whichever is the latest. For a non-SKU, the web shop promises the customer the replenishment lead time of the non-SKU at Jarola's supplier plus two days (to cover ordering and cross-docking time), only considering working days. In this case, it is also possible for the customer to provide their wish, provided that this is higher than the replenishment lead time plus two working days. Therefore, the expected shipment date of a non-SKU order line is the customer's wish or the replenishment lead time plus two working days, whichever is the latest.

A point of discussion is if the use of the replenishment lead time plus two working days is realistic, since purchase orders are often placed according to a fixed order and delivery schedule. This means that the customer lead time might be lower than the actual lead time. On the other hand, the replenishment lead times that are in the system are not in working days, while the customer lead time does consider only working days. Another point of discussion is that this expected shipment date is not considering if the customer's wish is sooner than the minimum expected shipment date. To measure this, it is necessary to perform a customer survey. However, this is outside the scope of this research.

The next problem to be dealt with is the option to deliver an order in parts or not. If an order is delivered in parts, all order lines can be considered as single sales orders for determining the expected shipment date. Of course, order lines are consolidated if they are shipped on the same day. If e.g., a sales order consists out of an order line with 3x SKU A and an order line of 2x non-SKU B, the order line with the SKU should be sent the same day, while the non-SKU order line will be sent later, after the item is ordered at and received from the supplier. In the case of partial deliveries, the sales order is considered to be on time if all single order lines are considered to be on time. Partial deliveries are costly and should therefore be minimised.

If a sales order is not to be sent in parts, the order is considered to be shipped on time if the maximum expected shipment date of all order lines is met. Using the same example sales order as before, but now with no delivery in parts, the order is considered to be on time if the complete order is shipped on the order date plus the replenishment lead time of non-SKU B plus two working days. It is likely that partial deliveries are happening more often when a non-SKU is in the order, since this order line extends the expected shipment date significantly (with the replenishment lead time plus two working days). If this is actually the case will be analysed in Subsection 2.4.3.

This leads to three different order types (in all cases, the maximum of the customer wish and the given expected shipment date is used):

1. **Sales order with only SKUs as order lines, placed before 20h.**
   Order is shipped on time if shipped the same day (only working days). In this case, delivery in parts does not have any influence as all items have the same expected shipment date.
2. **Sales order with non-SKUs and possibly SKUs as order lines with delivery in parts.**
   Order shipped on time if single order lines are shipped on time, according to replenishment lead time plus two working days (non-SKUs) and same working day (SKUs).
3. **Sales order with non-SKUs and possibly SKUs as order lines without delivery in parts.**
   Order shipped on time if order is shipped on maximum expected shipping date of the order lines.

Until now, all items, order lines, and orders are assumed to have the same weight in the determination of the reliability. It might, however, be fairer and more realistic to calculate a weighted average with e.g., the demand of the item as weight. Another option is to weigh strategically important products more in the determination of the delivery reliability. However, for this research all items, order lines, and orders are considered to have equal weight.

Forwarder Reliability

To determine the reliability of the forwarders, the actual shipment dates should be used. This is to exclude the internal process from the reliability, since this is already determined in the shipment reliability. The forwarder reliability is then the percentage of shipments that are delivered on time, given the realised shipment date, where on time is basically the next working day (two exceptions: (1) a sales order placed on Saturday or Sunday is delivered on Tuesday and (2) a sales order placed on Friday can be delivered on Saturday or Monday). Unfortunately, due to a lack of data, the above cannot be calculated. Fortunately, the defined goal of this research does not influence the forwarder reliability. It is, however, recommended to implement a link between the forwarders' and Jarola's systems to automatically communicate the actual delivery dates per sales order (line), since this is an important part of the overall delivery reliability to the customer.

Delivery reliability

The overall delivery reliability is the percentage of the sales orders that are delivered on time. For the calculation of this KPI, the expected shipment date should be used instead of the actual, to get an overall performance measurement. Then, the actual delivery date must be compared with the expected delivery date. However, as mentioned, no data is available for the actual delivery date. Therefore, for the remainder of this research, the shipment reliability is used as main KPI.

2.1.2 Measuring shipment reliability

Since no actual delivery dates are available, only the shipment reliability can be measured. A large dataset containing all sales order lines placed in 2021 with corresponding data is provided. The dataset did not contain the transfer orders (which are replenishment orders for the stores). Using only the sales orders gives a valid result, since the main goal is increasing delivery reliability to the customer, and the sales orders are directly sent to the customer or picked up by the customer at the store. The structure of this dataset and the details of the data analysis are given in Appendix B.

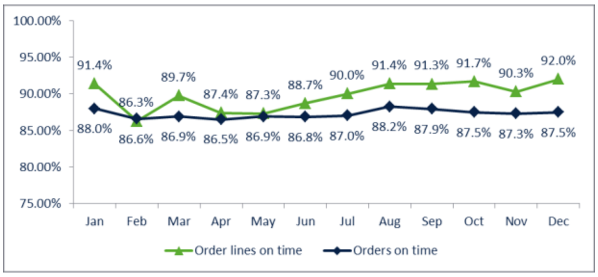

Figure 3: Shipment reliability order lines and orders 2021

The non-weighted shipment reliability for the order lines was 89.7% in 2021; the reliability per month is given in Figure 3. The shipment reliability over the orders is almost always lower than the reliability over the order lines (overall 2021 87.5%). On average, an order consists of 3.6 order lines (2021). Clearly, these results are lower than the currently used performance measurements (Figure 2(b)).

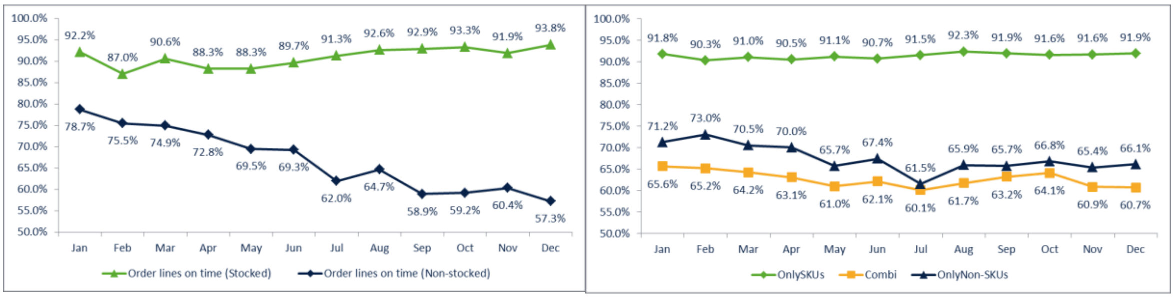

Figure 4: Shipment reliability (a) order lines stocked versus non-stocked 2021, (b) orders per order type 2021

Figure 4(a) gives the shipment reliability over the order lines for non-stocked and for stocked items. The order lines with non-stocked items have a much lower reliability than the stocked items, which is as expected. Probably, the cause of the decreasing reliability is due to supply issues which are caused by COVID. However, there is no evidence for this, as the realised replenishment lead times are not measured. Another possible cause is, as already mentioned, that the replenishment lead time plus two working days might not be realistic due to fixed order and delivery days. Figure 4(b) gives the shipment reliability per order type, which can be an order with only SKUs, an order with both SKUs and non-SKUs (combi), and an order with only non-SKUs. Orders with only SKUs perform constant and above average, while orders with only non-SKUs perform worse. Orders with both SKUs and non-SKUs perform even worse than orders with only non-SKUs, from which it can be concluded that the main cause of shipping combined orders too late is probably due to non-SKUs.

2.1.3 Causes of low reliability

To be able to act on the shipment reliability being too low, the causes must be determined as well. Possible causes of an order line being too late specifically for SKUs are:

1. *Inventory on hand was too low at expected shipping date, outlier (very large order quantity)*
   An outlier is a very large order quantity compared to the average order quantity of that item. If this happens one time, no actions have to be taken; however, if this happens often, the inventory of that item should be adapted to be able to cope with outliers.
2. *Inventory on hand was too low at expected shipping date, actual stock differed from digital stock*
   It can happen that the actual stock differs from the digital stock, due to e.g., an earlier order being picked wrongly. There are procedures in place to minimise the times that this happens by preventing and by counting.
3. *Inventory on hand was too low at expected shipping date, no outlier, no stock difference*
   If the inventory on hand was too low at the shipping date and there was no outlier and no stock difference, the inventory planning team should look at the inventory management for that item. There are many possible causes, e.g., it could be that an item is not available at the supplier, but it could also be that the forecast is wrong.

And the causes for non-SKUs order lines being too late are:

1. *The realised replenishment lead time was larger than the replenishment lead time in the system*
   If this is the case, it is advised to check if the replenishment lead time in the system is still up to date. If this is correct, and the historical realised replenishment lead times are also too high, measures should be taken by the purchasing department with the supplier to prevent future problems.
2. *The supplier has (a) fixed order- and/or delivery day(s) or a minimum order amount*
   Suppliers can have a fixed delivery schedule, e.g., the supplier always delivers orders on Tuesdays and Thursdays. If this is the case, the communicated replenishment lead time plus two working days might no longer be valid. Also, suppliers can have a minimum order amount which has to be ordered before the order is shipped.

3. *The non-SKU was ordered at the supplier too late*
   If the inventory planning team orders the non-SKU at the supplier e.g., three working days after the order is placed, the item will not be at the DC in time and therefore not shipped to the customer on time. Ordering too late can also be due to a fixed order day.
4. *The non-SKU was in the warehouse, but not processed by the inbound department yet*
   Incoming orders must be booked and processed by the inbound department, before they can be processed further. If this is not done the day of arrival, the item cannot be shipped the same day, which leads to the order being shipped too late.

For SKUs, all causes above are based on inventory being too low. In principle, all orders that must be shipped today, are picked and shipped today. However, there are many other possible causes for shipping too late. A main possible other cause is that when orders are only delivered when complete and one order line/item is out of stock or a non-SKU, the entire order is delayed. Another example is that currently, due to the space constraints, some inventory is stored at other warehouses. However, all shipments are done from the DC, so if an item is stored at a warehouse and the order is placed after the daily shipment to the DC is done, the item will arrive at the DC the next working day, resulting in a late shipment, while the inventory was sufficient. A last cause can be that the order line is picked too late due to e.g., personnel shortage; however, this happens very rarely.

To be able to determine the cause of the order line being too late, data is needed. Very important is the inventory on hand at the moment the order was placed and on the expected shipment date. Also, it must be determined when an order quantity is considered to be an outlier. Under the assumption that the order line size follows a certain distribution with mean μ and standard deviation σ, these parameters can be used to determine the interval $[\mu - k\sigma, \mu + k\sigma]$ using a factor k. Then, if an order line size is outside the interval, it is an outlier. Unfortunately, historical data about the inventory on hand is not available. Also, the realised replenishment lead time cannot be determined by historical data (deviations in replenishment lead times will be analysed in Section 2.2). To overcome this, the cause should be determined at the moment the order is being delayed, such that only the resulting cause must be saved, instead of all historical inventory on hand.

To be able to find possible causes in the used data (over 2021), other steps are taken. First, the shipment reliability is determined per supplier. This is not the supplier reliability; however, it could give an indication for which suppliers perform worse than others. Table 1 gives the largest three suppliers based on the number of sales order lines with non-stocked items in 2021. These top three suppliers are responsible for 13.8% of the sales order lines with non-stocked items.

The results of Supplier B are not good, since the reliability for non-stocked is 41.4%. Remarkably, the reliability of sales order lines with stocked items is also too low (80%) for Supplier B (the impact is significantly lower, since only 0.3% of the stocked sales order lines are supplied by Supplier B). On top of that, if the sales order line is shipped too late, this is done on average 9.3 days too late (the overall average is 5.8 days). Therefore, there is indication that this supplier is not performing as it should be, however, this could also be due to internal processes, such as ordering or processing too late (see possible causes for non-SKUs being too late). In Table 2, the three largest suppliers based on the number of sales order lines with stocked items are shown. They are responsible for 31.3% of the sales order lines with stocked items, with a combined shipment reliability of 91.6%.

Table 1: Shipment Reliability per supplier (sorted on highest % of non-stocked order lines)

Supplier	% Order lines stocked	Reliability stocked	% Order lines non-stocked	Reliability non-stocked
Supplier A	1.0%	90.4%	5.1%	100.0%
Supplier B	0.3%	80.0%	4.5%	41.4%
Supplier C	1.5%	91.3%	4.2%	50.7%

Table 2: Shipment Reliability per supplier (sorted on highest % of stocked order lines)

Supplier	% Order lines stocked	Reliability stocked	% Order lines non-stocked	Reliability non-stocked
Supplier D	13.7%	92.2%	0.9%	59.8%
Supplier E	9.6%	92.0%	0.7%	43.9%
Supplier F	8.0%	90.3%	1.3%	80.4%

Not including Supplier B in the analysis would result in an overall non-stocked shipment reliability over the order lines of 73.0%, which would be an increase of around 1.4%. Overall, the reliability over the order lines would have been increased with 0.1%. This is still rather significant, given that only 0.5% of the total order lines in 2021 were coming from Supplier B. The stocked reliability of the largest two suppliers (D and E) are higher than the overall stocked reliability (90.7%), which means that excluding these from the analysis would result in a lower reliability. If more sales order lines are coming from a supplier, probably purchase orders are placed more often at that supplier as well, which decreases the risk of a long-term stock-out. However, the non-stocked reliability of suppliers D and E is lower than the overall non-stocked reliability (71.6%). This can be since non-stocked items do not have safety stock, while stocked items do have safety stock. Again, the low shipment reliability for non-stocked items can be due to orders placed or process too late, due to lead times being not correct or not made by the supplier, or by having fixed ordering and/or delivery days, etc.

Looking at the origin of the sales order, a low reliability is found for orders coming from Order2Cash (orders placed by larger customers via an XML-file). Order2Cash is responsible for 7.2% of the sales order lines, with a reliability of 72.6%. Not including these order lines in the analysis would result in an overall shipment reliability of 90.8% over the order lines, an increase of 1.1%. Another origin, sales orders that are read from a PDF-file, also has a low reliability of only 42.7%, while being responsible for only 0.4% of the order lines. However, both these sales orders are mainly from the subsidiary Jarola Sales. Not considering this business unit in the analysis would increase the overall shipment reliability to 91% over the order lines, an increase of 1.3%.

When looking at how much too late order lines are shipped, it is remarkable that more than 50% of the late order lines with stocked items are sent one day too late. A remarkable finding is that 80.6% of the late Order2Cash and read in order lines are late only one day. This is 31.1% of all order lines that are late one day (from Table 3), while being responsible for only 7.5% of the total order lines. A cause could be, although not an excuse, that these orders are often large (on average 11.9 order lines) and wanted as soon as possible (expected shipment date is in 91.8% of the orders the same day). Based on 20 randomly picked orders that are one day late, it is found that the causes are mainly due to stock outs (11/20). A stock out for one item can also cause the entire order to be too late, if the order has the setting to deliver only if complete. Another cause is having to pick from another warehouse, which is considered as a stock out. There are also cases where the order was actually shipped the day before but was booked too late (3/20). The causes cannot be quantified due to that finding the cause has to be done manually and is very time consuming. There are also orders for which the actual reason is still unknown (6/20). For now, the assumption is made that the cause is mainly due to stock outs.

For the non-stocked items, only 18.6% of the late order lines are shipped one day too late. The average days too late is 6.0, while the average replenishment lead time of the late items is 3.9 days. This means that the late order lines with non-stocked items are on average more than 1.5 times the replenishment lead time too late (while this lead time was already considered in the expected shipment date). This again points to the indication that the replenishment lead times in the systems are not realised and/or the order is placed/processed too late. It is important to note that only working days are considered, while the replenishment lead times in the system are in calendar days.

Table 3: Cumulative percentage of late order lines with at most x working days too late

Days too late	1	2	3	4	5
Stocked	55.9%	66.0%	73.3%	78.2%	82.4%
Non-stocked	18.6%	35.7%	50.0%	61.9%	70.7%

To conclude, the causes that are found are still rather broad. The actual cause of shipping one day too late many times cannot be traced back due to lack of data. Therefore, we assume that this is mostly due to a stock out (in case of SKUs). The other causes all focus on having the right amount in stock and on the reliability of the replenishment lead times.

2.1.4 Dashboard

Using the data and the calculations, a concept dashboard is proposed to Jarola (Figure 5). Using this dashboard, the most important KPIs concerning shipment reliability can be followed by management and steps can be taken to improve them. Next to the shipment reliability (over order lines, orders, and stocking status), the average number of days a shipment is shipped too late is added. Logically, this KPI should be as low as possible. Another added KPI is the average number of order lines per order. Also, the number of partial deliveries is added, since this is an important cost related KPI and should therefore be minimised. Lastly, the causes are added to the dashboard. However, due to a lack of data, these are based on sample data (randomly generated). It is highly recommended to implement a way to determine the causes, such that actual data can be used. Having insight in these causes gives management and the inventory planners clear directions for improvement.

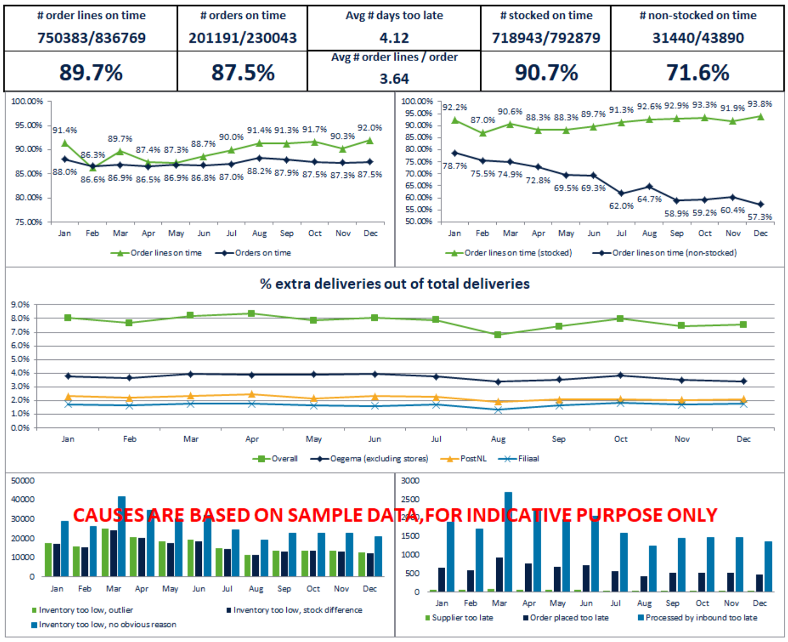

Figure 5: Concept dashboard shipment reliability

2.1.5 Conclusion

The research question for this section is *How can delivery reliability be defined at Jarola and what is the realised delivery reliability?* The answer to this question is:

- Delivery reliability is defined as the percentage of orders that are delivered on time. Due to a distinction in internal and external processes, this is split up into shipment reliability and forwarder reliability. Defining when an order is on time is mainly focused on delivering according to the common goals that are set by Jarola, which means that SKUs should be shipped the same day and non-SKUs should be shipped within the replenishment lead time plus two working days, unless the customer wishes the order after that time.

- Using the proposed definition, an overall shipment reliability in 2021 of 87.5% over the orders and 89.7% over the order lines is calculated. For stocked order lines, the reliability was 90.7%, while the non-stocked reliability was 71.6%. All these outcomes are lower than expected and than currently used (on average 93.6% over the orders).

Other main conclusions that can be drawn from this section are:
- An important finding is that many stocked order lines are shipped one day late. However, due to a lack of data, this cannot be further analysed. Based on 20 randomly checked orders, the assumption is made that stock outs were the main cause.
- Since order lines from certain suppliers are performing worse than others, reliability of the replenishment lead times is an important focus point which needs further examination.
- Other causes all connect to having the right amount in stock and on the reliability of the replenishment lead times.
- Since the causes are still broad, the analysis will be focused on improving inventory and non-inventory management, as non-stocked and stocked order lines are too often too late.
- To be able to focus on more specific causes, it is strongly recommended to implement a way to measure the shipment reliability according to the proposed definition, most importantly including measuring the causes of order lines being too late.

The next sections focus on finding the causes of the low reliability by focusing on how reliable the replenishment lead times are, how the current (non-)inventory management is done, and on how currently is decided between stocking or not stocking an item.

2.2 Reliability of replenishment lead times

The results discussed in Section 2.1 are that non-stocked items have a low reliability. Since the lead time to Jarola's customers is the replenishment lead time plus two working days, the certainty of the replenishment lead times in the system should be questioned. Also, the reliability for stocked items is too low and according to employees' opinions, suppliers do not always deliver on time, which also points to replenishment lead times not being realised. Therefore, the research question *How reliable are the replenishment lead times and is it needed to incorporate uncertainty in lead times into the (non-)inventory management models?* is addressed.

When a purchase order is placed at the supplier, a wished delivery or pick-up date is communicated with the supplier. Once the supplier confirms the purchase order, the supplier communicates a confirmed delivery or pickup date per purchase order line with the inventory planners. This means that it is possible that a purchase order has multiple delivery or pickup dates. This is also because replenishment lead times are agreed upon with the supplier on item basis. Since a purchase order line consists out of one item, we can safely say that the replenishment lead time per purchase order line is equal to per item. It is important to note that most of the suppliers deliver the goods to Jarola, but for some suppliers the goods are picked up using transportation that is arranged by Jarola. The replenishment lead times that are in the system are meant to be from the moment the purchase order is placed until the purchase order is delivered at the distribution centre of Jarola. To make sure that picked up purchase orders are at the DC on time, the replenishment lead time in the system of items that should be picked up at the supplier are longer than the time needed for the supplier to process the purchase order and the inventory planners manually take this into account when communicating the wished pick up date and planning the pickup.

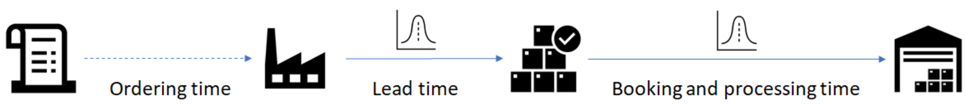

Figure 6: Process for replenishment orders

To determine the reliability of a supplier, the purchase order date plus the agreed upon replenishment lead time of the item has to be compared to the actual delivery date of the order line. However, agreed upon order and delivery days with the supplier have to be considered for this. If e.g. an item has an agreed upon replenishment lead time of six working days and the fixed order day is Monday and fixed delivery day is Friday, this means that the lead time is actually nine working days. Note that this is not considered for the shipment reliability for non-SKUs on purpose, since the web shop does not consider this as well. Furthermore, the goal is to realise that for non-SKUs the order and delivery days are not considered by making agreements with the suppliers.

An incoming purchase order has to be booked and processed by the inbound department. The moment the purchase order is booked and processed is the moment that the purchase order has arrived in the system. However, the inbound department does not always process the purchase order the same day that the order arrived, which has led to invalid data for determining the supplier reliability. Using the data, the time between placing and processing the purchase order can be measured. However, this time still includes the uncertainty of the booking and processing purchase orders too late. Therefore, the supplier reliability cannot be measured (visualised in Figure 6). The measurement that can be done is still useful, since this is measured from the moment the purchase order is placed until the moment the items are ready to be picked for Jarola's customers.

Using the method as described, without considering fixed order and delivery days, the realised percentage of purchase orders that are delivered on time is 32.1%. However, since the used realised replenishment lead times include the booking and processing of the order, this percentage is not fair to measure. Therefore, the focus will be on the difference in the realised replenishment lead times and the replenishment lead times in the systems in days. On average, the realised replenishment lead time is 7.1 days higher, comparing to the replenishment lead times in the system. This is more than a week, which is shocking. If fixed order days are considered in the analysis, this average realised replenishment lead time is reduced to 6.3 days too late. Considering only fixed delivery days this further reduces to 5.5 days too late on average and considering fixed order and delivery days reduces the days too late to 4.9 days on average. From Table 4, it can be seen that for non-stocked items, the days too late is more than two times as small when considering fixed order and delivery days. This makes sense, as purchase orders are placed the same or the next day, without considering fixed order days. Details about the data analysis and the methods used are given in Appendix D.

Table 4: Average days too late w.r.t. replenishment lead time in systems

	Overall	Stocked	Non-stocked
Order placed until order booked	7.1	7.9	4.8
Fixed order day until order booked	6.3	7.1	3.7
Order placed plus lead time until first fixed delivery day	5.5	6.3	3.1
Fixed order day plus lead time until first fixed delivery day	4.9	5.8	2.1

2.2.1 Conclusion

The research question that is treated in this section is *How reliable are the replenishment lead times and is it needed to incorporate uncertainty in lead times into the (non-)inventory management models?* From the analysis, it can be concluded that the replenishment lead times that are in the system are often not realised. This can be due to delays in the booking and processing of incoming orders or due to delays in the delivery of the supplier or both. Using the realised replenishment lead time from the moment the order is placed until the order is booked is not optimal for the problem analysis; however, for coping with the problem it is usable as the moment the order is booked and processed at the DC is also the moment the items are available for picking. Uncertainty in lead times is therefore an important point to consider in the inventory and non-inventory management.

2.3 Non-inventory management

Non-inventory management is defined as the management of non-SKUs. In Section 2.1, it is found that the shipment reliability of non-SKUs is specifically low (71.6% in 2021). In this section, the research question *How does Jarola cope with non-SKUs?* is addressed. To find the answer, interviews are conducted with the commercial director, the coordinator logistics and the operations director.

2.3.1 Item management

Jarola manages its items by categorising them into statuses. There are twenty statuses defined at Jarola (Appendix A). From these statuses, only the status IDs between 100 and 131 are in the scope of this research, because these are the most common statuses. Basically, the statuses 100 until 121 are SKUs, from which statuses 111 and 121 are mainly service items. The statuses 130 and 131 are non-SKUs. The status 130 items are the items that are on the web shop but are not kept in stock. The status 131 items are the items that are not shown to the customer via the web shop or in stores but are in the portfolio. These items can be ordered on special request from the customer. Both 130 and 131 items are directly ordered from the supplier to be cross docked via the DC to the customer.

Table 5: Statuses and the number of items per status

Status ID	Status description	Category	# Items	% Items
100	Items that are stocked at the stores and in the DC.	SKUs	3,467	1.8%
110	Items that might be stocked at the stores but are always stocked in the DC.	SKUs	8,216	4.3%
111	Items that might be stocked in the stores but are always stocked in the DC. Not available on the web shop. Mainly service items.	SKUs	46	0.0%
120	Items that are only stocked at the DC.	SKUs	10,196	5.3%
121	Items that are only stocked in the DC. Not available on the web shop. Mainly service items.	SKUs	425	0.2%
130	Items that are not stocked but are available on the web shop.	Non-SKUs	29,298	15.3%
131	Items that are not stocked and are not available on the web shop.	Non-SKUs	139,660	73.0%
Subtotal			**191,308**	**100%**
Other	See Appendix A (e.g., outlet)		56,390	
Total			**247,698**	

2.3.2 Non-SKUs

From Table 5, it can be seen that 88.3% of the items (the sum of 15.3% and 73.0%, for statuses 130 and 131) are non-SKUs. This means that these are responsible for a large part of the assortment. On the web shop, non-SKUs (only status 130) are displayed with an expected delivery date of the replenishment lead time plus two working days. If this total customer lead time is larger than ten working days, the web shop displays “On request”, such that Jarola can follow if there is demand on the item. The replenishment lead time of non-SKUs is on average 8.4 days, with a minimum of 1 day and a maximum of 197 days. 27.9% of the non-SKUs have a customer lead time larger than ten days, which means that these are displayed as “On request”. In this research, the customer lead time is still considered to be the replenishment lead time plus two working days.

Some exceptional items, e.g., very large, heavy or fragile, are shipped from the supplier to the customer directly (drop-shipment). Also, some non-SKUs are sent directly from the supplier to the stores to be picked up by the customer there. However, most of the non-SKUs are shipped from the supplier to the distribution centre of Jarola to be cross docked towards the customer, which is therefore the focus.

If a minimum order quantity (MOQ) is defined for the item and this quantity is larger than the required quantity, the minimum order quantity is ordered at the supplier. Sometimes the supplier is asked to make an exception; however, this is often not successful. If the MOQ is larger than the needed quantity, the left-over amount ($MOQ - Needed\ Quantity$) will be kept in stock until sold. To overcome having to order MOQs while needing less, many non-SKUs also have a MOQ for the customers of Jarola, which is equal to the MOQ of Jarola's supplier. For the non-stocked items, 75% have an MOQ of 0 or 1. 85% of the non-stocked items have an MOQ smaller than or equal to 10.

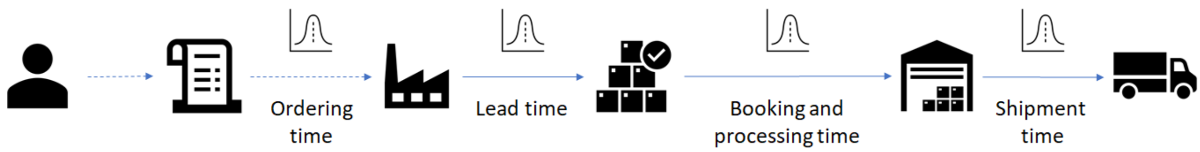

Figure 7: Visualisation of ordering and delivering process of a non-SKU

The process of ordering and delivering non-SKUs is visualised in Figure 7. If a customer orders a non-SKU, the inventory planning team orders that exact sales order (line) at the supplier (Ordering time in Figure 7). This purchase order should be done as soon as possible (the same or the next working day). If the purchase order is not placed the same or the next working day, the sales order will be too late since the customer lead time is defined as the replenishment lead time plus two working days, which is the first source of uncertainty. An example is that a supplier might have fixed days on which purchase orders can be placed. After the purchase order is placed, the replenishment lead time of the item is waited for, which is the second source of uncertainty. It could be that there are fixed delivery days agreed upon with the supplier or that the replenishment lead time is not correctly stored in the systems of Jarola. Also, the supplier could have a delay in their process. Then, if the purchase order has arrived at the DC of Jarola, there is a third source of uncertainty: the booking and processing of the order. A purchase order must be booked and processed before it can proceed to the outgoing goods. Due to e.g., shortage in personnel, it could be that the order is not booked on time, which leads to a delay. Since the delivery from the DC to the customer does not vary for SKUs and non-SKUs, this is not considered (Shipment time in Figure 7).

To be able to cope with these uncertainties, data is needed on how large they are. For the customer order, only the total days too late are available (discussed in Subsection 2.1.3). For the purchase order, only the total time between placing the order and having the purchase order booked and processed is available (discussed in Section 2.2). From a customer's perspective, most of these uncertainties are avoided if an item is stocked, and from Jarola's perspective, safety stock can be used to cope with these uncertainties.

2.3.3 Conclusion

This section focused on answering the research question *How does Jarola cope with non-SKUs?* Jarola manages its items by categorising them into statuses. SKUs are kept in inventory and are shipped from the DC to either the customer or the stores. Non-SKUs are ordered at the supplier as soon as possible after the sales order is placed at Jarola. The items are cross docked at the DC to the customer or the store. This leads to an expected lead time of the item's replenishment lead time plus two working days for ordering and cross-docking. It is found that the process of ordering and delivering non-SKUs has multiple sources of uncertainty, without having a safety net to cope with these uncertainties. Therefore, it is of importance to have the right items in stock. Having the right items in stock minimises the times the uncertainties in ordering non-SKUs must be coped with from a customer's perspective.

2.4 Keeping an item in stock or not

Since Jarola's assortment consists out of more than 200,000 items, and since the order and delivery process of non-SKUs has many sources of uncertainty, it is of importance to critically determine which items to stock and which not. Therefore, the research question *How does Jarola determine whether or not to keep an item in stock?* will be answered. It is found that the purchasing and commercial department decide together whether an item will be kept in stock. Data is gathered through interviews with representatives of these departments. A distinction must be made between deciding for items that are new to the assortment and existing assortment.

2.4.1 Items new in the assortment

When a new supplier is contracted, the entire assortment of that supplier is looked at. A part of the supplier's assortment is added to the portfolio. However, a large part is added as status 131 - items that are not shown to the customer on the web shop and are not stocked. For new items, the decision is mainly based on feeling, experience of the market, and sales data from the supplier. The decision makers sometimes know from experience if a similar item performs well and then base the decision for the new item on this experience. Another reason for the decision could be to create a strategic assortment group, for which either all items are SKUs, or none (this is mainly for presenting the items in stores).

2.4.2 Items in the existing assortment

The decision for existing assortment is based on sales data of the items, on experience, and on gut feeling. There is no clear decision rule that is used for the decision (e.g., if the demand is greater than x per year, the item is held in stock). If e.g., a salesman sees that the item might be better off kept in inventory, the decision for that item is reviewed. Furthermore, sometimes suppliers' assortments are checked (no periodic process, based on gut feeling commercial and purchasing department). In practice, the assortment is mainly judged to change items from non-SKU to SKU. The other way around is only done by exception. This means that there is no periodic review for checking the decision to keep an item in stock or not.

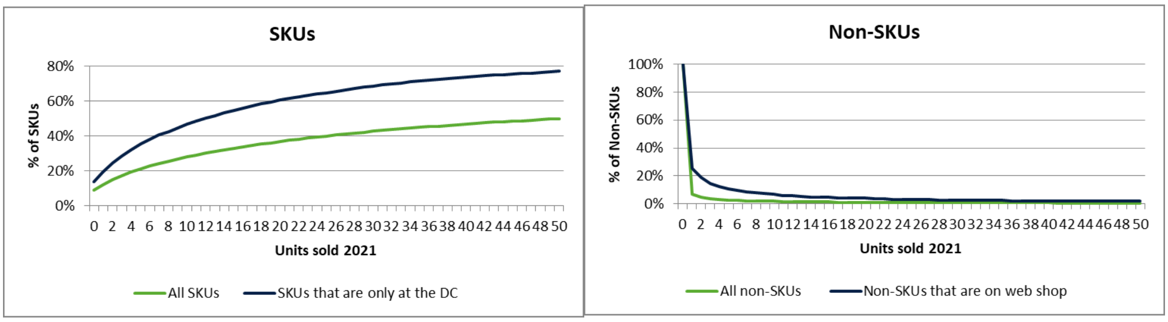

Figure 8: (a) % of SKUs with <= x sales (b) % of non-SKUs with >= x sales

From Figure 8, it can be seen that around 9% of the SKUs are not sold at all in 2021. From the SKUs that are only stored at the DC (status 120), 50% sold less than 12 units and almost 20% sold 1 or less units in 2021. From this, the conclusion can be drawn that there are too many SKUs that are probably not necessarily needed to be stocked. From the items that are on the website, but are non-stocked (item status 130), 7% of the items sold more than 10 units in 2021. Over all non-SKUs, only 2% sold more than 10 units in 2021. However, there are many more non-SKUs than that there are SKUs. Therefore, it can be concluded that the assortment should be checked both ways (from SKU to non-SKU and from non-SKU to SKU).

2.4.3 Partial Deliveries

In principle, a customer that places an order will get the order only when complete. On customer request or by commercial initiative, this can be changed. The extra delivery costs are paid by Jarola. The hypothesis is that partial deliveries are more likely to happen when an order has different non-SKUs or non-SKUs and SKUs, since non-SKUs are never in stock and therefore always have a higher customer lead time. Delivery in parts has to be minimised, since the transportation costs are paid by Jarola. The percentage of extra shipments is higher for orders that have both SKUs and non-SKUs (Table 6). This makes sense, since SKUs should be able to be shipped the same day, while non-SKUs must be ordered at the supplier first. The reason that orders with only non-SKUs have few extra shipments is that the average number of order lines is 1.2, which means that many orders only consist of one non-SKU. The hypothesis that partial deliveries are more likely to happen if an order consists of non-SKUs and SKUs is correct, from which it can be concluded that this must be considered when deciding whether or not to stock an item.

Table 6: (Extra) shipments and average number of order lines per order type

Order type	# Extra shipments	# Shipments	% Extra shipments	Avg # Order lines
Only SKUs	8,085	206,778	3.9%	3.3
Both	6,839	26,696	25.6%	9.7
Only non-SKUs	357	16,118	2.2%	1.2

2.4.4 Conclusion

The research question for this section was *How does Jarola determine whether or not to keep an item in stock?* Currently, for both existing and new assortment, the decision to stock or not is mainly based on gut feeling of the purchasing and commercial department. Sales data is used for existing assortment; however, no clear process for the decision is present. Furthermore, items' statuses are checked ad hoc and manually instead of periodically and automatically. Adding items to the assortment is always based on gut feeling, supplier's data, or customer's requests. Therefore, this cannot be optimised by an analytical decision rule and will always be a management/commercial decision. In the contrary, items in the existing assortment can be judged based on an analytical decision rule. Judgement needs to be done both ways, so from non-SKU to SKU and from SKU to non-SKU. From data analysis, it is found that there are SKUs that might be better off being a non-SKU and the other way around, since around 9% of the SKUs are not sold at all in 2021, and almost 2% of the non-SKUs have sold more than nine units in 2021.

Furthermore, it is found that delivery in parts is an important part of managing non-SKUs, since non-SKUs lead to a higher expected shipment date. If the customer wishes to receive the SKUs in the order earlier, partial delivery must be done, which costs extra for Jarola. If an order consists out of SKUs and non-SKUs, the chance is higher that partial deliveries have to be done, which must be considered when deciding to stock or not to stock an item.

In Section 2.3, it is found that having the right items in stock is very important. Furthermore, it is found that the decision whether or not stock an item is not done optimally. Therefore, creating a decision rule to decide whether or not to stock an item might improve the shipment reliability and decrease the cost due to a decrease in partial deliveries and ordering cost. The research will be focused on deciding whether or not to stock an **existing** item, so new assortment will be left out of the scope of this research. Due to strategic decisions such as supplier preferences, replacing an item, etc. the decision cannot be fully automated. However, an advice can be generated instead, such that the responsible people can look at the advice and only treat the items that are not strategically decided. The criteria that at least have to be considered are the sales and the strategic decisions.

2.5 Inventory management

Since the shipment reliability of stocked items is found to be too low as well (90.7% over the order lines in 2021). In this section, the focus is on the research question *How does Jarola manage their inventory?* Inventory is held at the DC in Coevorden and in stores. This research focuses solely on the inventory that is held at the DC. Jarola uses Slim4 by SlimStock as inventory management software. The focus is on the way this software is parameterised by Jarola. Jarola does not fear inventory. As a (technical) wholesaler, the idea is that many items can be delivered from inventory. Therefore, an A-item (according to ABC-classification) may never be out of stock. The disadvantage of the large assortment that Jarola has is that the B and C items take up a large part of the assortment and inventory. However, "having the B and C-items in stock is what made us the large organisation as we are today" (Director O. , 2022).

2.5.1 Forecast

The forecast is managed software wise by Slim4. The software calculates a tracking signal. If the tracking signal is above or below the (critical) threshold, the software automatically initialises the forecast, which means that the forecast and the corresponding parameters are recalculated. Afterwards, that SKU is also treated by an inventory planner as an exception, using their experience and knowledge to manually check the forecast and advised order quantity. Also, outliers are automatically left out of the forecast. Therefore, the forecast will not be further examined.

2.5.2 Classification of SKUs

Currently, SKUs are classified by a double ABC classification. This is done based on revenue and order lines. The revenue is calculated based on the forecast of the coming year multiplied by the cost price (which will be explained later). The order lines are based on the number of order lines in the past twelve months. The revenue classification is done according to a 70/20/10% distribution, while the order line classification is done according to a 65/20/15% distribution. An SKU is classified in ABC categories for the two criteria. These classifications are crossed into a final ABC-classification (Table 7). Also, the target service levels (volume fill rates) per class are given in the table.

Table 7: Final ABC classification of SKUs and target service level (volume fill rate) per classification

Double ABC classification based on revenue↓ and order lines→	A	B	C
A	A (97%)	A (97%)	A (97%)
B	A (97%)	B (90%)	C (90%)
C	A (85%)	B (85%)	C (85%)

Classifying SKUs is done to create a priority in to what extent certain SKUs should be managed, since giving all SKUs high priority is simply not possible. For the ABC-classification, this means that A-items should get the most attention, since these are the most important for the organisation. C-items should get the least attention, since these are the least important for the organisation. Looking at the realised distributions, the C-items are responsible for a larger part of the revenue than the B-items (Table 8). Since one of the criteria is revenue, this is not wished for. Also, the number of items in Class A (15.1%) is larger than the number of items in Class B (12.8%), while traditionally the A-items take up the smallest part of the SKUs. Therefore, it may be argued that the goal of classifying SKUs is not met, since the revenue is not divided in decreasing order over the final classes, and since the number of SKUs per class is not divided in increasing order over the final classes. To improve the inventory management, the classification method should therefore be changed.

Table 8: Inventory classification combined

Classification (Combined)	# SKUs	Stock (items)	Revenue	Order lines
A	15.1%	60.3%	78.0%	67.9%
B	12.8%	7.4%	8.1%	17.5%
C	72.1%	32.1%	13.8%	14.5%

2.5.3 Service levels

The used definition of the target service level is the Volume Fill Rate (VFR), which is "the fraction of product demand that is satisfied from products in inventory" (Chopra & Meindl, 2016, p. 329). Note that items that are in class A of order lines and in class C of revenue are classified as A-items but have a target service level of only 85%. Given the statement of management that an A-item may never be out of stock, this is rather low. Furthermore, the A-class of order lines means that these items can have significant effect on the shipment reliability, as this measures the number of order lines shipped on time. The B and C-class after crossing is also not consistent, since a B-item can have target service level 85% or 90%, which also holds for C-items. Overall, the current method focuses mainly on having higher service levels for items with higher revenue instead of items with higher order lines, while the shipment reliability focuses on the number of order lines shipped on time.

Under the assumption that all order lines that were too late, were too late due to a stock out, the shipment reliability as defined in Subsection 2.1.1 is equal to the order line fill rate (for stocked order lines). However, this assumption is not correct, since order lines can also be late due to e.g. another order line in the order being late, which can also be a non-stocked item. Unfortunately, this assumption has to be made since no data is available to determine which order lines were late due to a stock out. The realised fill rates (order line and volume) are determined over 2021. The realised fill rates overall and per classification are given in Table 9. A remarkable result is that the volume fill rates are lower than the order line fill rates. This can be due to the assumption that all late order lines are late due to a stock out, since one late order line can create entire other order lines (which can consist of large order quantities) being too late as well. Furthermore, the data analysis only includes of the order line is considered on time. If the order line is too late, all units in that order line are considered too late, also if that order line is delivered in parts.

Table 9: Realised Volume (VFR) and Order Line fill rate (OLFR) 2021

VFR	Overall	86.3%	OLFR	Overall	90.7%
A - 88.2%	B - 80.7%	C - 76.0%	A - 91.9%	B - 90.2%	C - 86.4%

2.5.4 Inventory policy

Inventory is basically managed by a periodic-review, reorder-point, order-quantity (R, s, Q) policy, where R is the review period, s is the reorder point, and Q is the order quantity. This policy is used for all items, and this is not to be changed. The policy assumes backordering. By conducting data analysis, it is found that only 0.5% of the order lines in 2021 are cancelled (without considering the reason of cancelling). Therefore, the backordering assumption is valid and will be used in the remainder of this research.

Review Period, Lead time, Cover time, and Cover Period

The review period is the period between reviewing the inventory position and possibly ordering new items and reviewing again. The replenishment lead time is the time the supplier needs to deliver the ordered goods (should be equal to the time from the moment the order is placed until the order is delivered at the DC). The cover time is set by the inventory planners as extra safety lead time. The cover time is the extra time that is forecasted and the demand that is forecasted during this period is considered for the reorder point. The cover time only influences the forecasted demand; it has no direct influence on the calculations of the safety stock. The total period that has to be covered is the cover period, which is the sum of the review period, the lead time, and the cover time.

Table 10: Statistics of review period, lead time, cover time and cover period (n=22,128)

Description	Review period	Lead time	Cover time	Cover period
Mean	16.4 days	13.2 days	16.2 days	45.8 days
Median	7 days	4 days	14 days	32 days
Mode	7 days	1 day	14 days	23 days
Min - Max	1 - 360 days	1 - 360 days	0 - 178 days	3 - 483 days

Statistics of the review period, lead time, cover time, and cover period are given in Table 10. 93.7% of the items have a review period of 7 days. This is also the standard input if a new item is imported into the assortment. Furthermore, 3.0% have a review period of 30 days. The tuning of the review period is based on gut feeling and by coordination with the supplier. The average replenishment lead time is 9 days. However, the replenishment lead time does have a maximum of 360 days. It is obvious that the higher the review period and replenishment lead time, the higher the average inventory. On average, an SKU has a cover period of 46 days. This is for more than one-third caused by the manually set cover time. Not considering cover time, the cover period is still on average 29.6 days, which means that it is extremely important to have the right amounts in stock, since a stock out can lead to high waiting times for the customer.

Suppliers can have a fixed order and delivery schedule. However, the replenishment lead times and review periods that are used do not always consider the fixed order and delivery days. An example is an item with a review period of three days and a replenishment lead time of one day. The supplier has a fixed order day on Wednesday and a fixed delivery day on Thursday. In this case, reviewing the item every three days does not make sense, since the ordering and delivery takes place only once a week. The replenishment lead time of one day is correct in this case, since if the order is placed on Wednesday, one day later is the delivery day on Thursday. Another item has a lead time of four days while the ordering day is on Wednesday and the delivery day is on Friday. This means that instead of four days, the lead time is either shorter (two days) or longer (nine days). Since the replenishment lead time and the review period are an important input for the safety and the cycle inventory, these should be improved. Incorporating the order and delivery days will mainly increase the cover period. This could therefore also be a reason that the extra cover time is rather long, as this is manual input from planners and management if the inventory is felt to be too low.

Safety Stock

The safety stock is, as mentioned, not directly influenced by the cover time. Of course, since the forecast during the cover period is influenced, a purchase order is placed sooner, which does lead to more inventory. However, this is not considered as safety stock in this case. Inventory planners can set an iron stock on top of the calculated safety stock. Currently, 2,319 items (10.4% of the stocked items) have an iron stock. The iron stock is used as a hard input number, no calculations are done to determine this stock, and they are based on gut feeling. The iron stock that is set is simply added to the calculated safety stock. The calculations of the safety stock depend on the demand distribution, but are strongly influenced by the target service level, in this case the Volume Fill Rate. The higher the target service level, the higher the safety stock.

The inventory management system assigns demand classes to items based on historical sales. Based on this class, the demand is assumed to be Normal for the fast moving items and Compound Poisson distributed for slow moving items. For the Compound Poisson distributed items, the arrivals are modelled using Poisson and the order line size is modelled by an Empirical distribution. In case of Normal demand, the safety stock is determined. In case of Poisson demand, the reorder point is determined, and the safety stock is determined by subtracting the expected demand during the cover period.

Reorder point

The reorder point is calculated by Slim4, using the forecasted demand during the cover period (lead time + review time + cover time) and the safety stock. If present, event forecast and other confirmed extra customer orders are considered, as well as an iron stock. Since this is an automated calculation, there is no reason to further examine this topic. The parameters that are needed to calculate the reorder point do have to be examined. The way of calculating the reorder point is given in Equation (1). Here, $\hat{x}_{R+L+C}$ is the forecasted demand during the cover period.

$$s = \hat{x}_{R+L+C} + Safety\ stock + Iron\ stock \tag{1}$$

Slim4 automatically calculates the forecast $\hat{x}_{R+L+C}$. The iron stock and the cover time are choices made by management/inventory planners, these should be zero in the ideal case. Therefore, the only part that is left to examine are the target service levels. These are also choices of management and are strongly related to the classification of the items, which is a management decision as well.

Order Quantity

Since inventory is managed by an R, s, Q policy, there is basically a fixed lot size. To determine the lot size, first the Economic Order Quantity (EOQ) is calculated using Equation (2). Here, c_O is the order cost per order line, D is the one-year-ahead forecasted demand, h is the holding cost parameter per year as percentage of the purchase price, and c_p is the purchasing price of the item (Jarola currently uses a cost price, see below).

$$EOQ = \sqrt{\frac{2c_O D}{hc_p}} \tag{2}$$

Then, the EOQ is limited dependent on ABC-class, to avoid having large quantities in stock of items that do not sell well. If the item is in the A-class, the order quantity is limited to be smaller than or equal to 10 weeks of demand forecast, for the B-class, this is 16 weeks of demand forecast and for the C-class, this is 26 weeks of demand forecast.

For many items a Minimum Order Quantity (MOQ) is agreed upon with the supplier. If this MOQ is larger than the calculated EOQ, this quantity is used. Otherwise, the EOQ is used as MOQ. Also, in many cases an Incremental Order Quantity (IOQ) is used. This means that order quantities must be $Q = MOQ + IOQ * x$, with $x = \{0,1,2, \dots\}$ to cope with e.g., pallets. The MOQs that are agreed upon with the supplier are in the interval $[0; 113{,}400]$. However, 76.7% of the stocked items have an MOQ smaller than or equal to 100. 7.6% of the items have an MOQ that is equal to 0 or 1. For stocked items, 30.0% of the IOQs are equal to the item's MOQ. 65.1% of the SKUs have an IOQ smaller than or equal to 10, while 92.7% have an IOQ smaller than or equal to 100. Furthermore, 97.7% of the SKUs have an MOQ that is equal to or a multiple of the IOQ ($MOQ \bmod IOQ = 0$).

It is noted by the inventory planners that the EOQ is often found to be too low. From Equation (2), it can easily be seen that this can be due to a too low ordering cost and/or a high holding cost. Therefore, the holding and ordering costs need to be examined on its accuracy. The demand is according to the forecast, which we assume to be good. Another cause for the EOQ to be too low is that the EOQ is rounded on weeks of demand forecast too much.

For the following analysis, the EOQ is calculated based on the sales of January 2021-January 2022, provided there has been demand, without considering rounding on weeks of demand forecast. It is found that 69.6% of the EOQs are larger than or equal to the MOQs. Also, 90.3% of the EOQs are larger than or equal to the IOQs. If the EOQ is smaller than the MOQ or the IOQ, the EOQ cannot be ordered, since the order quantity is constrained by the MOQ and the IOQ. Slim4 automatically changes the order quantities according to these constraints, however, if an inventory planner manually has changed an order quantity, this quantity will be ordered. More than 30% of the SKUs have a larger MOQ than the EOQ, which strengthens the statement that the EOQ is often found to be too low and therefore the accuracy of the ordering and the holding cost have to be examined.

Cost price and Purchasing price

For many stocked items, Jarola uses a cost price. This cost price is the purchasing price plus some additions, dependent on the supplier and the item. The additions can be due to transportation cost, import duties, deprecation, and/or handling cost. In terms of ordering and holding cost parameters used in the EOQ, these additions have to be separated over the two. Currently, Slim4 uses the cost price for the calculations where a price is needed. This means that for the EOQ the cost price is used instead of the purchasing price.

From Equation (2), it can be seen that using a cost price that can include cost for transportation and import duties (which are obviously ordering cost, since these are paid per order line) is not correct. Doing so makes the EOQ tend to order more often and keep less inventory, while the price that is used is higher due to higher ordering cost. These additions can be used to add to the standard ordering and holding cost to create item specific parameters, however, currently this is not done properly. This is a relatively easy improvement of the used cost parameters.

Holding cost parameter
The holding cost parameter per year as percentage of the purchasing (currently cost) price that is used in the calculations is 25%. This is based on the interest, space, and risk principle, using a 5-10-10% distribution. These are chosen since 25% is an often-used percentage and by estimation. However, currently an interest of 5% is rather high. Furthermore, a new DC is built, which might mean that the costs of space are higher. Also, there are certain items with high volume that might be more expensive to keep in inventory than other small items.

Ordering cost parameter
For most items and suppliers, a standard ordering cost parameter of €10,- per order line is used. For so-called Uglies (large items, e.g., hard to transport) an ordering cost parameter of €25,- per order line is used. The cost price has additions for transportation and import duties; however, as mentioned this is not used for the ordering cost. To create a more realistic EOQ, this should be changed. Furthermore, there is no distinction between foreign suppliers that deliver from e.g., China and suppliers that are close to Coevorden. Also, there are different agreements in place with the suppliers (some suppliers do not charge transportation costs, other after a certain amount, etc.). Therefore, differentiation in the ordering costs over the suppliers or items might be needed to create a more realistic EOQ.

2.5.5 Conclusion
The research question that is treated in this section is *How does Jarola manage their inventory?* Jarola manages their inventory using Slim4 software. A double ABC-classification is used to classify the SKUs in priority with target service levels of 97%, 90%, or 85%. The policy that is used is an R, s, Q policy. From the analysis of the current inventory management, it can be concluded that some parameters can be improved:

- According to the current classification, the proportion of revenue that is made by C-items is higher than by B-items. Therefore, the classification of stocked items needs to be improved. Furthermore, one category of items that are classified as A-items only has a service level of 85% and a B and C-item can have a target service level of 90% and 85%. So, also the target service levels per classification have to be examined. Overall, the classification focuses mainly on having higher service levels for items with higher revenue instead of items with higher order lines, while focusing on order lines has influence on the shipment reliability.
- The replenishment lead times and the review periods do not always consider the fixed order and delivery days. Since this could be a reason for too high or too low inventory levels, these should be improved.
- The EOQ is often found to be too low, since only 70% of the SKUs have a larger EOQ than their MOQ. The EOQ is also felt to be too low by the inventory planners. This can be due to the holding cost being too high and/or the ordering costs being too low. Also, no differentiation between foreign and local suppliers is used. Furthermore, the used cost price that is the purchasing price plus some additions is not used (correctly) in the determination of the cost parameters. Therefore, the holding and the ordering costs have to be examined on its accuracy.

2.6 Conclusion

The main of goal of this chapter is to analyse the current situation and further define the problem of having a too low delivery reliability. The main conclusions are:

- The overall shipment reliability in 2021 was 89.7% over the order lines and 87.5% over the orders. For non-stocked respectively stocked order lines, the shipment reliability was 71.6% and 90.7% in 2021.
- Most of the realised replenishment lead times are larger than the replenishment lead times in the system: over all suppliers the average realised replenishment lead time is 7.1 days larger than the replenishment lead times in the system. Note that these lead times are measured including the processing and booking at the DC, which is also a source of uncertainty. This is an important focus point which has to be considered for the inventory and non-inventory management.
- There is often a fixed order and delivery schedule in place per supplier. This means that orders should be placed only on the agreed upon day and that deliveries only take place on the agreed upon days. It is found that the replenishment lead times and the review periods do not consider fixed order and delivery days (which is also the case for non-SKUs).
- It is found that there are multiple sources of uncertainty in the process of ordering non-SKUs (Figure 7), which are hard to measure in the current data structure. Therefore, to minimise how often these uncertainties have to be coped with, it is of high importance for Jarola to have the right items in stock. Furthermore, it is found that costly partial deliveries are more likely to happen when non-SKUs are in the order.
- The decision to keep an existing item in stock or not is not checked periodically, but ad hoc or after a notification of a salesman. Also, items are mainly changed from non-SKU to SKU, while the other way around can decrease unnecessary inventory. Around 9% of the SKUs are not sold in 2021; therefore, there is reason to believe that there are items stocked that might be better off non-stocked. On the other hand, 2% of the non-SKUs sold more than 10 units in 2021, which gives indication that there are also non-SKUs that might be better off stocked.
- The current classification settings are not optimal, because the C-items are responsible for more revenue than the B-items. Furthermore, the target service levels have to be examined, since one A-class after crossing (the combination of C-class on revenue, and A-class on order lines) has a lower target service level of 85% than the other A-classes after crossing (97%). The current classification focuses mainly on having high service levels for items with high revenue, while the items with high number of sales order lines are less focused on regarding service levels.
- The analysis showed that for the calculation of the EOQ a cost price is used with additions that should be included in the ordering cost instead. Also, it is found that the holding costs might be too high (25%) and/or the ordering might be too low, because the EOQ is found to be too low by the inventory planners and by comparing with the agreed upon MOQs.
- Another conclusion that will not be analysed further in this research is that due to a lack of data, the outcomes of the causes in the dashboard are based on randomly generated data. It is recommended to implement the right fields in the ERP system, such that the cause of shipping too late can be determined. This will enable the organisation to give a clearer direction on where possibilities lie to improve.

The next chapter focuses on finding knowledge in literature for deciding whether or not to stock an item and on how SKUs can be classified. Since Slim4 can cope with the theoretical challenges of uncertainty in replenishment lead times, no literature review is needed on this topic.

3 Literature review

The goal of this chapter is to gain knowledge through literature search. Knowledge is needed on how an optimal decision can be made to stock or not to stock an item (Section 3.1). Furthermore, knowledge is needed on how SKUs can be classified (Section 3.2). The search queries and used databases are given in Appendix E.

3.1 Methods to decide whether an item is an SKU or a non-SKU

In Subsection 2.4.2, it is found that it is of high importance for Jarola to have the right items in stock, since coping with non-SKUs means coping with multiple sources of uncertainty. Furthermore, in Section 2.4, it is found that this decision is currently only based on gut feeling, sales, and experience. To be able to deal with this problem, knowledge is needed on how to determine if an item should be stocked or not. Therefore, the research question that needs to be answered is *What methods are present in literature to decide whether an item is an SKU or a non-SKU?*

Silver, Pyke, & Thomas (2017) describe a set of factors that can influence the decision to stock or not stock the item, (1) the system cost, (2) the unit variable cost of the item, (3) the cost of a temporary backorder, (4) the fixed setup cost, (5) the carrying charge, (6) the frequency and magnitude of demand transactions, and (7) the replenishment lead time. However, creating a general model to handle all these factors would be “of limited value to the typical practitioner because of its complexity” (Silver, Pyke, & Thomas, 2017, p. 372).

There are many methods and models available in literature. Silver, Pyke, & Thomas (2017) describe a decision rule based on the EOQ, where an item should be stocked if a certain system cost of having the item stocked is greater than the order cost per order divided by the expected order line size. Fenske (1968) determines the total profit under non-stocking and under stocking as a function of demand and gives three methods to determine the cut-off level. If demand is greater than the cut-off level, the decision should be to stock the item, otherwise the item should not be stocked. According to Shorrock (1978), there are two essential points to be considered: (1) Whether or not the item must be stocked to enable a particular lead time to be achieved. If a company wants to promise a delivery time of 10 days, but the procurement lead time is more than 10 days, the item should be stocked. (2) Whether or not it will be cheaper to order economic quantities and hold these in inventory rather than order directly against each demand. Park (1980) describes a model under Poisson demand and Exponential replenishment time where the backorder versus inventory carrying cost is optimised. These models and models by Croston (1974) and Johnson (1962) are more extensively described in Appendix E.

The cost minimisation or profit maximisation models are not directly suitable for Jarola’s case. The models of Silver, Pyke, and Thomas (2017), Fenske (1968), and Croston (1974) assume negligible lead time and no backordering, which is not the case for Jarola, as lead times and backorders should definitely be incorporated. The model of Johnson (1962) does not consider lead times. The model of Shorrock (1978) does include the lead time by first having to decide if the company wants to deliver the item within the lead time, however, this cannot be analytically determined which makes the model not suitable for Jarola’s case. The model of Park (1980) assumes a base stock policy under stocking, where every time an order is placed by a customer, a new item is ordered for stock at the supplier, which is an assumption that cannot be made in Jarola’s case.

Another approach to decide whether or not to stock items is SKU rationalisation, which is “the process of assessing which products you should add, keep, or remove from your inventory” (Johnson B. , 2021). This approach is rather conceptual and focused on completely discontinuing items from the assortment, but it does lead to useful insights for the decision. From case studies regarding SKU rationalisation, it is found that operational departments such as logistics are often focusing on minimising costs, while commercial departments are often focusing on revenue and customer satisfaction (Enz, Schwieterman, & Lambert, 2019). From this, it can be concluded that a decision based on only cost is not sufficient. Enz, Schwieterman, and Lambert (2019) state that SKU rationalisation has to be aligned with the corporate goals and strategy, which can be interpreted as those strategic decisions have to be considered for the decision of stocking an item or not. Criteria that are given in Enz, Schwieterman, and Lambert (2019) are, among others, sales volume, strategic criticality, profit contribution, and substitutability. Staskiewicz, Haug, and Hvam (2022) state that to perform SKU rationalisation, SKU characteristics have to be identified using among others master data. Using this, substitutes for certain SKUs can be identified. Furthermore, complementarity of items can be identified.

To conclude, the analytical models found in literature cannot be used directly. However, they can be used as base or starting point for a new model. E.g., the model of Fenske (1968) is inspiration for determining the profit functions under stocking and under non-stocking and then comparing the outcomes for the expected demand. Criteria found using SKU rationalisation will be used for the non-analytical part of the decision (it is already determined that the decision keeps depending on human judgement). The most important found criteria are sales volume, strategic criticality, profit contribution, substitutability, and complementarity.

3.2 Methods to improve inventory management

In Section 2.5, it is found that the classification of SKUs, the holding costs, and the ordering costs have to be further researched and/or improved. In this section literature research is performed on how to classify SKUs, to answer the research question: *What methods are present in literature to classify SKUs?*

Since an organisation like Jarola holds many different SKUs, managing each item individually is not realistic. Therefore, SKUs are often categorised into certain classes, which then is used to determine target service levels and inventory policies per class. A well-known method in literature to classify SKUs is the ABC-classification. This classification is based on the Pareto law, also referred to as the 80/20 rule, because typically 20% of an organisation's SKUs account for 80% of the sales (Slack, Brandon-Jones, & Johnston, 2013). The next 30% of the items typically account for 10% of the sales, which is the B-class. The other 50% of the items typically account for the last 10% of the sales; the C-class. The classification is typically based on revenue ($Demand * value$), where the items with the highest revenue are in class A. The ABC-classification can easily be extended to more classes (D, E, ...). Usually, the number of classes is limited to six (Teunter, Babai, & Syntetos, 2010).

Another way of classifying SKUs is the so-called two-digit classification, which is a classification based on two criteria. This means that there are nine classes instead of three. The two-digit classification can be done on the revenue and on the number of transactions (this is basically the current way of classifying the SKUs at Jarola). Also, a technique for the second digit of the two-digit classification is the XYZ-classification. The method is equal to the ABC-classification; however, this method classifies according to demand variability, with X as class for low demand variability and Z as class for items with high demand variability (van Kampen, Akkerman, & van Donk, 2012). Another two-digit classification is on the revenue and on the criticality of the item (Silver, Pyke, & Thomas, 2017), but there are many more available in literature. There are also methods using more than two criteria, e.g., obsolescence, reparability, criticality, and lead time (Chen, Li, & Liu, 2008). When using multiple criteria, there are methods available such as the Acceptability analysis (Li, Wu, Liu, Fu, & Chen, 2019), the Gaussian Mixture Model (Zowid, Babai, Douissa, & Ducq, 2019), Analytical Hierarchical Process (AHP) approach, Genetic Algorithm (Chen, Li, & Liu, 2008), etc. to determine the overall classification.

There are also less straightforward classifications in literature, e.g. classification based on Inventory Theory (Zhang, Hopp, & Supatgiat, 2001). They use the method that SKUs are ranked in ascending order according to the $\frac{D_i}{l_i c_i}$ value of the item, where D is the demand, l is the replenishment lead time (assumed constant, and c is the unit cost of the item. Then, the items should be classified into classes A, B, and so on and every class should be given a fixed target service level. Another classification method is based on a cost criterion (Teunter, Babai, & Syntetos, 2010). The classification is called the "cost criterion", as it uses the ratio of backorder costs and holding costs: $\frac{b_i D_i}{h_i Q_i}$. The items should be ranked in descending order and then classified into classes A, B, and so on. The target service levels should be fixed per class. The paper shows from a numerical experiment that this method outperforms the standard ABC-classification and the classification by Zhang et al. (2001).

To conclude, the classification of SKUs is very extensively studied and used in practice, there are also many extensions present in literature. There are also more mathematical classifications present in literature, which base the model on cost and inventory theory. However, since Jarola already uses a double-digit classification on revenue and order lines and this is also a well-known and proven method in literature, this is most suitable model to follow. Jarola's first priority is not to reduce inventory, as it is to improve the customer service level. Therefore, the method of classifying SKUs will not be changed; however, the used parameters can be changed.

3.3 Conclusion

The first research question that is treated is *What methods are present in literature to decide whether an item is an SKU or a non-SKU?* Using SKU rationalisation, criteria are found that has to be considered when implementing a decision rule. Among others, substitutability and complementarity have to be considered when deciding to stock an item or not. An item that has a clear substitute already in stock might be easier decided to non-stock, while an item that is complementary to another item might be better off stocked, since it might result in backorders or lost sales otherwise.

Multiple models that use a mathematical approach have been found (Silver, Pyke, & Thomas, 2017) (Fenske, 1968) (Shorrock, 1978). The main approach is determining the total cost function under stocking and under non-stocking and then optimising with respect to demand. However, none of the models found in literature are sufficient to model the situation of Jarola, since no model considers both lead times and backorders. Therefore, the mathematical models of Silver, Pyke, & Thomas (2017), Fenske (1968), and Shorrock (1978) will be mainly used as basis.

The second knowledge question was how to classify SKUs: *what methods are present in literature to classify SKUs?* SKU classification is very extensively studied and used in practice, there are also many extensions present in literature. There are also more mathematical classifications present in literature, which base the model on cost and inventory theory. Since Jarola already uses a double-digit classification on revenue and order lines and this is also a well-known and proven method in literature, this is most suitable model to follow. Jarola's priority is not to reduce inventory, as it is to improve the customer service level.

Using the obtained knowledge, models can be created for the decision whether or not to stock an item and for classifying SKUs. However, first the focus is on coping with uncertainties in the replenishment lead times. After that, the focus will be on creating a model for deciding whether or not to stock an item and on improving inventory management.

4 Uncertainty in replenishment lead times

In Section 2.2, it is found that the realised replenishment lead times from the moment the purchase order is placed until the purchase order is processed are not always smaller than or equal to the replenishment lead times that are in the system. In this chapter, the focus is on what effects uncertainties in replenishment lead times have on inventory, costs, and shipment reliability and on how to cope with these uncertainties.

4.1 Effect on inventory and shipment reliability

The research question that will be addressed is *What is the effect of having deviations in the lead times on the inventory and on the shipment reliability?* In this section, first the focus is on what effect uncertainty in replenishment lead times has on the non-inventory management. Then, the focus is on the effect of uncertainty in replenishment lead times on the inventory management.

4.1.1 Effect on non-inventory management

For non-SKUs, the promised customer lead time is the replenishment lead time in the system plus two working days, which means that if the realised replenishment lead time is longer than the lead time in the system, this has direct influence on the shipment reliability of non-SKUs.

To see what effects the uncertainties have, the realised replenishment lead times (from moment of ordering to moment of booking and processing) are used in the determination of the shipment reliability over 2021 (same data as in Subsection 2.1.2). This means that the sales order (line) is now considered to be on time if the sales order is shipped after the realised replenishment lead time plus two working days. Using this, the shipment reliability over the non-stocked order lines improves from 71.6% to 84.0%. Overall, the shipment reliability over the order lines increases with 0.9%, from 89.7% to 90.6%. The shipment reliability over the orders improves with 1.6%, from 87.5% to 89.1%. It is remarkable that the shipment reliability over the orders increases more than the reliability over the order lines, which means that orders are often late due to a non-SKU being late. The increase is significant, which means that the replenishment lead times should be improved by either updating them or by making sure the current lead times in the system are realised.

4.1.2 Effect on inventory management

For SKUs, the inventory management uses the replenishment lead time in the system to determine the needed safety stock and the reorder point. This means that if the realised replenishment lead time is larger than the replenishment lead time that is used in the calculations for the reorder point, the stock levels are underestimated, which might lead to stock outs.

To see what effect the uncertainty of the replenishment lead times has on the inventory, simulations are performed using Slim4. The KPIs that are used are the total average units in inventory and the total average value of inventory. The average units in inventory per item is based on the safety stock that Slim4 calculates, plus half the order quantity according to Slim4 (which considers MOQs, IOQs, EOQs, and specific units such as pallets). The average value in inventory is based on multiplying the average inventory with the cost price. The totals are determined by summing the units or value over all stocked items. Real data and the currently used settings up to and including 16-05-2022 are imported into the test environment, this means that the output of the simulations is based on the data of that moment, e.g., seasonal effects are therefore not incorporated. Jarola currently uses cover time to cope with uncertainties, however, keeping this might lead to invalid simulation output. Therefore, all cover times are set to 0. The data that is created using those settings is used as starting point. Then, the realised replenishment lead times (from moment of ordering until moment of booking and processing) are imported and Slim4 performs all calculations based on these settings. This means that the required safety stock, reorder point, etcetera are recalculated, which is then used to calculate the described KPIs.

Slim4 has the following options to cope with uncertainty in replenishment lead times:
1. Add a certain time to the current replenishment lead time.
2. Multiply the current replenishment lead time with a certain factor.
3. Use the standard deviation of the lead time and use this to increase the safety stock.

In the current dataset, it is hard to measure the standard deviation of the replenishment lead time, since the standard deviation should be measured per item and one item does not have many purchase order lines. It is, however, possible to determine the average replenishment lead time that is in the system and the average realised replenishment lead time per supplier, by using the purchase order lines (same data as in Section 2.2). Therefore, Option 1 will be used for the simulations.

Using the purchase order lines, the average realised and the average replenishment lead time in the system is determined per supplier. Then, the average extra days needed for a purchase order to be booked and processed is determined per supplier. Every item per supplier gets that extra lead time added to the replenishment lead time that is in the system (using Option 1 in Slim4). The simulation results in a total increase in inventory of 12.0% in units and 9.9% in value. Since the inventory increases significantly using the realised replenishment lead times, the realised service level and therefore the shipment reliability will very likely increase significantly as well. This is, however, hard to simulate.

4.1.3 Conclusion

The conclusion that can be drawn from the results is clear: having deviations in the replenishment lead times has significant effects on the shipment reliability of the non-stocked items. Furthermore, using too short lead times leads to significantly underestimating inventory and therefore to lower service levels.

4.2 Coping with deviations in replenishment lead times

The research question that is addressed in this section is *How can the shipment reliability be improved considering deviations in replenishment lead times?* To improve the shipment reliability, it is very important to have the right replenishment lead times in the system. Therefore, the replenishment lead times should be updated and should be kept up to date.

Unfortunately, currently the realised replenishment lead times can only be measured from the moment the order is placed until the moment the order is booked. This is not a valid measurement for the actual arrival date of the order at the DC. Although the current measurements still result in good input for the (non-)inventory models, it is highly recommended to change the process such that the actual replenishment lead times of the suppliers can be measured validly, such that (1) the replenishment lead times in the systems can be updated and/or (2) the purchasing department can make agreements with the supplier.

Changing this process also results in the possibility to measure if the time needed for booking and processing the incoming orders is too long. If this is the case, the inventory planning team should act towards the responsible person of the receiving team. It might be of help for the receiving team to have business rules that create priority in incoming orders. An important business rule can be to first book and process the incoming orders that have backorders in it (a non-SKU should in this case be considered as a backorder). However, it is even better to make sure that all orders that come in today, are also processed today, which is the goal of the organisation.

For updating the replenishment lead times, it is also highly recommended to consider fixed order and delivery days in the lead time that is used in the systems. Now, it is possible that an item has a replenishment lead time of one day, while the fixed order day is on Monday and the fixed delivery day is on Friday (which means a lead time of four days). The order and delivery schedule is per supplier, while the replenishment lead time is per item. Due to this, these have to be updated in two different systems. Currently, the replenishment lead time have to be updated in the product content management system, while the order and delivery schedules have to be updated in the ERP system. Furthermore, the replenishment lead times have to be updated by the Product Content Management department, while the order and delivery schedules have to be updated by the purchasing department. It is recommended to let one department be responsible for the updating of these two parameters, such that it is easier to let these correspond with each other. Since the replenishment lead time and the order and delivery schedule have to be agreed upon with the supplier, it is recommended to let the purchasing department be responsible for updating.

Checking the order and delivery schedule also gives the chance to check the review periods. If an order can be placed once per week on a Monday, the review period should also be adapted to seven days, since reviewing an item every three days does not make sense if an order can only be placed once every seven days. This not only reduces the workload of the inventory planning team, it also increases the inventory to a level that it should be at, since the correct input parameters are then used for the calculations of the reorder point and the safety stock.

Since the replenishment lead times are found to be too low, changing the replenishment lead times will increase inventory. However, this is still recommended to implement as soon as possible, since this is a very important parameter for the determination of the needed inventory levels. Having the wrong replenishment lead times (assuming too low) leads to underestimating inventory and therefore leads to backorders. For non-SKUs, the effects are even stronger since the replenishment lead time plus two working days is used as promise to the customer. Therefore, this has direct influence on the shipment reliability to the customer.

According to company policy, ordering non-SKUs at the supplier should be done immediately after the customer orders that item at Jarola. However, some suppliers have a minimum order amount or fixed order days. It is therefore recommended to make agreements with the suppliers with those constraints to create a separate supply chain for the non-SKUs, e.g., shipping non-SKUs in single packages instead of by truck consolidated with the replenishment orders for SKUs might be a solution for many smaller non-SKUs. If such a solution is not possible, it might be better to either stock or discontinue the item, or to promise a longer customer lead time, which considers at least fixed order and delivery days. Then, the purchase order can be consolidated with other items for replenishment of the inventory.

It is recommended to let the inventory planning team become owner of the deviations of the replenishment lead times, and to let the inventory planning team act towards the purchasing department in case of inconsistent replenishment lead times. The purchasing department should have contact with the suppliers about deviations in the replenishment lead times, since these make other agreements as well (deviations might also come in handy for price negotiations). The purchasing department should therefore also be responsible for updating the replenishment lead times in the system. If deviations in replenishment lead times are accepted, these should be implemented into the inventory system (Slim4), such that the needed inventory levels are increased accordingly. It is, however, important to keep in mind that deviations in replenishment lead times are hard to implement for non-stocked items, which leads to a lower shipment reliability.

4.3 Conclusion

The first research question that is answered is *What is the effect of having deviations in the lead times on the inventory and on the shipment reliability?* It is shown that using the realised replenishment lead times for determining the shipment reliability over 2021, the result is that for non-stocked order lines the reliability increases with 12.4%, from 71.6% to 84.0%. Overall, the shipment reliability over the order lines increases with 0.9% from 89.7% to 90.6% and over the orders with 1.6% from 87.5% to 89.1%. On top of that, it is shown through simulations that increasing the replenishment lead times lead to a significant increase in inventory of 12% in units. From this, it can be concluded that it is very important to have the correct lead times in the system, such that Slim4 can calculate the needed inventory with the correct input data.

The second research question that is answered in this chapter is *How can the shipment reliability be improved considering deviations in replenishment lead times?* To improve the shipment reliability directly, having the correct replenishment lead times in the system is extremely important, since non-SKUs are promised to be shipped to the customer within that lead time plus two working days. First of all, the measurements should be changed such that the actual replenishment lead time of the supplier can be measured separately from the internal process of booking and processing. A system should be set in place (e.g., a dashboard) which shows which suppliers/items deviate from the replenishment lead times in the system, such that the inventory planning team can take the right steps towards the purchasing department or the supplier. Doing this also helps keeping the replenishment lead times up to date. Furthermore, if deviations take place due to the internal process, actions should be taken to minimise these deviations.

Although updating and keeping the replenishment lead times lead to an increase in shipment reliability, the improvements are not enough. Therefore, the next two chapters focus on how to avoid the uncertainties that are present when ordering non-SKUs by developing a model to decide whether or not to stock an item. After that, the focus is on how to improve the inventory management.

5 Decision model SKU vs. Non-SKU

In this chapter, the goal is to determine a decision model to decide between stocking or not. The literature review shows that a model based on cost and profit can be used to decide whether or not to stock an item; however, it also shows that this is not enough, since other (non-analytical) criteria have to be considered as well. In this chapter, first the decision criteria are formulated (Section 5.1). Then, the model based on the analytical criteria is formulated by creating cost and profit functions (Section 5.2). Thereafter, the method to cope with the non-analytical criteria is formulated by designing decision trees (Section 5.3). Lastly, the needed input parameters for the analytical part of the model are determined (Section 5.4).

5.1 Decision Criteria

By combining knowledge gathered from literature and from interviews with the decision makers, the decision criteria for deciding whether or not to stock an item are found. These are listed and explained in this section. The research question for this section is *What criteria are there for a model for keeping an item in stock or not?* To ensure validity of the list, the model is tested by the decision makers (described in more detail later). Also, conversations with the decision makers have taken place. These methods have led to adding another criterion (number of customers).

5.1.1 Costs and profit

Models found in literature are often based on costs and profit, but none of the found models include both replenishment lead times and backorders. Therefore, to be able to use this criterion, a cost function under stocking and under non-stocking has to be created. From theory, it is known that inventory costs consist of holding, ordering, and shortage costs, while non-inventory costs consist of ordering and shortage costs. In Section 2.3, it is found that in Jarola's case there are also partial delivery cost that has to be considered under both stocking and non-stocking. The profit is obviously equal to the revenue minus the total cost. Using total cost functions and the expected revenue, the expected profit can be determined as well.

5.1.2 Replenishment lead time

The replenishment lead time is an important criterion, since non-stocking items should be delivered to the customer after the replenishment lead time plus two working days. The longer this lead time is, the more reason to either stock or discontinue the item, since longer lead times probably lead to fewer sales if the item is non-stocked. Furthermore, using the results from Section 2.2, uncertainty in replenishment lead times has to be considered as well. For stocked items, a large replenishment lead time means a larger safety stock, which leads to higher holding cost. For non-stocked items, the replenishment lead time should be taken into account in the backorder costs.

5.1.3 Accepted waiting time customer

Another criterion is how long the customer is willing to wait. If the item is always needed directly (e.g., service items), or at least within the replenishment lead time, the item has to be stocked. This criterion requires human judgement, because data about this criterion is not present and hard to measure. This criterion is strongly connected to the replenishment lead time, since the longer the replenishment lead time, the higher the chance that the customer is not willing to wait for that time.

5.1.4 Substitutability

If an item is substitutable and a substitute is stocked, the decision not to stock an item is easier. Then, if a customer wants the item, the first step is to offer the substitute, which in principle can be delivered from stock. If customers still want the non-stocked item, this can still be ordered, and the assortment is still broad. Substitutability is hard to model, since the right master data has to be present (which is currently not). The decision makers have knowledge about the assortment and therefore probably know if substitutes are present in the assortment.

5.1.5 Complementarity

A complementary good is "a good that is purchased and used in combination with another good" (Goolsbee, Levitt, & Syverson, 2016, p. 15). Using the orders and order lines from a year to date, the number of times an item is ordered together with the analysed item can be counted. If items are very often ordered together with the analysed item, it might be a complement. Complementarity is also subject to human judgement. E.g., a gutter needs holders. If a certain type of gutter needs a specific holder, either both the holder and the gutter should be stocked, or neither.

5.1.6 Purchasing agreements

Items can be stocked due to purchasing agreements with the supplier, such as having an entire assortment line in store, which are based on agreements with the supplier to create purchasing advantages. Furthermore, if a right of return is agreed upon with the supplier to be able to offer fast lead times to the customer and therefore having a larger chance of selling the items, stocking the item is attractive since the risk of obsolete stock is lowered. Also, suppliers can be strategic partners of the organisation, which can lead to lower purchasing prices and higher margins. In the ideal case all purchasing agreements such as right to return are known in the master data. However, this is not (always) the case.

5.1.7 Risk of obsolete

Some items might have higher risk of becoming obsolete. An example is smart lighting, due to fast development in techniques and updates, these types of items are often becoming obsolete faster than e.g., sewage pipes. Another example is glue, which has an expiration date. Using knowledge of the assortment this should be considered in the decision. If an item has a higher risk of becoming obsolete, the decision might tend to non-stocking, since the risk of inventory becoming obsolete is basically zero for non-stocked items. Having a higher risk of becoming obsolete can be modelled in the profit optimisation by increasing the holding cost parameter.

5.1.8 Strategic criticality

Strategic assortment decisions such as having the largest or broadest assortment can be a reason to stock an item. Another reason is that certain item groups are more important for the strategic goals of the organisation than other groups, e.g., tools such as drilling machines are of less importance for the strategic goals than sewerage items such as drainpipes. Strategic criticality can partly be taken from the product group and supplier; however, it remains mainly human judgement.

5.1.9 Number of customers

Next to the number of order lines (which is considered in the cost and profit optimisation), the number of customers is also an important criterion. If an item is sold multiple times, but only to one customer, the decision might still be to non-stock the item (if e.g., that customer always orders the item on time such that the item can be ordered at the supplier).

5.2 Model Formulation – Analytical Criteria

Different criteria have been identified to decide whether or not to stock an item. However, not all criteria can be determined analytically. In this section, a model will be formulated based on cost and profit and the replenishment lead time. Based on this model, an advice can be generated to stock or not to stock the item (or to discontinue). Then, in the next section, the method to cope with the other criteria to make a final decision will be discussed. The results from these sections will be used to answer the research question *How can the decision whether or not to keep an item in stock be improved?* In this section, first the requirements and general assumptions are formulated. Then, the cost functions are determined. Using these cost functions, the profit functions are determined. Based on the profit functions, the advice generation is discussed.

5.2.1 Requirements and General assumptions

- As is described in Section 2.4, the model can only be used for existing items, since new items have no historical data and there is too much human judgement involved in the decision.
- The space constraint is not considered. This is justifiable since it is found that there are also SKUs that could be non-SKUs. Furthermore, the new DC creates new space.
- It is assumed that purchasing prices are not lower if an item is stocked and that the demand under stocking is equal to the demand under non-stocking. Furthermore, it is assumed that the purchasing prices are not subject to the height of the demand. There are items that are subject to these types of agreements, however, this is exceptional.
- Sufficient data needs to be present for the item, most importantly a distribution of the demand. Slow moving items are assumed to have Compound Poisson distributed demand, while fast moving items are assumed to have Normal distributed demand. Whether an item is a slow or a fast mover is based on the class Slim4 uses, which bases this on sales and the sales pattern. Since the decision whether or not to stock is not a discussion point for fast moving items, only slow moving items will be considered.
- For the determination of the expected backorders under stocking, for the sake of simplicity, a continuous review policy with fixed order quantity (s, Q) is assumed, but the lead time is changed into the lead time plus the review period. Furthermore, full backordering is assumed.
- The chance and cost of partial deliveries will be determined based on historical data. This will be discussed in Subsection 5.4.4.

5.2.2 Cost functions

In literature, models based on costs have been found to decide whether or not to stock an item. However, none of the models suffice the situation for Jarola, e.g., Silver, Pyke, and Thomas (2017) assume negligible lead times and no safety stock. Therefore, cost functions will be determined under stocking and under non-stocking, using a similar approach as Silver, Pyke, & Thomas (2017) and (Fenske, 1968). Table 11 gives an overview of all the notations used in the following sections.

Total cost function under stocking $E[TC_S(D)]$

From theory, it is known that the total cost of an item in inventory is the sum of the holding, the ordering, the purchasing, and the shortage cost. Note that in the EOQ derivation as well as in the To Stock or Not To Stock model of Silver, Pyke, & Thomas (2017, p. 372), shortages as well as safety stock are not included. However, since shortages do occur in Jarola's situation and safety stock is present for stocked items, this has to be considered. The purchasing cost will not be considered in the cost functions, because these are included in the profit functions. Lastly, using the results from Subsection 2.4.3, the partial delivery cost has to be considered. Appendix F gives a detailed derivation and method of calculations of the total cost function under stocking.

Then, the total cost under stocking is equal to the sum of the holding, the ordering, the shortage, and the partial delivery cost. The order quantity is determined based on the EOQ, MOQ, and IOQ. If the EOQ is smaller than the MOQ, the MOQ is used. If the EOQ is larger than the MOQ, the EOQ is rounded according to the nearest multiple of the IOQ. Furthermore, the order quantity cannot exceed the total forecast for the first seven months, to avoid large quantities in stock for slow-moving items (this is in line with Jarola's current inventory management, see Subsection 2.5.4).

The holding cost is the safety stock plus the cycle stock (half the order quantity) times the holding cost parameter and the purchasing price. In the assumptions, it is mentioned that only Compound Poisson demand is considered. For Compound Poisson demand, the safety stock is determined by first determining the reorder point and then subtracting the demand during the cover period $(R + L)$, where the expected demand during the review period plus the lead time is calculated using $E[D_{R+L}] = E[D]\frac{R+L}{365}$.

Table 11: Notation used for model SKU versus Non-SKU

Notation	Definition
	Input variables
MOQ	Minimum Order Quantity
IOQ	Incremental Order Quantity
h	Yearly holding cost per item as percentage of purchase price
c_p	Purchase price per item
c_{sell}	(Average) selling price per item
c_O	Ordering cost per order
c_{Sh}	Shortage cost per item per day short as percentage of purchase price
c_{PD}	Cost per extra delivery
$p_{PD,S}$	Probability of an extra delivery under stocking
$P_{PD,NS}$	Probability of an extra delivery under non-stocking
R	Review period in days
L_{Repl}	Lead time in days
$E[J]$	Expected Order line size
VFR_{Target}	Target Service Level (Volume Fill Rate) for C-items
$E[D]$	Expected yearly demand
	Auxiliary variables
EOQ	Economic Order Quantity (calculated using Equation (2))
Q	Used order quantity (based on EOQ, IOQ and MOQ)
$E[BO]$	Backorders at an average point in time
s	Reorder point
SS	Safety stock
$E[D_{R+L}]$	Expected Demand during review period plus lead time
	Output variable
$E[C_h]$	Expected total yearly holding cost
$E[C_O]$	Expected total yearly ordering cost
$E[C_{Sh}]$	Expected total yearly shortage cost
$E[C_{PD}]$	Expected yearly partial delivery cost
$E[TC_S]$	Expected cost per year under stocking
$E[TC_{NS}]$	Expected cost per year under non-stocking
$E[P_S]$	Expected profit per year under stocking
$E[P_{NS}]$	Expected profit per year under non-stocking

To determine the reorder point, a similar but simplified approach as Slim4 uses for the slow-moving items is used. This method is easy to calculate and does not need new input parameters. It looks at the minimum number of customer arrivals/order lines that should be covered in the review period plus the lead time to realise at least the target service level. Then, using the expected order line size, the reorder point is determined.

In mathematical terms: the reorder point is calculated using the expected number of order lines during the review period: $\mu = \frac{E[D]}{E[J]}\frac{R+L}{365}$. Then, using the cumulative Poisson distribution function ($F(x;\mu) = \sum_{i=0}^{x} \frac{\mu^i e^{-\mu}}{i!}$) the minimum value of x that satisfies $F(x;\mu) \geq VFR_{Target}$ is multiplied with the expected order line size $E[J]$: $s = x * E[J]$. Then, $SS = s - E[D_{R+L}]$. VBA code to calculate the reorder point is given in Appendix F.

The order cost is the number of purchase orders per year times the order cost parameter. The number of orders per year is equal to the yearly demand divided by the order quantity. The shortage cost is the expected backorders at a random point in time times the shortage cost parameter and the purchase price. The expected backorders are determined using the approach of Axsäter (2006), who determines the distribution of the inventory level and then determines the expectation of the inventory level, given that it is smaller than or equal to zero. This is under the assumption that a continuous review policy with fixed order quantity is used, which is obviously not the case. Therefore, the lead time is changed to the lead time plus the review period to create a more realistic approach. Details and VBA-code to calculate the expected backorders are given in Appendix F.

The partial delivery cost is the number of customer orders times the chance of a partial delivery times the cost of a partial delivery. The chance of a partial delivery is per order placed by a customer for the item. The costs are the cost of a shipment. These parameters will be determined later.

The total cost function under stocking is then:

$$E[TC_S(D)] = E[C_h] + E[C_O] + E[C_{Sh}] + E[C_{PD}] \tag{3}$$

$$E[TC_S(D)] = \left(s - E[D_{R+L}] + \frac{Q}{2}\right) hc_p + \frac{E[D]}{Q} c_O + E[BO] c_{Sh} c_p + \frac{E[D]}{E[J]} p_{PD,S} c_{PD} \tag{4}$$

Total cost under non-stocking $E[TC_{NS}(D)]$

The total cost under non-stocking is different than under stocking. First, there is basically no holding cost (except if the MOQ is larger than the order line size). Secondly, the ordering cost is different, since the EOQ is not ordered. Lastly, in Subsection 2.3.2, it is found that partial deliveries are more likely to happen if a non-SKU is ordered. The total cost function under non-stocking, given that the MOQ is smaller than or equal to the expected order line size, is therefore the sum of the ordering, the shortage, and the partial delivery cost. If the MOQ is larger than the expected order line size, holding cost are also incurred.

Since an order is placed at the supplier every time a non-SKU is ordered at Jarola, the number of order lines has to be used to determine the ordering cost. This means that, given that the expected order line size is larger than or equal to the MOQ, the ordering cost under non-stocking are:

$$E[C_O] = \frac{E[D]}{E[J]} c_O \quad if\ E[J] \geq MOQ \tag{5}$$

However, if the MOQ is larger than the expected order line size, the MOQ has to be ordered at the supplier. Then, also a holding cost is incurred. The average inventory on hand is then equal to $\frac{MOQ-E[J]}{2}$, since if the purchase order is placed, a customer order is already placed and after receiving the purchase order, the purchase order is immediately cross docked to the customer. Then, the MOQ minus the ordered quantity by the customer is kept in stock and the holding and ordering cost under non-stocking are:

$$E[C_h] = \frac{MOQ - E[J]}{2} hc_p \quad if\ E[J] < MOQ \tag{6}$$

$$E[C_O] = \frac{E[D]}{MOQ} c_O \quad if\ E[J] < MOQ \tag{7}$$

These costs are based on the assumption that in the end all stock can be sold, and no extra obsolescence costs are incurred.

The shortage cost is per item per time unit as percentage of the purchase price. This is to incorporate the longer lead time to the customer into the cost function. Although the longer lead time is communicated to the customer, an item is always short since basically no inventory is held (the fill rate is zero). Therefore, the expected shortage cost is the average lead time multiplied by the expected demand multiplied by the shortage cost per item per day multiplied by the purchasing price.

$$E[C_{Sh}] = L\frac{E[D]c_{Sh}}{365}c_p \qquad if\ E[J] \geq MOQ \tag{8}$$

However, if the MOQ is larger than the order line size, there can be inventory. If there is inventory, there is no shortage, since it can be delivered from stock. The part of the orders for which an order has to be placed at the supplier is then equal to the expected order line size divided by the MOQ, since per cycle only one customer has to cope with the replenishment lead time.

$$E[C_{Sh}] = \left(\frac{E[J]}{MOQ}L\right)\frac{E[D]c_{Sh}}{365}c_p \qquad if\ E[J] < MOQ \tag{9}$$

In Subsection 2.3.2, it is found that partial deliveries are more likely to happen if a non-SKU is ordered. Every order line creates an extra chance $p_{PD,NS}$ to have a partial delivery, which will be based on historical data (these parameters should be updated periodically, since improvements should lead to a lower probability). The cost per delivery c_{PD} is dependent on the type of delivery (Truck or Package). The chances and costs will be determined later in Section 5.3. Then, the total yearly cost for partial deliveries is the number of customer orders times the chance of an extra delivery times the cost of an extra delivery.

$$E[C_{PD}] = \frac{E[D]}{E[J]}p_{PD,NS}c_{PD} \qquad if\ E[J] \geq MOQ \tag{10}$$

However, if the MOQ is higher than the order line size, there can be inventory, which leads to a lower chance of an extra delivery. Again, the part of the orders for which an order has to be placed at the supplier is the expected order line size divided by the MOQ, which means that 1 minus that probability is the chance that an order can be delivered from inventory. Therefore, the cost for partial deliveries is different if the MOQ is larger than the expected order line size:

$$E[C_{PD}] = \left(\frac{E[J]}{MOQ}\frac{E[D]}{E[J]}p_{PD,NS} + \left(1 - \frac{E[J]}{MOQ}\right)\frac{E[D]}{E[J]}p_{PD,S}\right)c_{PD} \qquad if\ E[J] < MOQ \tag{11}$$

Then, the total cost under non-stocking is:

$$E[TC_{NS}(D)] = E[C_h] + E[C_O] + E[C_{Sh}] + E[C_{PD}] \tag{12}$$

If the MOQ is smaller than or equal to the expected order line size:

$$E[TC_{NS}(D)] = \frac{E[D]}{E[J]}c_O + L\frac{E[D]c_{Sh}c_p}{365} + \frac{E[D]}{E[J]}p_{PD,NS}c_{PD} \tag{13}$$

If the MOQ is larger than the expected order line size:

$$\begin{aligned} E[TC_{NS}(D)] = {} & \frac{MOQ - E[J]}{2}hc_p + \frac{E[D]}{MOQ}c_O + \left(\frac{E[J]}{MOQ}L\right)\frac{E[D]c_{Sh}c_p}{365} \\ & + \left(\frac{E[J]}{MOQ}\frac{E[D]}{E[J]}p_{PD,NS} + \left(1 - \frac{E[J]}{MOQ}\right)\frac{E[D]}{E[J]}p_{PD,S}\right)c_{PD} \end{aligned} \tag{14}$$

5.2.3 Profit functions

It is well-known that the profit is equal to the revenue minus the cost. Using the total cost functions, the expected profit can be determined. For this, the purchasing cost does have to be considered. Note that selling price of an item can be different per customer, which means that the average selling price has to be used.

$$E[P_{NS}(D)] = E[D](c_{sell} - c_p) - E[TC_{NS}(D)] \tag{15}$$

$$E[P_S(D)] = E[D](c_{sell} - c_p) - E[TC_S(D)] \tag{16}$$

5.2.4 Advice generation

Basically, the advice generation is simple: the advised status is the status under which the profit is highest. However, a point of attention is if an item has an MOQ that is larger than the expected order line size. If this is the case, the model calculates inventory costs for the non-stocked option as well. In that case, an item is basically stocked, but according to the status it is not. The holding cost under non-stocking is always lower than under stocking, since no safety stock is held. To overcome having too many stock for items that are non-stocked by status, the advice is changed to stocking the item if the holding cost under non-stocking is more than half (50%) the holding cost under stocking. The reason 50% is chosen is since the cost under non-stocking is than significantly smaller than under stocking, although some stock is still there. However, this percentage is subject to be changed by a management decision.

Another point of attention is the possibility to extend the advice. Since profit is used to generate an advice, a negative profit for both options should result in an advice to discontinue the item. If the profit for both the stocked and the non-stocked option is smaller than 0 the advice is still either to stock or not to stock the item, based on the highest profit; however, a line is added with the advice to discontinue the item, as the costs are higher than the revenue. The reason a hard advice to discontinue the item will not be given is that human judgment plays an important role and that discontinuing is more drastic than non-stocking. Discontinuing the item means changing the item status to 131 (not in stock, not on the web shop). An example is that from a strategic perspective, having a broad assortment presented to the customer is important. Therefore, for the remainder of this research, two approaches are used to generate advices with the model. The first approach does not include the option to discontinue, while the second does.

Profit optimisation without discontinuation

The advice to stock or not is generated based on the highest profit. If holding cost under non-stocking are incurred and the holding cost under non-stocking are larger than 50% of the holding cost under stocking, the advice is to stock the item.

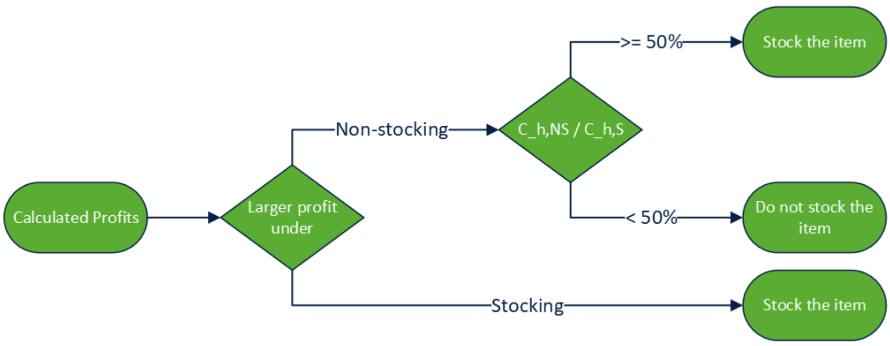

Figure 9: Decision tree - profit optimisation

Profit optimisation with discontinuation

The advice is extended with the option to discontinue in case both profits are smaller than 0. The discontinuation advice is still combined with the advice if discontinuing would not have been included, such that the decision maker knows what the second-best option would be if e.g., it is important to keep the item in the assortment from a strategic perspective.

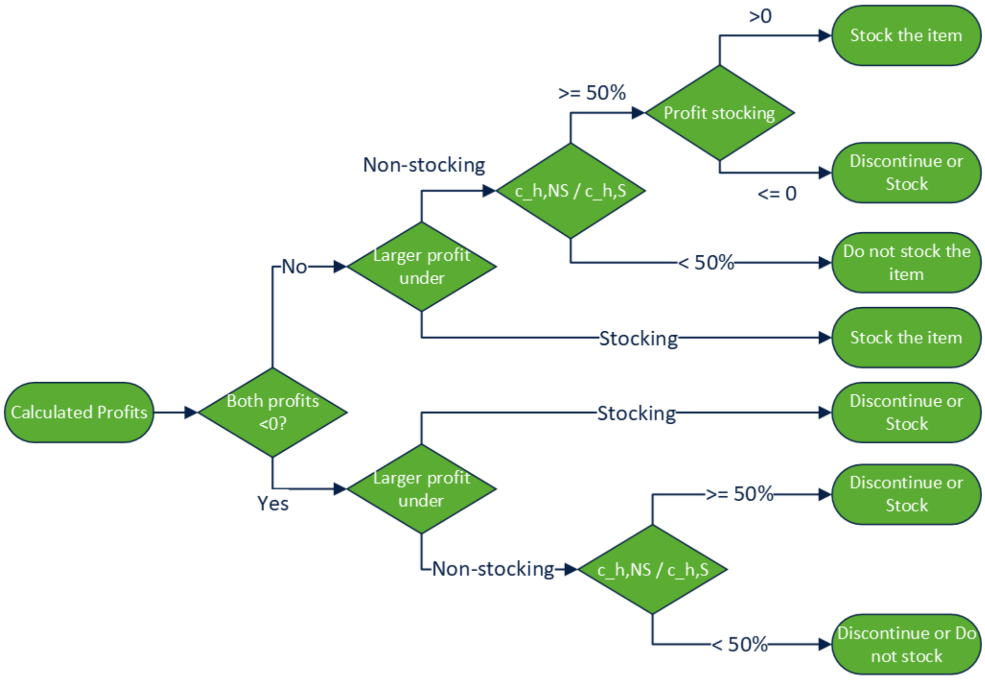

Figure 10: Decision tree - profit optimisation with option to discontinue

5.2.5 Dashboard

To help the decision maker, a dashboard is created with all available and necessary information to make the decision. A working prototype is created with a dashboard (Figure 12). Below Figure 12, an explanation is given of the dashboard. When using the model in practice, it is convenient for the decision maker to see all items that are advised to be changed per supplier. To this end, the prototype has the option to create a list with all items that are advised to change of the to be analysed supplier, which is automatically sorted in descending order on the absolute difference between the profits under stocking and under non-stocking (Figure 11).

ARTIKELEN DIE WIJZIGING ADVIES HEBBEN						
Leveranciernummer						
Artikelen in assortiment	4293	Vind alle artikelen met wijzigingadvies van leveranciernummer				
Artikelen berekend	2842		Opmerking (VRP)			
Artikelen met wijzigingsadvies	243		Opmerking (Slim4)			
Artikelbeschrijving	Artikelnummer	Huidige status	Advies	Winst Voorraadhoudend	Winst Niet-v	Verschil
		STOCKED	NONSTOCK	€ -202.22	€ 0.00	€ 202.22
		NONSTOCKED	NONSTOCK OR DISCONTINUE	€ -202.09	€ -9.32	€ 192.77
		NONSTOCKED	STOCK OR DISCONTINUE	€ -20.53	€ -167.01	€ 146.48
		NONSTOCKED	NONSTOCK OR DISCONTINUE	€ -128.19	€ -12.41	€ 115.78
		NONSTOCKED	NONSTOCK OR DISCONTINUE	€ -107.46	€ -12.43	€ 95.03
		NONSTOCKED	STOCK	€ 123.94	€ 29.09	€ 94.85
		STOCKED	NONSTOCK	€ 185.79	€ 277.90	€ 92.11
		NONSTOCKED	NONSTOCK OR DISCONTINUE	€ -90.62	€ -0.54	€ 90.08
		STOCKED	STOCK OR DISCONTINUE	€ -4.84	€ -88.56	€ 83.72
		NONSTOCKED	STOCK	€ 83.77	€ 2.25	€ 81.52
		NONSTOCKED	STOCK	€ 176.23	€ 99.84	€ 76.39

Figure 11: List of advised items per supplier, sorted in descending order on profit difference

5.2.6 Conclusion

The profit functions can be used to generate an advice to stock, non-stock or stock/non-stock or discontinue the item. However, this advice does not consider the non-analytical criteria (accepted waiting time customer, substitutability, complementarity, purchasing agreements, risk of obsolescence, number of customers, and strategic criticality). The next section focuses on how to cope with the non-analytical criteria, to make the final decision.

Figure 12: Dashboard with necessary and available information (Dutch) (Based on random prices and parameters)

1. The basic information of the item: the purchasing price, the average selling price, the average margin (these are not displayed due to confidentiality issues), unit, replenishment lead time, review period, product group, sales class in Slim4, ABC-class and corresponding service level, current status and latest change, order quantity constraints for replenishment and for the customer.
2. The basic information of the supplier: the average days too late (from ordering to booking at the DC), the minimum order amount, extra shipping cost, the number of orders placed year-to-date, the order and delivery schedule and the comments that are added by the inventory planning team.
3. Complementarity: by clicking on the button, the data is checked for complementarity and the top 10 items that are ordered together with the checked item are displayed, with the status of that item and the number of matching orders. For the prototype, code is written to check for complementarity and the item numbers with the number of matching orders is given.
4. Sales and order lines year-to-date: a graph of the sales and number of order lines per month (negative demand are returns).
5. Sales and order lines year-to-date and expecting: the total sales and order lines and the expected sales and order lines. The possibility to manually fill in the expected sales is created.
6. The cost optimisation: the cost for the expected sales given in block 5 is given here. The total cost is also given, and the advice based on the profit is given (green cell).
7. A graph of the total cost under stocking and under non-stocking for an expected demand range around the expected sales and order lines.
8. The advice based on the profit, based on the decision tree in Figure 10.

5.3 Model Formulation – Non-analytical Criteria

To cope with the non-analytical criteria, decision trees will be created for three options: (1) if the advice is to change the item from non-stocked to stocked, (2) if the advice is to change from stocked to non-stocked, and (3) if the advice is to discontinue.

5.3.1 From Non-stocked to Stocked

If an item is advised to change from non-stocked to stocked, the first criterion that is important is if there are stocked substitutes in the assortment. If this is the case, the decision maker should manually check the decision. If e.g. the substitute is sufficient to fulfil at least the demand that is needed within the customer lead time, the item might still be better off non-stocked. The next criterion is if the item is strategically important and if there are purchasing agreements in place. If the item is not of strategic importance, it could be that non-stocking the item is better. On the other hand, if the corresponding supplier accepts returns, the item might be stocked. The third criterion is if the number of customers is lower than the number of order lines. If there are many order lines coming from only one customer and this customer never needs the item within the customer lead time, the item might still be better off non-stocked. Then, the decision maker should check if the item has a high risk of obsolescence and if the expected sales can cope with the risk of obsolescence.

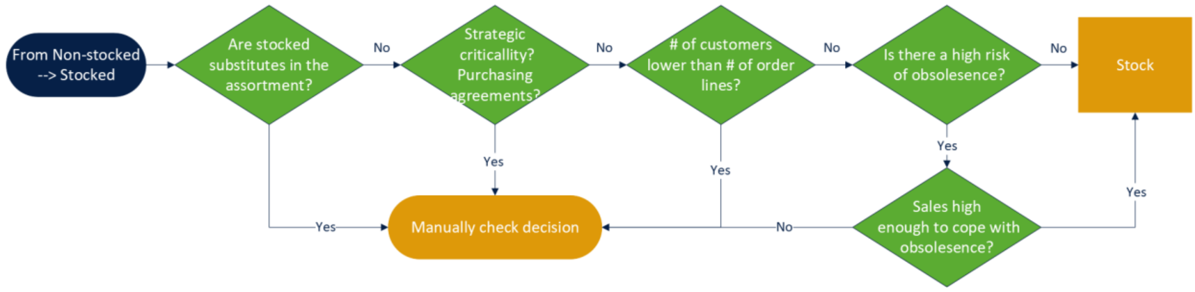

Figure 13: Decision tree - Advice from Non-stocked to Stocked

5.3.2 From Stocked to Non-stocked

Changing an item from stocked to non-stocked requires the decision maker to check if the item is often needed within the customer lead time. If this is the case, and no substitutes are stocked to cover this demand, it might be better to stock the item. Furthermore, the decision maker should check if there are stocked complements. If this is the case and no substitutes are stocked, it might again be better to stock the item to cope with complementarity. Lastly, the decision maker should consider if the item has purchasing agreements such as displaying that item in the stores or that the item is strategically important. If this is the case, it might be needed to stock instead of non-stock.

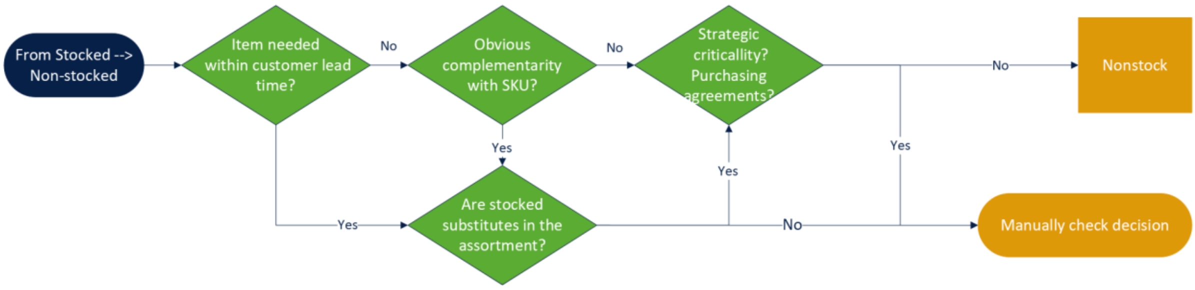

Figure 14: Decision tree - Advice from Stocked to Non-stocked

5.3.3 To Discontinue

Discontinuing an item means not displaying the item to the customer anymore; however, the item does stay in the portfolio. If the item is a complement of a stocked item, it could be better to keep the item stocked or to also discontinue the complement. Again, if substitutes are stocked, this might change this decision. Lastly, it might be that the item should be displayed to the customer to keep the broad assortment from strategic perspective or by purchasing agreements.

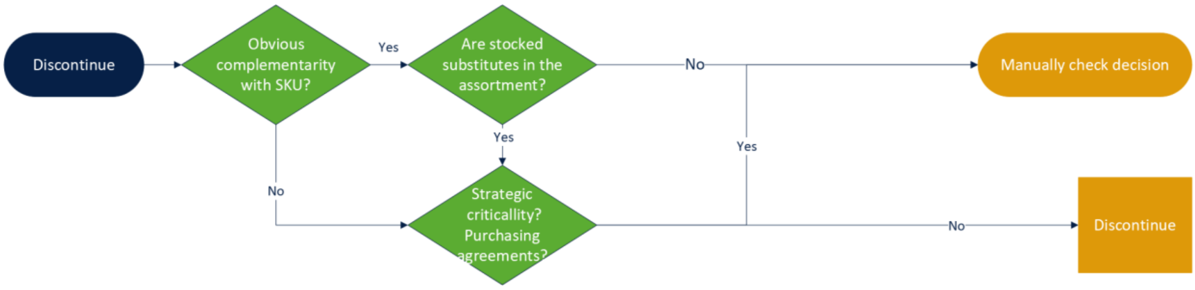

Figure 15: Decision tree - Advice to Discontinue

5.3.4 Conclusion

The research question addressed in the previous two sections is *How can the decision whether or not to keep an item in stock be improved?* Using the profit and cost functions, an advice can be generated to stock, non-stock or discontinue the item. This advice is, however, without considering the non-analytical criteria. To cope with the non-analytical criteria, decision trees are created per possible advice. This combines the analytical criteria with the non-analytical criteria and with human judgement, which leads to a well-considered decision to stock, non-stock, or discontinue the item.

5.4 Input parameters

Now that the model is determined, the input parameters need to be determined. The research question *What are the correct input parameters for the model?* is addressed in this section. For the cost/profit optimisation, the holding, ordering, shortage, and partial delivery cost have to be determined. Furthermore, the chance of a partial delivery for stocked and non-stocked items has to be determined. Also, the measured lead times will be used instead of the lead time in the system (based on Section 2.2). Details of the parameter determination are given in Appendix G.

5.4.1 Holding cost

The holding cost are determined following the approach of Durlinger (2016), which means that the holding cost consists out of the WACC, the storage, and the risk cost. The holding cost is determined per year as percentage of the purchase price. Durlinger's (2016) suggestion to differentiate over the volume is not followed; however, this is a suggestion for further research, since Jarola does have items in inventory that are not that expensive, but do have a high volume.

The WACC can be calculated, however, this percentage is also a predetermined percentage available at the controller. No change is needed in the WACC, so the current WACC of **10%** will be used. For the storage cost, two approaches are used, the first based on the storage cost at a logistic service provider and the second based on internal cost. The differences in outcomes of these approaches are not significant (**6.0% and 6.7%**). The risk cost is found to be **4.0%.** Summing these three terms leads to a holding cost between 20.0% and 20.7%. This number is rounded to **20%**. The currently used holding cost is 25%, which means that the holding cost parameter is indeed lower.

For some items, an addition for handling and depreciation is used. Some items have handling cost for e.g., packing single items in a bag of 25 pieces. On top of the standard holding cost, this addition is added to the holding cost per item. If an addition is used, this is on average 38.1% of the purchase price. However, this is largely due to the handling cost (51.5% on average). Only considering depreciation, the addition is on average 8.5%. Currently, only 33 items have an addition for handling and only 56 items have an addition for depreciation. From the responsible department is found that the cost price additions are currently not up-to-date and therefore need improvement to become more accurate. Although many items do not have an addition, while they might need to have one, for the time being these additions are used during the research.

5.4.2 Ordering cost

To determine the ordering cost, again Durlinger's (2016) approach is used. Following Durlinger's (2016) suggestion to differentiate over the supplier, the ordering cost will be determined in two parts: the costs independent of supplier and the transportation costs per supplier.

The ordering cost (excluding transportation) is determined by summing all costs that are incremental with the number of orders related to ordering products. E.g., the purchasing department is not considered in the cost determination; however, the receiving team and the inventory planning team are. It is found that the order cost per order line is equal to **€10.** The found order cost is equal to the currently used order cost. It is however important to note that this is without the transportation cost. As mentioned, a cost price is used which is the purchase price plus possible additions. Furthermore, for some suppliers the goods are picked up at the supplier and the costs are paid by Jarola, while some compensation might be paid to Jarola by the supplier. This means that a distinction has to be made for items that have transportation cost through a cost price and items that do not: items that do have transportation cost through a cost price should use an order cost of **€10 + Addition** (different per item). Items that do not have transportation cost through a cost price should use an order cost of €10.05 + €4.58 = €14.63, which is rounded to **€15,-.**

In the ideal case, all items should have a fitting cost price addition, which means that if that addition is zero, deliveries are free. If deliveries are free, the ordering cost is lower which means that orders should be placed more often. This can have a positive influence on the inventory costs, since ordering more often leads to a decrease in cycle inventory. It is therefore recommended to update the additions and to keep these up to date. Another option would be to clearly determine a transportation cost per order line per supplier and use this on top of the €10,-. To cope with extra transportation cost specifically for non-stocked items (e.g., if the minimum order amount cannot be ordered and extra transportation cost are incurred) an extra field is created in the prototype.

5.4.3 Shortage cost

The shortage cost has to be determined under stocking and under non-stocking. If a shortage occurs under stocking, this leads to either backordering or lost sales. If an order is backordered too long, it can lead to lost sales afterwards as well. However, based on historical data, we assume full backordering. Factors such as customer satisfaction and reputation damage have to be considered but are very hard to measure cost-wise. Fortunately, a relationship is found between the shortage cost per time unit per unit short (B_3) and the volume fill rate (P_2), given the holding cost parameter (h). Following Axsäter (2006), the following relationship is found:

$$B_3 = \frac{hP_2}{1 - P_2} \tag{17}$$

This relationship is found under a continuous review policy with fixed order quantity. Since a periodic review policy is used in Jarola's case, this is not completely valid. Furthermore, for Poisson demand, this relationship only holds if demand is full Poisson. Since used demand distribution is a Compound Poisson demand distribution, this is also violated. However, determining the shortage cost using other methods is very hard, therefore the assumption is made that this relationship holds for Jarola's case.

If an item is not in stock, there is always a shortage when an order is placed by a customer. Obviously, the shortage cost from Equation (15) is meant to be determined for stocked items, since a non-stocked item has a fill rate of zero. However, to be consistent and for simplicity, the same cost parameter will be used for non-stocked items by using the fill rate that would have been used if the item would be a stocked item. This is justified, since the parameter is per time unit per item as percentage of the purchase price.

To check if the assumptions and simplifications that are made are justified, a sensitivity analysis will be conducted on this parameter. For now, using $h = 20\%$ and $P_2 = 85\%$, the shortage cost that will be used is 113%.

5.4.4 Partial Deliveries chance and costs

The chance of a partial delivery happening is based on the dataset from 2021. These chances should be updated over time, since improvements in processes might decrease the chances and therefore the costs. The packing slip date is used as actual shipment date. Therefore, if an order has multiple packing slip dates, there are multiple deliveries. If the packing slip date of an order line is larger than the minimum packing slip date of the order, the item is considered as a cause for a partial delivery. Then, counting the number of times the item (or order line) is considered as the cause and counting the number of times the item is considered in total (total number of order lines with that item) and dividing these, the probability of a partial delivery per item is determined. This probability obviously only holds under the status the item is in at the moment of measuring. Therefore, the average over the product groups for stocked and for non-stocked items is determined. For the determination of this average, only items with at least ten order lines in 2021 are considered, to create a solid base.

Then, if the item had at least ten order lines in 2021, the empirically determined probability is used for the calculation of the cost for the status the item is currently in. The average of the product group for the other status (stocked/non-stocked) is used for the calculation of the cost for other status (so, the status the item might be changed to). If the item had less than ten order lines in 2021, the average probability of the product group is also used for the cost of the status the item is currently in. On average, the probability of a stocked item having a partial delivery is 2.8%. For a non-stocked item, this is 11.8%.

The cost of partial deliveries is dependent on the delivery method that is needed for the item. If an item needs to be transported via truck, the costs are higher than if the item is shipped via a package. For the customer, the shipping costs are €5.75 for a package item and €50.00 for a truck item. However, using the full amount is not fair, because for low demand, these costs are dominant very fast, and shipments might be consolidated. Therefore, these costs are divided by two: €2.88 and €25,-.

5.4.5 Replenishment lead times

The model also requires the replenishment lead time as input. The replenishment lead times are present in the system per item; however, in Section 2.2, it is found that these are not as trustworthy as they should be. Due to the evaluated items being slow movers, just using the realised lead times is not fair as one outlier can increase the cost significantly and therefore give an unfair advice. Therefore, a weighted average is used which is determined by weighing the realised lead times by the number of purchase order lines and the lead time in the system as one. If only one purchase order line is placed in the previous year for the item, the average between that realised lead time and the lead time in the system is used. However, if many purchase order lines are placed, the realised replenishment lead times are becoming more important.

$$LT_{Used} = \frac{\#POlines * LT_{Real} + LT_{System}}{\#POlines + 1} \tag{18}$$

5.5 Conclusion

The first research question that is addressed in this chapter is *What criteria are there for a model for keeping an item in stock or not?* The found criteria are costs and profit, replenishment lead time, accepted waiting time of the customer, substitutability, complementarity, purchasing agreements, risk of obsolete, strategic criticality, and number of customers.

The second research question that is addressed is *How can the decision whether or not to keep an item in stock be improved?* A model is created to decide whether to stock, not to stock, or discontinue an item. An advice can be generated based on the profit functions, which leads to two types of advices: (1) is either stock or not stock the item and (2) is stock, non-stock or stock/non-stock or discontinue the item. Since the decision cannot be made based on the model alone, a dashboard is created for the decision maker. Furthermore, decision trees are created for coping with the non-analytical criteria. Using the advice that is generated by the model, the dashboard, the decision trees, and human judgement, a well-considered decision can be made for the item.

The third and last research question that is addressed in this chapter is *What are the correct input parameters for the model?* It is found that the current ordering and holding cost are indeed not up to date. The ordering cost per order line are found to be €10 + additions if an item has additions that should be considered as ordering cost, and €15 if there are no additions. The holding cost is found to be 20%. The backorder costs are found to be 113% as percentage of the purchase price per year. The partial delivery chance is item dependent and based on historical data (2021), the same holds for the realised replenishment lead times.

6 Evaluation and Implementation Model SKU vs. Non-SKU

In Chapter 5, a model is created to give advice to stock, to not stock, or to discontinue an item. Then, the model gives the available information to the decision maker and decision trees to cope with the non-analytical criteria. In this chapter, first the way the list of evaluated items is determined is described (Section 6.1). Then, the model verification and validation are described (Section 6.2). Next, the model is evaluated (Section 6.3) and a sensitivity analysis is performed (Section 6.4). Lastly, the limitations are discussed (Section 6.5) and an implementation plan is formulated (Section 6.6).

6.1 Evaluated Items

The research question for this section is *For which items should an advice be generated?* The goal of the model is to decide whether or not to stock an item. Many items do not need an advice, because the current status is obviously not to be changed. Also, the decision requires human judgement. Therefore, to reduce the workload, the number of items should be reduced. First, for this analysis, the date the status is last changed should be at least one year ago, since otherwise the data gathered is not representative for that status or it might be that the item is new in the assortment. Also, this makes sure that items are not constantly changing from status.

For the stocked items, only the common items are considered (status 100, 110, and 120, see Appendix A), e.g. customer-specific items are left out. Service items are excluded, because these are often needed to be stocked, to be able to serve the customer quickly. Since fast moving items are not open for discussion, only the slow movers are included. Whether an item is a slow mover is based on the demand class that is used in Slim4, only the demand classes irregular, slow, and all sales zero are included. For non-stocked items, only status 130 (non-stocked, displayed on web shop) and 131 (non-stocked, not displayed on web shop) are considered. This is in line with the scope. Many non-stocked items have not been sold at all in the previous year. If this is the case, the item does not have to be considered, since the item should be non-stocked. Using these exclusions, the total number of items considered is reduced from 247,697 to 10,962 (Table 12).

Table 12: Items included and excluded in evaluation model SKU versus Non-SKU

All items			**247,697**
Filtering on date last status change (<01/01/2021)	247,697	-90,558 =	**157,139**
Filtering on common items (status 100, 110, 120)	**157,139**	**-152,316 =**	**4,823**
Filtering on demand class	4,823	-2,491 =	2,332
Items considered (status 100, 110, 120)			**2,332**
Filtering on item status 130, 131	**157,139**	**-31,045 =**	**126,094**
Filtering on sales 2021 being <= 0	126,094	-117,464 =	8,630
Items considered (status 130, 131)			**8,630**
Items considered in total		**2,332 + 8,630 =**	**10,962**

6.2 Model Verification and Validation

The developed analytical part of the model is an abstraction of reality. Therefore, this part of the model needs to be verified and validated. The model is extensively tested by a prototype model, which is built up step-by-step. Testing if changes have the wished effects has constantly taken place. The results of the model are compared with the opinions of experts (which is a proper method of validation according to Law (2013)). The goal is (1) to check if the model represents reality by comparing with expert opinions and (2) to find flaws and possibilities for improvement (debugging).

Two random samples of 100 items are created. The samples are drawn from the items for which an advice is generated (Table 12), this does not mean that the advice is to change the status of the item. Each set of items is checked by two different decision makers. The decision makers are asked to first decide whether to stock the item or not based on the current way of working, so on sales, experience and gut feeling, without having the advice of the model. Then, the decision maker is asked to make the decision using the model and the advice the model has generated. The decision maker is asked to make a decision with and without considering the possibility of discontinuing. Per list and per decision maker the deviations are analysed and the reason for the deviation is noted.

The following reasons are found in the deviations:
- **MOQ** – If the advice to stock an item is due to the MOQ, but the decision maker decides not to stock the item.
- **Wrong data input (model failure)** – The prototype model is built in Excel using exported data. It is found that some orders have been cancelled or returned since the data is exported, which led to wrong data input for some items.
- **Advice model stocked or discontinue, discontinue advice is followed up** – The decision maker is asked to decide with and without the option to discontinue. If the advice is to stock or to discontinue, this means that the advice is to stock if the option to discontinue is not considered. Looking at historical sales this advice is not logical, which often leads to deviations. In this case, the discontinue advice is followed up for the decision where discontinuing is an option.
- **Advice model stocked or discontinue** – The same as above holds, however, in this case, the decision is to non-stock, while the advice was to stock or to discontinue and the discontinuation advice is not followed up.
- **High risk of obsolescence** – If the model advised to stock the item, but the decision maker decided to non-stock the item due to risk of obsolescence.
- **Number of customers** – The model does not consider the number of different customers that have placed an order. If only one customer has placed multiple orders, this might tend to non-stocking more than if multiple customers have placed orders.
- **Doubtful item** – For some items the profits under stocking and under non-stocking are very close to each other. If this is the case and the decision maker decides to not follow the advice, it is considered a doubtful item.

Table 13: Results validation (number of items checked = 100)

Item list	1		2	
Decision maker – List	1	2	3	4
Number of deviations	**31**	**26**	**24**	**24**
MOQ	3	4	1	0
Wrong data input (model failure)	1	0	2	1
Advice model stocked or Discontinue (Discontinue advice is followed up)	3	0	0	0
Advice model stocked or discontinue	3	7	8	8
Risk of obsolescence high	1	0	0	0
Number of customers	0	2	2	2
Doubtful item	20	13	11	13

From Table 13, it can be concluded the 74% of the advices are followed up. An important criterion that should be added as criterion is the number of customers, since 3 out of 4 decision makers added this as motivation for deviations. Another important point of attention is when both profits are smaller than zero, but the profit under stocking is still larger than the profit under non-stocking. The advice is then to stock or discontinue the item, but the result is that the decision makers still decide to not stock the item. This category could also be considered as doubtful items, but it is a rather large group of items.

A remarkable result is that only decision maker 1 has used the discontinue option. The decision maker followed the advice 14 times out of the 31 times it was advised. The other decision makers did not use the discontinue option at all (the other set also had 31 items with the advice to be discontinued). This means that this advice is less trustworthy with respect to the opinion of the experts than the advice without option to discontinue. Overall, the conclusion is that the model definitely needs human judgement to be able to be used in practice, but the advices are good most of the times (74%).

6.3 Model Evaluation

This section is used to answer the research question *What are the effects of the decision model on the shipment reliability and costs?* The model is used to generate advices over the 10,962 items (Table 12). Only considering the options to stock or not to stock leads to 4,030 advices to change, which is 36.8% of the total considered items. Using the advice decision tree with option to discontinue leads to 5,336 advices to change, from which 1,635 are to either keep the current status or to discontinue (Table 14). Note that 78.7% of the considered items are currently non-stocked, which explains why the largest part of the advised changes is from non-stocked to stocked.

Table 14: Advices Model stock or not (items considered are 10,962)

From	To	Advice based on	
		Profit	**Profit and discontinue**
Stocked	**Non-stocked**	794	228
Non-stocked	**Stocked**	3,236	1,946
Stocked	**Discontinue**	0	807
Non-stocked	**Discontinue**	0	2,355
Total		4,030	5,336
% Of items advised to change		36.8%	48.7%

The non-analytical criteria cannot be used for the evaluation, since this is very time-consuming and this needs to be judged by the decision makers. In practice, the model would be used to review a small set of items periodically, instead of reviewing all 10,962 items at once. Therefore, for the evaluation is assumed that all advices are followed up. Under this assumption, the costs and the profits are calculated. Since this is based on profit and cost optimisation, it makes sense that the costs decrease. Using the advice without considering discontinuation, the costs decrease with 26.7% and the profit increases with 6.7%. Using the advice with the option to discontinue, the costs decrease even further with 39.8% and the profit increases more with 8.6% with regard to the current situation. In the current situation, the largest part of the total cost is due to the ordering cost (Figure 16). Although this remains the largest part, this decreases when using the advices. This makes sense, since most changes are from non-stocked to stocked. For stocked items, a more economic order quantity can be used instead of always directly ordering what the customer orders. The same reasoning explains why the holding cost increase and the shortage cost decrease. Overall, the total cost decrease and the profit increases significantly. Details of the costs and profits are given in Appendix H.

Figure 16: Cost distribution and total cost and profit per situation Evaluation model SKU versus Non-SKU

The average purchase price over all items for which an advice is generated is €50.67. Remarkably, the average price of the items that are advised to change is €29.11. Even more remarkable is that the average price of items that are advised to be discontinued is €19.56. It does make sense, since the highest cost factor is the ordering cost, which is not dependent on the purchase price. The other cost factors are, which means that the lower the purchase price, the more influence the ordering cost have, the higher the chance that the item is advised to be stocked or discontinued. Items that are advised to change from non-stocked to stocked have a lower purchase and selling price than items that are advised to change from stocked to non-stocked, but the margins are high. Items that are advised to be discontinued have a low purchase price and a low margin. From this, it can be concluded that low-valued items with low margins should be checked at with more care, since discontinuing might be a better option. Other low-valued items should also be checked at with more care, since the ordering cost are relatively high.

Figure 17: Average Purchase price (columns) and Margin (line) per advice

Looking at the number of considered items and the number of advised changes per product group, H19 – Pressure pipes and Fittings (e.g., compression couplings) is the largest product group. This product group also has the largest number of items that are advised to change from stocked to non-stocked. Furthermore, many items are advised to be discontinued. This is a strategically important product group with many items and many choices for the customer, which means that human judgement plays an important role and substitutes, complements, and having a broad assortment should be considered. Product group H24 – Tools has the most items that are advised to change from non-stocked to stocked, or to be discontinued. This means that items are cheaper to be stocked than to be non-stocked, but discontinuing is even better according to the model. This is, contrary to H19, a strategically less important product group, which also results in lower margins. For this product group, it is important to check the strategic importance considering having a broad assortment, but also not having more items than necessary in the assortment. This again proves that human judgement still plays an important part in the determination of stocking or not. Appendix A gives an overview of all product groups and the corresponding descriptions.

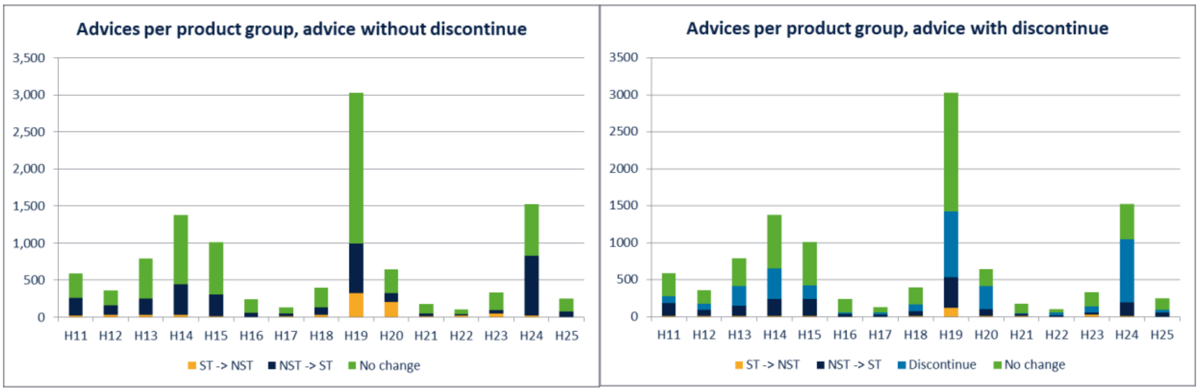

Figure 18: Advises per product group, (a) advice without discontinue, (b) advice with discontinue

Since the main goal of the research is to increase delivery reliability (or shipment reliability), the advices from the model are used to simulate the effects on the shipment reliability. The same data to determine the shipment reliability in Subsection 2.1.2 is used (which are the sales orders over 2021). The results are evaluated for both methods, by using the advice directly, without human judgement. For the advice with the option to discontinue, the order lines are not considered in the analysis if the advice is to discontinue, which means less order lines. If the status of the item in the order line is changed, the order line is now considered on time if a randomly generated number between 0 and 1 is smaller than or equal to the calculated shipment reliability for the new status over 2021. For stocked order lines, the realised shipment reliability over the considered order lines is used (which is 88.1%), because using the overall would not be fair since fast movers with high service levels are also included in that analysis. For non-stocked order lines, the overall shipment reliability over 2021 is used: 71.6%. The number of order lines with an item for which an advice is generated is reduced from 836,769 to 27,279. The current situation is given in Table 15.

Table 15: Current situation – Stocked versus Non-stocked

	Total	Stocked	Non-stocked
Number of order lines	836,769	792,879	43,890
Order lines on time	750,383 (89.7%)	718,943 (90.7%)	31,440 (71.6%)
Number of order lines (analysed items)	27,279	11,880	15,399
Order lines on time (analysed items)	17,172 (62.9%)	10,472 (88.1%)	6,700 (43.5%)

For the simulation, the parameters that are found in Section 5.3 are used. The advised status of the item is used for the data of 2021. The results are given in Table 16. The overall shipment reliability over the order lines is increased with 0.5% (advice without discontinuation) and 0.6% (advice with discontinuation). The shipment reliability over the orders is increased as well, with 0.9% (advice without discontinuation) to 88.3% and 1.1% (advice with discontinuation) to 88.5%. Knowing that only 3.3% of the order lines are considered, the increase is still significant. This is mainly due to many non-stocked order lines changing to stocked order lines, which means that the uncertainties are avoided from a customer's perspective. The shipment reliability over the orders increases more than the reliability over the order lines, which points to that non-SKUs are the cause of many orders not being shipped on time.

Table 16: Simulation – Model Stocked versus Non-stocked

Profit	**Total**	**Stocked**	**Non-stocked**
Number of order lines	836,769	801,799	34,970
Order lines on time	754,471 (90.2%)	726,826 (90.6%)	27,645 (79.1%)
Difference	**+0.5%**	**0.0%**	**+7.4%**
Number of order lines (analysed items)	27,279	20,800	6,479
Order lines on time (analysed items)	21,260 (77.9%)	18,355 (88.2%)	2,905 (44.8%)
Difference	**+15.0%**	**+0.1%**	**+1.3%**
Profit with discontinue	**Total**	**Stocked**	**Non-stocked**
Number of order lines	831,899	798,351	33,548
Order lines on time	750,826 (90.3%)	723,764 (90.7%)	27,062 (80.7%)
Difference	**+0.6%**	**0.0%**	**+9.0%**
Number of order lines (analysed items)	22,409	17,352	5,057
Order lines on time (analysed items)	17,615 (78.6%)	15,293 (88.1%)	2,322 (45.9%)
Difference	**+15.7%**	**+0.0%**	**+2.4%**

Figure 19 gives the effect the order lines in a product group have on the overall shipment reliability. From this, it can be concluded that mainly product group H24 – Tools can have a significant effect on the overall reliability, especially since the number of order lines is relatively low. It is remarkable that product group H24 has such a significant effect on the overall reliability, since this is not a strategically important product group. It does make sense, since many order lines are non-stocked. Also, product group H19 – Pressure pipes and fittings can have a significant effect on the overall reliability, however, there are also many order lines that are coming from that product group.

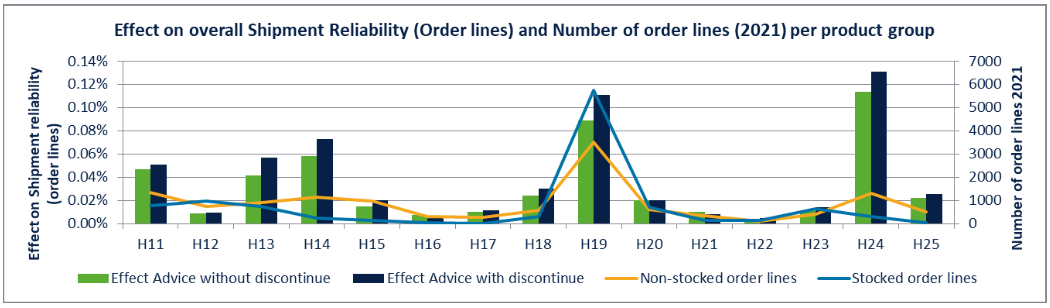

Figure 19: Increase in Shipment Reliability (order lines) after advises

The conclusion that can be drawn from this simulation is that the model does help to avoid the uncertainties that play an important role for non-stocked items. The changes are mainly from non-stocked to stocked, or from non-stocked to discontinue. Since the advice is based on cost/profit optimisation, the costs are obviously lowered using the advice. However, the results are not as significant as wished for, since the overall shipment reliability over the order lines only increases with 0.5% (advice without option to discontinue) or 0.6% (advice with option to discontinue). The increase is more significant looking at the shipment reliability over the orders: 0.9% (advice without discontinuation) and 1.1% (advice with discontinuation). Looking at the product groups, mainly product group H24 – Tools should be checked for the decision whether or not to stock the items, since the effects on the shipment reliability are the largest, while not having the most order lines.

6.4 Sensitivity analysis

Details of the Sensitivity analysis can be found in Appendix H. A sensitivity analysis is done on the following parameters:

- Holding cost: the holding cost is set to 18% and to 22%, since the standard holding cost is 20%. It is found that the model is not sensitive to the holding cost.
- Ordering cost: the ordering cost is set to €10 and to €12.5, instead of the standard €15. For items with an addition, the standard €10 + addition is used. It is again found that the model is not sensitive to the ordering cost. However, it should be noted that this could change when specific transportation cost is added per supplier.
- Partial delivery cost: the partial delivery cost is set to €5 and €1 for a package shipment and to €30 and €20 for a truck shipment. It is found that the model is rather sensitive to these costs. For the €5 (package) and €30 (truck), the number of items that are advised to change from non-stocked to stocked is 3,547, while this is only 2,867 for the €1 (package) and €20 (truck). This holds only for the advice without the option to discontinue. The option with discontinuation is not that sensitive to the partial delivery cost. Knowing this makes it important to update the chances of a partial delivery per item, since these change over time when processes are improved.
- Service level for stocked C-items: changing the service levels from 85% to 80% and 90% does not result in significant changes, which means that the model is not that sensitive to the service level.

- Note that no sensitivity analysis is done on the backorder costs. This is since that parameter is dependent on both the service level and the holding cost (Equation (17)). Considering that the model is not sensitive to those two parameters, we can conclude that the model is also not sensitive to the backorder costs.

6.5 Limitations

Unfortunately, the model has certain limitations. First, the profit optimisation does not consider the number of customers, as it only considers the number of order lines. An item that is often ordered by the same customer that does not need the item within the replenishment lead time plus two working days might be better off to be non-stocked, but due to having multiple order lines, the model probably advises to stock the item. Next to the number of customers, the other criteria that are not modelled or analysed analytically are a limitation, since the decision cannot be automated, and it is still an advice model.

In the current evaluation, the service items are not considered on purpose. Service items are needed to be stocked, since these are often needed very quickly, e.g., to prevent down time on certain machines. There are however service items that might not be needed to be stocked anymore, because the machines that these are used for are no longer in the market. This, however, depends fully on human judgement and is therefore left out of the model evaluation. Furthermore, the used ordering and holding cost are based on the additions that are currently in the system. It might be that these are not up to date for all items and that for these are either under or overestimated.

Also, it is assumed that the sales are equal under stocking and under non-stocking; however, one can understand that it is likely that a customer orders a product sooner if an item is in stock than if the item shows a lead time that is longer, or even “On request”. Furthermore, the assumption that the purchasing price is equal under stocking and under non-stocking might not be true, since sourcing larger quantities often leads to lower purchasing prices. Moreover, the model assumes that if an MOQ should be ordered, all items are sold eventually, without having more chance of obsolescence. This might, however, not be a correct assumption since we are dealing with slow movers. Lastly, the model is currently based on and tested on 2021 data. Doing this means that there is chance of overfitting data over the used data. Due to 2020 being a non-representative year (due to Covid-19), this could not have been avoided.

6.6 Implementation

The research question addressed in this section is *How can the model to decide whether or not to keep an item in stock be implemented in the organisation?* The model requires implementation from an organisational perspective and from a technical perspective. These are discussed separately.

6.6.1 Organisational Implementation

The organisational perspective focuses on how the processes can be implemented through departments and people. Implementing a model requires change management. The end-user must understand why a change is required and why the model is implemented. To do so, the problem analysis can be used. It is clear that there are many uncertainties in the ordering process of a non-SKU (Figure 7) and it is also clear from the data that there are non-SKUs that might be better off being non-SKUs and the other way around (Figure 8).

Deciding whether or not to stock an item cannot be done for all items and also not every day. Therefore, the advice should be generated periodically for a set of items that are taken by some business rules. In Section 6.1, it is described which items are used for the evaluation. These steps can also be used as standard business rules.

Obviously, checking every item every day, week or even month is not realistic. Therefore, it is recommended to check every supplier periodically. It is recommended to do so once every half year, however, this is open for discussion and can also be dependent on the supplier. In the used data for the evaluation, there were 130 suppliers with at least one item that is advised to change. This means that if all suppliers should be checked twice per year, there are 260 checks. If checking is a weekly task, assuming 45 working weeks per year (holidays etc.), this means every week six suppliers should be checked. In the evaluation, a supplier has on average 31 items that are advised to changed, which means that on average 186 items per week should be checked. The larger suppliers should not be checked in the same week but should be divided over different weeks to spread the workload. Suppliers are linked to a purchaser, which means that if all purchasers only check their own suppliers, this further reduces the workload.

Performing checks on weekly basis per supplier enables the logistical department to cope with the changes better. If a significant number of items are changed from non-stocked to stocked for a supplier, this means that an order can be placed for all those items in one order. This can also be communicated with the receiving team, such that extra staff can be planned for the day the extra items arrive to process the 'new' items (e.g., create space). This process also enables the commercial department to start selling the product as "stocked" from the moment the first inventory has arrived, instead of selling an item as "stocked" while there is no inventory present yet. Furthermore, if the commercial or purchasing department decides to stock an item because they expect large sales, the expectation should be communicated with the logistics department to base its forecast and inventory levels on. The other way around (from stocked to non-stocked) enables the logistics department to start requesting to return leftover stock of the 'new' non-stocked items to the supplier or enables the commercial department to create a plan to sell out the leftover stock by e.g., a discount.

For doubtful items that are decided to be stocked, it is recommended to make agreements with the supplier to be able to return the items, if after a year the decision to stock the item turns out not to be the right decision. Furthermore, for items which are decided to be non-stocked, it is recommended to make sure that the replenishment lead time in the system is correct and to make the agreement with the supplier that the item is stocked at the supplier. Also, certain agreements should be made with suppliers for non-stocked items, e.g., that an order can be placed, no matter what the fixed order and delivery days are.

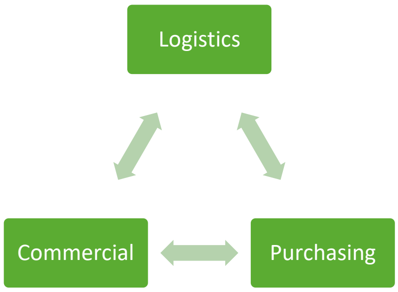

Figure 20: Communication lines between Logistics, Purchasing, and Commercial

To successfully implement the above, it is important to create a clear communication line between the commercial, the purchasing, and the logistics department (visualised in Figure 20). Periodic meetings to discuss exceptions and progress helps increasing the communication, but it might also help to create a better sense of the overall process, which is delivering the products that are wished by the customer, when the customer wishes them.

6.6.2 Technical Implementation

The prototype of the model is built in Excel. However, for stability, automatic updating, and user-friendliness, it is recommended to implement the model into the business intelligence tool: QlikSense. The model should be built such that the decision maker can filter on the supplier he/she wants to check and then see all items that are advised to change for that supplier, considering the described business rules. In the ideal case, the decision maker should be able to see which suppliers have to be checked in the current week. Formulas and methods to determine certain input and output are given in this thesis. This step should be done by the Business intelligence and data specialists in the organisation.

6.7 Conclusion

The first research question of this chapter was *For which items should an advice be generated?* Business rules have been described and executed to reduce the total number of items to 10,962. The second research question of this chapter was *How can the validity of the model be ensured?* Validation is ensured by using conversations with subject-matter experts and comparison of results with opinions of experts. The model is also verified by comparison of results with opinions of experts and by testing extensively.

The third research question was *What are the effects of the decision model on the shipment reliability and costs?* Using simulation over the 2021 data, the profit increases significantly with 6.7% (advice without discontinue) and 8.6% (advice with discontinuation) and the costs decrease significantly with 26.7% (advice without discontinuation) and 39.8% (advice with discontinuation). This is mainly due to the ordering cost decreasing, since many items change from non-stocked to stocked and can therefore be ordered in more economic order quantities. Furthermore, the overall shipment reliability over the order lines increases with 0.5%, which is relatively high, since only 3.3% of the total order lines are considered in the evaluation. The shipment reliability over the orders increases more with around 1.0%.

The fourth research question was *How sensitive is the decision model to the input parameters and what are the model's limitations?* It is found that the model is only significantly sensitive to the partial delivery cost, which therefore needs to be updated after improvements are implemented. The model's limitations are mainly that the number of customers is not considered. Furthermore, the decision is still very dependent on human judgement.

The last research question in this chapter was *How can the model to decide whether or not to keep an item in stock be implemented in the organisation?* The model can be implemented by using the described business rules to reduce the number of items that need a generated advice. Furthermore, it should be implemented such that every supplier is checked periodically (twice per year) by checking a certain number of suppliers every week. Furthermore, to create support within the organisation, it is recommended to create clear communication lines between the commercial, purchasing, and logistics department through periodic meetings to discuss exceptions and progress.

The overall conclusion is that the model does help to avoid the uncertainties that play an important role for non-stocked items. However, the simulated improvements are not as significant as wished for, since the overall shipment reliability over the order lines only increases with 0.5% (advice without option to discontinue) or 0.6% (advice with option to discontinue).

7 Inventory optimisation

In Section 2.5, it is found that the current inventory management at Jarola is not optimal. The ABC-classification and assigned target service levels do not perform as they should be. Furthermore, in the previous chapter, it is found that the ordering and holding cost are not realistic anymore, which leads to an unrealistic EOQ. In this chapter, the focus is on coping with these found problems to improve the inventory management. Lastly, in this chapter, the results of a brief analysis on where possibilities lie to decrease the current inventory are presented.

7.1 Classification and Target service levels

The research question that will be addressed in this section is *What are the effects of changing the classification and the target service levels on the inventory (costs), the weighted average service levels, and the shipment reliability?* Recall that currently SKUs are classified by a double ABC classification, based on revenue and order lines. The revenue classification is done according to a 70/20/10% distribution, while the order line classification is done according to a 65/20/15% distribution. An SKU is classified in ABC categories for the two criteria. Then, the classifications are crossed into a final classification, as given in Table 7. The goal of this section is to find improvements for the classification and target service level settings in Slim4 by conducting simulations.

7.1.1 Key Performance Indicators

Multiple KPIs are measured using the data from the simulations and are then used for determining the best option.

The weighted average service levels

The goal is to have a service level as high as possible, while keeping the total units/value of the inventory to a minimum. The weighted average service level can be calculated based on the target service level and some weight. This KPI is determined over three different weights, namely the forecasted demand, the forecasted revenue, and the number of order lines Year To Date (YTD). The term $ForecastedDemand$ is replaced by $ForecastedRevenue$ or $\#OrderLinesYTD$ when determining the other weighted average service levels. The forecasted demand is based on the forecast Slim4 made. The revenue is calculated by multiplying the forecasted demand with the cost price. The KPI is determined as follows, with I being the total number of SKUs. This KPI is also determined per final classification A, B, and C.

$$Weighted\ average\ service\ level = \frac{\sum_{i=1}^{I} ServiceLevel_i * ForecastedDemand_i}{\sum_{i=1}^{I} ForecastedDemand_i} \tag{19}$$

The average total units/value in inventory

An increase in target service level almost always means an increase in inventory. This means that there is a trade-off between keeping inventory levels to a minimum and increasing service levels. The total units in inventory is based on the safety stock that Slim4 calculates, plus half the order quantity Q according to Slim4 (which considers MOQs, IOQs, EOQs, and specific units such as pallets). This KPI is also determined per final classification A, B, and C.

$$Average\ total\ units\ in\ inventory = \sum_{i=1}^{I} SafetyStock_i + \frac{1}{2} Q_i \tag{20}$$

The value of the inventory is determined by using the average units per item, namely by multiplying this with the cost price c_p. This is then summed over all items.

The distribution over the final ABC-classification

The final ABC-classification is dependent on the revenue and order line ABC-classification. To see how the final ABC-classification performs, the distributions are determined. These are determined for the revenue, the order lines, and the number of SKUs.

7.1.2 Results

The focus is on only changing the parameters of the current classification (the distributions of the classifications, the cross method, and the target service levels) to increase weighted average service levels, shipment reliability and to create a correct priority in the ABC-classification. To see what effect the settings have on the KPIs, simulations are performed using Slim4. Real data and the currently used settings up to and including 16-05-2022 are imported into the test environment, this means that the output of the simulations is based on the data of that moment, e.g., seasonal effects are therefore not incorporated. Jarola currently uses cover time to cope with uncertainties, however, keeping this might lead to invalid simulation output. Therefore, all cover times are set to 0. The data that is created using those settings is used as starting point. Then, the settings are changed and Slim4 performs all calculations based on these settings. This means the required safety stock, reorder point, etcetera are recalculated, which is then used to calculate the described KPIs. Using the current settings, the weighted average service levels (Equation (19)) are 94.9% using revenue as weight, 92.6% using order lines and 94.7% using demand (Current settings are given in Table 17).

Since the goal of the research is to increase the shipment reliability, the changed settings are also simulated over the shipment reliability data of 2021. This is done by assuming that the changed items will have a realised shipment reliability equal to the target service level. Then, using the random number generator in Excel, if the random number is larger than the target service level, the order line is considered to be too late. Otherwise, the order line is considered to be on time.

Table 17: Settings Simulations classification and target service levels

Sim	Classification	Cross method: Rev \ OLs	A	B	C	Target service levels: Rev \ OLs	A	B	C
Current	Double ABC on revenue (70/20/10%) and order lines (65/20/15%)	A	A	A	A	A	97%	97%	97%
		B	A	B	C	B	97%	90%	90%
		C	A	B	C	C	85%	85%	85%
1	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) Service level classification CA is changed to 97%.	A	A	A	A	A	97%	97%	97%
		B	A	B	C	B	97%	90%	90%
		C	A	B	C	C	97%	85%	85%
2	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) Classification symmetrical Consistent service levels	A	A	A	A	A	97%	97%	97%
		B	A	B	B	B	97%	90%	90%
		C	A	B	C	C	97%	90%	85%
3	Double ABC on revenue (70/20/10%) and order lines (70/20/10%) Classifications equal distributions Classification symmetrical Consistent service levels	A	A	A	A	A	97%	97%	97%
		B	A	B	B	B	97%	90%	90%
		C	A	B	C	C	97%	90%	85%

The overall goal of this research is to increase the shipment reliability, which focuses on orders/order lines shipped on time. Knowing this, it is remarkable that the C-class for revenue and the A-class for order lines only has a target service level of 85%, while being classified as A-items. Items in this class are low-valued items with many order lines, which probably have a large effect on the shipment reliability over the order lines and a relatively low effect on inventory value. This class is responsible for 6.6% of the total order lines in 2021, while also being responsible for 5.4% of the too late order lines. The hypothesis is that increasing this target service level can have significant influence on the shipment reliability over the order lines. Therefore, the first setting that is changed is the target service level of the CA-classification (C for revenue, A for order lines) (Simulation 1 in Table 17). The target service level is changed from 85% to 97%, consistent with the other A-items.

The result of the first simulation is that the value of the inventory slightly increases (0.2%), while the number of units in stock increases more (1.8%). This makes sense, since the increase of service level is on low valued items (C-class for revenue), but with many order lines (A-items for order lines). The weighted average service levels increase with 0.2% (revenue), 1.0% (order lines), and 0.7% (demand) to 95.1%, 93.6%, and 95.4% in the simulation (Figure 21). Simulating this change over the data from 2021, the overall shipment reliability increases with 0.5% over the order lines and 0.2% over the orders, considering only 6.6% of the order lines. This means that the hypothesis is true since the main increase is in the service level with order lines as weight and the shipment reliability increases.

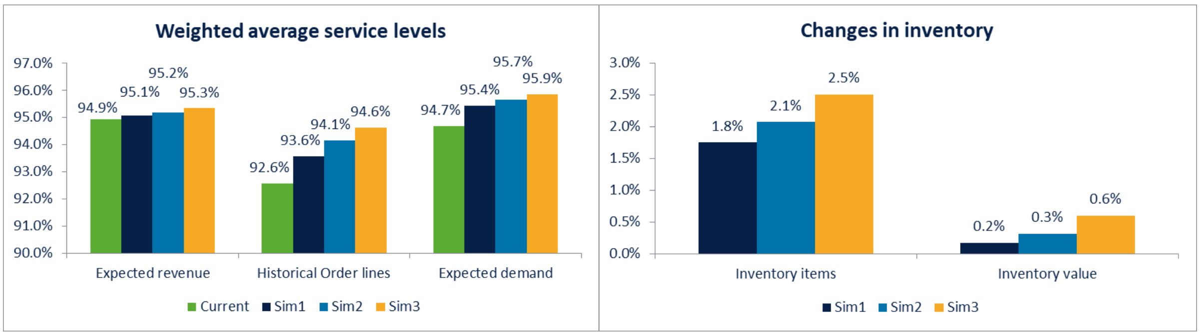

Figure 21: Simulation results Classification and service levels – Weighted average service levels and Changes in Inventory

Since the results of the first simulation are positive, the corresponding settings are kept in the next simulations. To further increase the shipment reliability and the service levels, the service level of CB-items (C for revenue, B for order lines) can be increased from 85% to 90%, since the final classification says that this class is a B-class. Furthermore, to create consistency in class and corresponding target service level, the final ABC-class of the BC-class (B for revenue, C for order lines) is changed from C to B, corresponding to the current target service level of 90% (Simulation 2). The hypothesis is that this also creates the right priority order in the final classification, since this is currently not the case and this is (logically) not changed after Simulation 1 (Table 18).

Table 18: Simulation results - Realised ABC-distribution

Sim	SKU distribution			Revenue distribution			Order lines distribution		
	A	B	C	A	B	C	A	B	C
Current	15.4%	12.7%	71.9%	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%
Sim1	15.4%	12.7%	71.9%	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%
Sim2	15.4%	18.6%	65.9%	78.6%	14.9%	6.5%	68.0%	19.8%	12.2%
Sim3	17.4%	21.6%	61.0%	80.0%	14.5%	5.4%	72.1%	19.2%	8.7%

These settings indeed result in better realised ABC-distributions (Table 18), which are in decreasing order: 79/15/6% for revenue and 68/20/12% for order lines. Also, the number of SKUs is better divided over the classes: 15/19/66%. Furthermore, the weighted average service levels increase with 0.2% (revenue), 1.5% (order lines), and 1.0% (demand). The shipment reliability increases further as well, with 1.3% over the order lines and 0.6% over the orders, considering 15.2% of the order lines. On the other hand, the inventory also increases the most (2.0% in units and 0.3% in value), which makes sense, since only one crossed class has a target service level of 85%.

To further increase the weighted average service levels, a next step is to change the distribution of the order lines classification from 65/20/15% to 70/20/10% (equal to the revenue distribution) (Simulation 3), since this leads to classifying more items as A-item for order lines, which leads to a higher target service level for those items. This indeed leads to a further increase for the weighted average service levels of 0.4% (revenue), 2.0% (order lines), and 1.2% (demand). Also, changing these settings lead to a larger increase in shipment reliability of 1.6% over the order lines and 0.9% over the orders, considering 18.6% of the order lines. However, it also leads to the largest increase in inventory of 2.5% (units) and 0.6% (value). An overview of the settings per simulation and the current situation is given in Table 17. Details of the results are given in Appendix I.

7.1.3 Conclusion

The research question addressed in this section is *What are the effects of changing the classification and the target service levels on the inventory, the weighted average service levels, and the shipment reliability?* The effects of changing the settings are clearly simulated using Slim4 and the results are that the inventory increases in items more than it increases in value (using the simulated settings). The service levels also increase by changing the settings according to the simulations, as does the shipment reliability.

7.2 Ordering and Holding cost

In the previous chapter, it is found that the ordering and the holding cost were indeed not realistic for Jarola's case. The ordering cost is not differentiated over the suppliers, while the cost per supplier is significantly different. Furthermore, the holding cost is found to be lower than currently used. The research question that is addressed is *What is the effect of changing the holding and ordering cost on the inventory?* To evaluate what influence changing the ordering and holding cost has on the inventory, simulations are conducted in Slim4. Recall that the EOQ is heavily dependent on these two parameters:

$$EOQ = \sqrt{\frac{2\boldsymbol{c_O}D}{\boldsymbol{h}c_p}} \tag{21}$$

7.2.1 Key Performance Indicators

The average total units in inventory are in principle equal to the used KPI in the previous section. However, the safety stock that is calculated in Slim4 is not influenced by the height of the order quantity; therefore, the comparison is based on only the average cycle stock. The value is calculated by multiplying the average units with the cost price.

$$Average\ total\ units\ in\ inventory = \sum_{i=1}^{I} \frac{1}{2} Q_i \tag{22}$$

A KPI that is added is the expected number of purchase order lines in the coming year. This is determined by dividing the total expected demand by the order quantity:

$$Number\ of\ purchase\ order\ lines = \sum_{i=1}^{I} \left(\frac{D_i}{Q_i}\right) \tag{23}$$

7.2.2 Results

The first setting that is changed is the holding cost from 25% to 20% for all stocked items, without changing the ordering cost. Changing this setting leads to an increase of 4.8% in inventory units and 5.6% in inventory value. It does, however, also lead to a decrease of 6.6% in the number of purchase order lines. To see how sensitive the inventory is to a small change in holding cost, simulations are also performed for 18% and 22%. The inventory value is rather sensitive to the holding cost parameter, while the inventory units and the expected number of orders are not significantly sensitive. The results are summarised in Table 19.

Table 19: Results simulations holding cost parameter

Holding cost	20% (w.r.t. 25%)	18% (w.r.t. 20%)	22% (w.r.t. 20%)
Inventory units	+4.8%	+2.1%	-2.0%
Inventory value	+5.6%	+5.0%	-4.6%
# Of order lines	-6.6%	-0.1%	+0.1%

The next setting that is changed is the ordering cost, without changing the holding cost (this is set to the current 25%). Currently, a distinction is made for the ordering cost between so-called uglies and non-uglies. Uglies have an ordering cost of €25,-, while non-uglies have an ordering cost of 10,-. This setting is changed to the found method: items that have additions have an ordering cost of €10,- + the addition and items that do not have an addition have an ordering cost of €15,-. This results in an increase of 4.8% in units and 6.4% in value. The number of purchase order lines significantly decreases with 10.3%. Doing the same, but then with a holding cost of 20%, the increase in inventory is 14.2% in units and 13.7% in value, with a decrease in purchase order lines of 18.2%.

7.2.3 Conclusion

The research question addressed is *What is the effect of changing the holding and ordering cost on the inventory?* Using the realised transportation cost leads to significant changes. Therefore, it is recommended to analyse the suppliers and to determine clear rules for the transportation cost, mainly for the foreign suppliers. Although using these parameters increases the inventory, the increase is based on the optimal order quantity, which minimises cost. The inventory is very sensitive to the ordering and holding cost, which means that changing this parameter should only be done after serious consideration and in steps, to avoid having a sudden increase in inventory. It is recommended to focus on finding the actual transportation cost per order line per supplier, to have the most realistic ordering cost. The ordering and holding cost have low influence on the service levels. Therefore, for the goal of this research (to increase shipment reliability), this is not a priority.

7.3 Decreasing inventory

All the simulations result in increases in inventory, while the inventory has been increasing significantly in the past two years (Figure 2(a)). To be able to justify the increase in inventory for increasing the service level, other inventory should be able to decrease. The research question is therefore *How can the total inventory be decreased?*

To analyse the inventory, the physical stock on 16/05/2022 is used and categorised. If an item is non-stocked by status, the inventory on hand is categorised as non-stocked stock. If an item has the status that it should be stocked, the inventory on hand of that item is categorised in the categories Iron, Safety, Cycle, and Other stock (the method is described in Appendix I). The iron stock is an extra safety stock that is manually put in the system and is added on top of the calculated safety stock. The safety stock is the calculated safety stock. The cycle stock is assumed to be the full order quantity, instead of half the order quantity, since we are dealing with current inventory on hand, we use the maximum possible cycle stock. The left over inventory on hand is categorised as Other stock, which can be seasonal, strategic, overstock, non-moving, etc.

From Figure 22, it can be concluded that there is too many non-stocked stock. This is also helpful for the implementation of the model to decide whether or not to stock an item: if an item is changed from stocked to non-stocked, a plan should be made to sell out the left-over inventory. Another conclusion is that there is too much other stock. Other stock can be strategic, seasonal, non-moving, etc. which unfortunately cannot be categorised further with the current data. It is recommended to further categorise this stock by saving which inventory is ordered as strategic and which items are seasonal. Appendix I contains information about the distribution of inventory per product group.

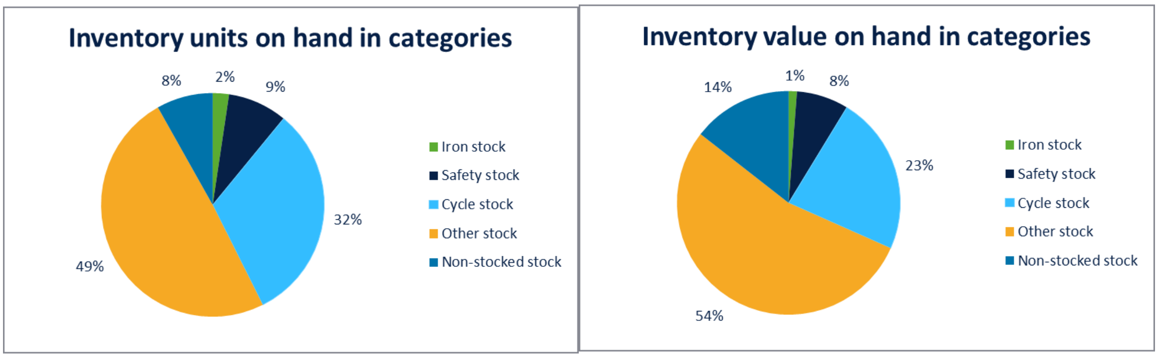

Figure 22: Inventory per category in (a) units and (b) value

The conclusion that can be drawn from this brief analysis is that the first step to decrease inventory should be to start selling or returning the non-stocked stock. The next step should be to start looking at why the largest part of the inventory is other stock and how this can be further categorised and reduced. Also, the iron stock is basically unnecessary, since the safety stock is already calculated and used to cope with uncertainties.

7.4 Implementation and Recommendation

The research question that will be addressed in this section is *How can the inventory management be improved and how should this be implemented?*

7.4.1 ABC-classification and Target Service levels

Regarding ABC-classifications and target service level, using the performed simulations, the second simulation seems to be the best one, since this resulted in a significant increase in weighted average service levels, while not resulting in significantly larger increases in inventory. Therefore, the recommendation is to at least change the current settings to the settings of Simulation 2, which means a symmetrical classification with consistent service levels per class. If a larger increase in inventory is justified, Simulation 3 might be a better option, since this results in even higher service levels and in the highest increase in shipment reliability. For the implementation, it is important to note that the settings proposed are based on zero cover time. Changing the current settings without setting the cover time to zero will result in more significant increase in inventory.

For the implementation, the recommendation is to not change the settings in one step, to avoid a sudden large increase in inventory and a sudden increase in work for the receiving team. To overcome this, it is recommended to change the settings step-by-step. The main increase in inventory is caused by changing the target service level of the crossed classification for C-items for revenue and A-items for order lines from 85% to 97%. The other steps do not increase the inventory that much; therefore, these can be implemented without high risk. Implementing the changes can be done in three ways:

1. First change the target service level for the combination CA to 91% (half the change) and wait until all extra inventory is ordered and booked. Then change it to 97% and wait until the extra inventory is also ordered and booked. Then change the other settings.
2. Change all settings and let the inventory planning team manually divide the extra inventory over time (e.g., make sure that the extra inventory is not ordered all at once but every week a part).
3. Change all settings and let the inventory planning team order all needed extra inventory at once and plan extra staff for the receiving team.

7.4.2 Holding and Ordering cost parameters

Changing the holding and ordering cost parameters does not have much influence on the service levels or the shipment reliability, but it does have influence on the costs. Since changing the ordering and holding cost for the determination of the EOQ results in significant increases in inventory, it is not recommended to change the parameters for now, considering that a new DC is being built and there is already a lot of inventory. The recommendation is to first focus on increasing the service levels and the shipment reliability. When the time is right, it is recommended to first find the transportation cost per supplier per order line before implementing a change in ordering cost parameters. Furthermore, it is recommended to implement changes step-by-step to avoid sudden increases in inventory. Due to changing markets and changing operational processes, it is recommended to determine the ordering and holding cost at least once per year. From the simulations, it can be seen that these parameters have significant influence on the inventory, which means that it is important to keep these up to date.

Lastly, it is found that currently SQL code is used to determine the EOQ in Slim4. This is implemented long ago, but it can also be implemented through functions in Slim4. Doing so results in a clearer view of what the settings are and leads to a lower error sensitivity and is therefore recommended to be changed. This is also required for differentiating the holding and/or ordering cost over the suppliers or volume.

7.5 Conclusion

The goal of this chapter was to improve the inventory management by improving the input parameters that are the responsibility of Jarola. The following conclusions and recommendations can be formulated:

- For the classification of SKUs and for the target service levels it is recommended to change the current settings to a symmetrical crossing method and a consistency in the target service levels (Simulation 2, Table 17). This does lead to an increase in inventory of 2.1% in units and 0.3% in value, however, it also leads to an increase of 0.2% (revenue), 1.5% (order lines), and 1.0% (demand) for the weighted average service levels and an increase in shipment reliability of 1.3% over the order lines and 0.6% over the orders.
- Using simulations, it is found that the inventory is very sensitive to the holding and the ordering cost. From this, it can be concluded that it is worth it to further research the actual transportation cost per supplier to get a more realistic ordering cost and therefore a more realistic order quantity. Since the Economic Order Quantity is used, this automatically minimises the cost. It is however not recommended to implement the parameters just yet, since these do not have much influence on the service levels and the shipment reliability.
- All recommendations and conclusions lead to an increase in inventory, while the inventory already increased significantly in the past years. To be able to justify this increase, insights are presented in where possibilities lie to decrease inventory. The first possibility is to decrease the inventory of non-stocked items. Also, the other stock and the iron stock can be decreased.

8 Conclusions and Recommendations

The research is concluded by answering the main research question. Thereafter the recommendations for successfully implementing the presented solutions are formulated. Afterwards, the research is discussed and suggestions for further research are formulated.

8.1 Conclusion

Every chapter contains a conclusion section with the conclusions per research question. This section answers the main research question:

How can Jarola improve the delivery reliability to the customer?

Since measuring the delivery reliability is not possible, the shipment reliability is used. The overall shipment reliability in 2021 was 89.7% over the order lines and 87.5% over the orders. For non-stocked respectively stocked order lines, the reliability was 71.6% and 90.7% in 2021.

It is found that the replenishment lead times that are in the system are often not realised. It is shown through simulations that using the realised replenishment lead times for determining the shipment reliability over 2021, the shipment reliability for non-stocked order lines increases with 12.4% from 71.6% to 84.0%. Overall, the shipment reliability increases with **0.9% (from 89.7% to 90.6%) over the order lines and 1.6% (from 87.5% to 89.1%) over the orders.** Furthermore, it is shown that increasing the replenishment lead times leads to a significant increase in inventory (around 12% in units). From this, it can be concluded that it is very important to have the correct lead times in the system, such that Slim4 can calculate the needed inventory with the correct input data, which very likely leads to an increase in service levels and shipment reliability as well.

Jarola copes with non-SKUs by ordering these at the supplier after the customer orders the item at Jarola. Then, the promised customer lead time is the replenishment lead time plus two working days. It is found that there are multiple sources of uncertainty in the process of ordering non-SKUs, which are hard to measure in the current data structure. Therefore, to minimise how often these uncertainties have to be coped with, it is of high importance for Jarola to have the right items in stock. A model is created to give advice on whether or not to stock an item. Using simulation over the 2021 data and the advises from the model, **the overall shipment reliability increases with 0.5% (from 89.7% to 90.2%) over the order lines and with 1.0% (from 87.5% to 88.5%) over the orders,** which is relatively high, since only 3.3% of the total order lines are considered in the evaluation. Furthermore, the profit increases significantly with 6.7% (advice without discontinue) and 8.6% (advice with discontinue) and the costs decrease significantly with 26.7% (advice without discontinue) and 39.8% (advice with discontinue).

Jarola manages their inventory using Slim4. Items are classified according to a double ABC-classification based on revenue and order lines. The used service level is the volume fill rate. It is found that the current classification settings are not optimal, because the C-items are responsible for more revenue than the B-items. Furthermore, the current classification focuses mainly on having high service levels for items with high revenue, while the items with high number of order lines are less focused on regarding service levels. For the classification of SKUs and for the target service levels it is recommended to change the current settings to a symmetrical crossing method and a consistency in the target service levels (Simulation 2). This does lead to an increase in inventory of 2.1% in units and 0.3% in value, however, it also leads to an increase of 0.3% (revenue), 1.5% (order lines), and 1.0% (demand) for the weighted average service levels and **an increase in shipment reliability of 1.3% over the order lines and 0.6% over the orders**.

8.2 Recommendations

This section contains the recommendations that are formulated based on this research.

Create a dashboard that shows the shipment reliability

In the second chapter the delivery reliability is defined, and the shipment reliability is measured over 2021. The definition and the results are different than the currently used KPIs. To manage according to the right information and to see if improvements have influence on the KPI, it is recommended to create a dashboard that shows the shipment reliability according to the proposed definition. Furthermore, it is highly recommended to implement a method that saves the cause of an order (line) being too late, since finding causes is currently manual work or based on (educated) guesses. Lastly, it is recommended to create a link between the forwarders' and Jarola's systems to be able to measure the overall delivery reliability.

Update the replenishment lead times and keep them up to date

The easiest step to increase shipment reliability to the customer is to update the replenishment lead times. While updating the replenishment lead times, the order and delivery schedules should also be taken into account. This should be done by first changing the process such that the time from placing the order until the order is delivered at Jarola can be measured. Measuring this gives the chance for the purchasing department to negotiate better lead times with the supplier or to change the lead time in the system to a realistic and up-to-date lead time. Furthermore, this gives the chance to manage the internal process of booking and processing incoming orders better. A dashboard should be created, and the inventory planning team should be made responsible for following the realised replenishment lead times with respect to the replenishment lead times in the system. Cooperation between the inventory planning team and the purchasing department should result in up-to-date lead times, which lead to more realistic inventory levels and therefore better realised service levels. For non-SKUs having the right replenishment lead time in the system leads to keeping the promise to the customer more often, which directly increases shipment reliability.

Implement and use the model to decide whether or not to stock an item

To use the model to decide whether or not to stock an item, the model should be implemented in a software package such as QlikSense (BI-tool). Then, a schedule should be made to decide which supplier is checked when, such that periodic reviews are done. The items that should be checked can be determined using the described business rules, such as only slow movers and only items with a last status change at least one year ago. It is highly recommended to increase the communication lines between the commercial, purchasing, and logistics department to create a more plannable supply chain and to decrease unnecessary inventory and increase service levels.

Change the ABC-classification and Target service levels

The current inventory management is not optimal. By changing the settings for the ABC-classification and the assigned target service levels to be consistent (A – 97%, B - 90%, C - 85%) and symmetric, the realised service levels and the shipment reliability will increase, while keeping the increase in inventory to a minimum.

Do not change the parameters needed for the EOQ yet, but find the actual transportation cost

To let Slim4 calculate a more realistic EOQ the holding and ordering cost parameters should be changed to more realistic ones. Furthermore, it is recommended to use the purchasing price for the EOQ instead of the cost price, which uses additions in the wrong place. For the ordering cost, it is recommended to find the actual transportation cost per supplier per order line or update the used additions for all items. However, due to the EOQ having low influence on increasing shipment reliability but it does have high influence on inventory, it is recommended to wait with changing these parameters until the shipment reliability is increased to a desired level.

8.3 Discussion

The first point of discussion is the data analysis using the data over 2021. The shipment reliability is determined using the booking date of the packing slip as actual shipment date; however, it is found that some packing slips are manually booked the day after the order was actually shipped. Furthermore, the data of the items, such as status, replenishment lead times, review periods, etc. are exported on a later date and linked to the item in the order lines. Due to this, it is possible that the data of the item has changed since the order line was placed until the data of the items is exported. It is expected that this does not have large influence on the results of this research; however, it might result in small differences in the analyses. Lastly, 2021 might not be a very representative year due to Covid-19. Covid-19 has caused significant disruptions in almost all supply chains that may have led to delays in production and replenishment lead times. This also explains the delays in the replenishment lead times in the system and gives more reason to update the replenishment lead times in the system.

Another point of discussion is that Excel is used for all data analysis and calculations, while other programs such as MySQL could have been more appropriate due to the large data sets. Using Excel meant high calculation times and lots of VBA coding, however, due to having few to no alternatives results in that Excel was the best option. For actual use within the organisation, it is recommended to not use Excel, but a Business Intelligence tool, which can be linked to live data and can calculate large datasets faster.

8.4 Suggestions for Further Research

Certain points that might be interesting to look into are found during the research. These are described in this section.

First, only part of the used settings and data synchronisation methods used in Slim4 are analysed. Since this already resulted in recommendations for significant changes it is recommended to research the other settings and the data synchronisation is Slim4 further. An example is that the cost price is used instead of the purchasing price. Furthermore, the additions might be used for the transportation and holding cost. A part of this is also to research whether using a differentiated holding cost parameter over the volume of an item is useful.

Also, it might be worth to research if a separate supply chain for non-SKUs can help. Having such a stream means making agreements with the suppliers and changing the process of incoming orders, but it might result in shipping non-SKUs quicker. Furthermore, this enables the organisation to make agreements about returning non-SKUs in case of cancelled or returned orders from customers, which leads to less unnecessary inventory.

A criterion for the model to stock or not to stock is the accepted waiting time of the customer. Through customer surveys it could be measured if the customers need the item within the replenishment lead time. If this is not the case, items might be better off non-stocked, which can reduce inventory.

Another suggestion to create a more plannable supply chain regarding inventory and outgoing goods is to create a program that stimulates longer lead times towards the customer. An example is that the customer pays less shipping costs if the order is needed in a week instead of tomorrow.

It is found during the research that when an item has a customer lead time larger than ten days, the website displays "On request". However, when checking out, the customer can pick tomorrow as wished delivery date, which can be misleading for the customer. This does not require any research, but it is recommended to not let the customer pick a date that is at least after the replenishment lead time plus two working days.

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Appendix A Item Statuses and Product groups

Table A-1: Statuses and descriptions

Status ID	Status description (EN)
99	Item not ready for purchase and sales
100	Items that are always stocked at the stores and in the DC.
110	Items that might be stocked at the stores, but are always stocked in the DC.
111	Items that might be stocked in the stores, but are always stocked in the DC. Not available on the web shop. Mainly service items.
120	Items that are only stocked at the DC.
121	Items that are only stocked in the DC. Not available on the web shop. Mainly service items.
130	Items that are not stocked, but are available on the web shop.
131	Items that are not stocked and are not available on the web shop.
300	Customer specific produced item + components
310	Customer specific ordered for review
320	Customer specific ordered with inventory
340	Semi-finished item
350	Customer specific service
400	Out of assortment
410	Outlet
420	Out of assortment, return supplier
430	Out of assortment, lot trade
500	Out of assortment supplier
600	Twickto item (brand of toys)
800	Internal use
900	Discharged

Table A-2: Product group and descriptions

Product group	Description (Dutch)
H11	Riolering
H12	Regenwaterafvoer
H13	Lucht & Ventilatie
H14	Elektra & verlichting
H15	Verwarming
H16	Sanitair
H17	Bouw & dakbedekking
H18	Bevestiging & Onderhoud
H19	Drukleidingen & fittingen
H20	Slangen & koppelingen
H21	Pompen
H22	Beregening
H23	Agro & Tuin
H24	Gereedschappen
H25	Persoonlijke bescherming
H26	Platen & profielen

Appendix B Details Data Analysis

Due to confidentiality issues, parts of this Appendix are left blank.

Research Motivation

"The average percentage of order lines delivered on time over 2021 was 93.6%"
From QlikSense, dashboard Order Performance I, filtered on Site_Groep "DCCO". Non-weighted average over the months is taken.

"Looking at the percentage of orders delivered on time using the current measurements, the average percentage of orders with non-stocked items in it is 76.0%, while the average percentage of orders with stocked items in it is 94.8%."
From QlikSense, dashboard Order Performance I, filtered on Site_Groep "DCCO", and item status 100, 110, 111, 120, 121 (Stocked) or 130, 131 (non-stocked). Non-weighted average over the months is taken.

"1.3% of the total order lines are non-SKUs"
The same data that is taken from QlikSense as above is used.

"This has led to an increase of the total inventory of 74% (items) and 49% (value)" / Figure 2(a)
The total inventory (items) data are taken from QlikSense, dashboard "Voorraadaantallen", filtered on Site_Groep = "DCCO" and Year = "2021". The total inventory (value) data are taken from QlikSense, dashboard "Voorraadwaarde", filtered on Site_Groep = "DCCO" and Year = "2021".

Figure 2(b)
From QlikSense, dashboard Order Performance I, filtered on Site_Groep "DCCO".

Shipment Reliability

Data is provided for the year 2021. These data are used to measure the current delivery reliability. The dataset contains out of more than 800,000 order lines. Also, a dataset containing all packing slips of the orders in 2021 is provided (also > 800,000 lines). This is used to check if the shipping date of the order line is also the actual shipping date. The structure of the data is given in the ER-diagram in Figure B-1.

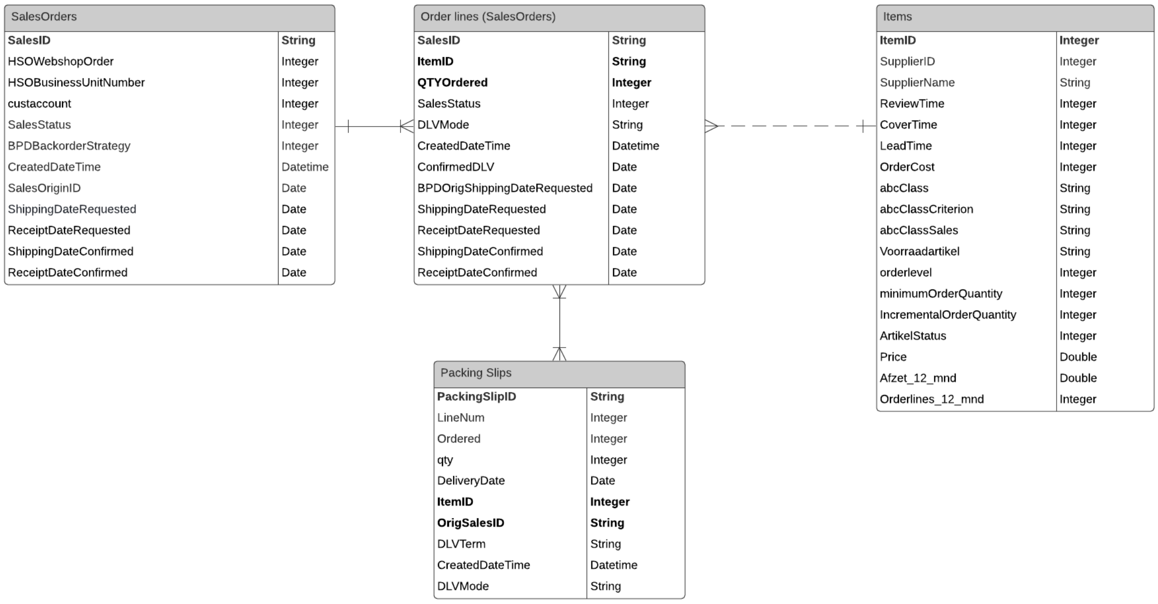


Figure B-1: ER-diagram of Data (dotted line due to data from other sources)

First, the definition defined in Subsection 2.1.1 is implemented by determining the expected shipment date $E[SD_{i,j}]$ for all orders i with order lines $j = 1,2, \dots, J$. The first step to do so is to consider the time the order is placed, since an order placed after 20h should be considered as if the order is placed the next day. The column CreatedDateTime is split into a column CreatedDate and a column CreatedTime. Then, a new column is added to table Order lines called CreatedDate20h, with the following function (for all orders i):

$$CreatedDate20h_i \;=\; If(CreatedTime_i \leq 20{:}00, CreatedDate_i, CreatedDate_i + 1) \quad \forall i$$

Secondly, it is necessary to know whether or not the item was an SKU or a non-SKU at the time of the order. Unfortunately, these data are not available. To overcome this, the current statuses (February 2022) of the items are used (StockStatus). It is possible that statuses have changed, however, given the large dataset, it is assumed that this is marginal to the result. This also holds for the lead times (LT_j) of the items. The chance that these data is changed since then is even smaller than the item status. Since an order line can only consist out of one item, the same subscript j is used.

Thirdly, the table Order lines also consist of shipping costs and returned order lines. The shipping costs all have an ordered quantity (QTYOrdered) of zero and the returned order lines have negative ordered quantities. Therefore, all order lines with $QTYOrdered \leq 0$ are not considered in the rest of the analysis. Also, the cancelled order lines are taken out of the analysis.

Another challenge is found in the open order lines. The expected shipment date can still be in the future, so simply considering all to be too late is not correct. Therefore, all open order lines with an expected shipment date on or before 31/12/2021 are considered as too late. All other order lines are not considered in the calculations.

Then, the expected shipment date ($E[SD_{i,j}]$) is determined as follows (new column in Order lines). First, without considering the customer's wish (the adding of days to the created date is done with working days):

$$E_1[SD_{i,j}] = \begin{cases} CreatedDate20h_i + LT_j + 2\ workingdays & if\ StockStatus_j = "NONSTOCKED" \\ CreatedDate20h_i & if\ StockStatus_j = "STOCKED" \end{cases}$$

The requested shipping date in the table Order lines is not correct. This date is changed if the ATP is changed. Therefore, the requested shipping date of the order is used as the customer's wish:

$$E[SD_{i,j}] = \max\left(E_1[SD_{i,j}], ShippingDateRequested_i\right) \qquad \forall i,j$$

Lastly, it is checked if the expected shipping date is on holidays or weekends, and this is corrected for.

The next step is to find the realised shipping date. In the table Order lines this should be ShippingDateConfirmed. However, this is not the actual shipping date. To find the actual shipping date, the packing slips are used. A packing slip is created after the order (line) is packed in the distribution centre. If an order (line) is packed today, it is also shipped today. There is an exception: the shifts in the DC are supposed to end at 00:00h, however, this is not always met. The shift does not end before all order (lines) are packed and sent, so sometimes the packing slip is created after 00:00h. Therefore, the column CreatedDateTime in table Packing slips is split into CreatedDate and CreatedTime. Because the picking sometimes is done until after 00:00h, but always before 03:00h, the CreatedDate03h is determined (new column in Packing slips). For all packing slips k:

$$CreatedDate03h_k = If(CreatedTime_k \leq 03:00, CreatedDate_k - 1, CreatedDate_k) \qquad \forall k$$

Then, the packing slips must be linked to the order lines. This is a challenge, because an order line can have multiple packing slips, a packing slip can have multiple order lines, and multiple order lines can have multiple packing slips. To overcome this challenge, the following steps are executed: First, the number of packing slips and the number of order lines per [order number]-[item number] are determined. To do so, extra columns are created in Order lines and in Packing slips that combine the order number with the item number: $= [order\ number]\&" - "\&[article\ number]$. A distinct list of the order lines' new key is created, and then the following function is used to determine the number of packing slips and number of order lines per new key:

$$= COUNTIF(PackingSlips; Key)$$

$$= COUNTIF(OrderLines; Key)$$

This is then linked to the keys in the table Packing slips and Order lines. A loop is done over all order lines. For every order line, another loop is done over the packing slips. If the new keys match, the following distinction is made:

1. **If the number of packing slips = 1 and the number of order lines = 1**
   Actual Shipment Date is the $CreatedDate03h$ of the packing slip. After this is found, the loop over the packing slips is stopped and the loop continues with the next order line.
2. **If the number of packing slips > 1 and the number of order lines = 1**
   In this case, the maximum date of the packing slips must be found for the order line. This maximum date is then the actual shipment date. If this is the first packing slip of the order line, the $CreatedDate03h$ is saved as current maximum shipping date. Also, a counter is updated to +1. If the counter is equal to the number of packing slips, the current maximum is the $CreatedDate03h$ and the loop over the packing slips is stopped and the loop continues with the next order line.
3. **Number of packing slips = 1, number of order lines > 1**
   In this case, the corresponding packing slip date is the actual shipment date for all corresponding order lines. The same procedure as (1) is used.
4. **Number of packing slips > 1, number of order lines > 1**
   In this case, again the maximum date of the packing slips must be found for the order lines. The same procedure as (2) is used for all order lines.

The actual shipment dates are added to the table Order lines as ActualShipmentDate. Next, the OnTimeShipmentOL (new column in Order lines) is determined by:

$$OnTimeShipmentOL_{i,j} = \begin{cases} 1 \text{ } if \text{ } ActualShipmentDate_{i,j} \leq E[SD_{i,j}] \\ 0 \text{ } otherwise \end{cases}$$

The Shipment Reliability of the order lines is then:

$$ShipmentReliabilityOL = \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} OnTimeShipmentOL_{i,j}}{Total\#OLs}$$

The OnTimeShipment over the orders is determined by summing the number of order lines and the number of on time order lines in the order:

$$OnTimeShipment_i = \begin{cases} 1 \text{ } if \sum_{j=1}^{J_i} OnTimeShipmentOL_{i,j} = J_i \\ 0 \text{ } otherwise \end{cases}$$

Where J_i is determined by:

$$J_i = COUNTIFS\big(Orderlines, Orderlines(SalesID_i) = Orders(SalesID_i), OnTimeShipmentOL_{i,j} = 1 \text{ } or \text{ } 0\big)$$

And the sum of the OnTimeShipmentOL's is determined by:

$$\sum_{j=1}^{J_i} OnTimeShipmentOL_{i,j} = COUNTIFS\Big(Orderlines, \big(Orderlines(SalesID_i) = Orders(SalesID_i), OnTimeShipmentOL_{i,j} = 1\big)\Big)$$

The Shipment Reliability of the orders is then:

$$ShipmentReliability = \frac{\sum_{i=1}^{I} OnTimeShipment_i}{I}$$

The above gives the method to determine the shipment reliability over all the data. If the reliability over a certain time period (e.g., January) is needed, only the order lines that are created in January are considered. To increase the speed of the program, considering that the data analysis had to be done in Excel, a VBA-code is written. Firstly, the needed data is written into arrays (one array for order lines and one for packing slips), since this increases calculation speed due to not having to write the results on screen. Then, the loop as described is written.

Causes of low shipment reliability

Table 1/Table 2/"if the order line is shipped too late, this is done on average 9.27 days too late (the overall average is 5.79 days)."

To create an overview per supplier, first an overview per item is created. A distinct list of the items sold in 2021 is created. Then, the number of order lines per item is determined by a COUNTIF-function, with criteria that the OnTimeShipmentOL is either 0 or 1 (to filter on only the order lines that are also considered in the reliability calculations), and the item number is equal to the item number. The number of late order lines is determined similarly, but only using OnTimeShipmentOL = 0. This count is also done for stocked and non-stocked items by using the sales status as criterion. Also, the average days too late per item is determined by an AVERAGEIF-function, with criteria that item number is equal to item number and the days too late is larger than zero (to not consider zeros).

A distinct list of the suppliers is used to create the overview per supplier. The number of order lines per item is summed if the supplier ID is equal to the supplier ID. For late items, the late order lines are summed. The average of the days too late is taken as well, this is therefore a non-weighted average. Using the late order lines and the total order lines the reliability per supplier is determined. Since many suppliers do not supply significant amounts, the sorting is done on % of total order lines instead of on reliability.

"Not including Supplier B in the analysis would result in an overall non-stocked shipment reliability of 73.0%, which would be an increase of around 1.4%."

Total non-stocked order lines of supplier B:

Total non-stocked order lines late of supplier B:
Total non-stocked order lines on time of supplier B:
Reliability non-stocked order lines without Supplier B: 73.0%
Same approach used for overall reliability and for stocked reliability and suppliers D and E.

"Order2Cash is responsible for 7.2% of the order lines, with a reliability of 72.6%."
Using a COUNTIF-function with criteria OnTimeShipmentOL either 0 or 1 and Origin = Order2Cash, the total number of order lines is found that are coming from Order2Cash. Dividing this by the total number of order lines gives 7.2%. The same principle is used for on time order lines coming from Order2Cash, which gives us the ability to determine the reliability.

Table 3
The days too late is determined by Excel function NETWORKDAYS by finding the difference between the actual and the expected shipment date. Then, the data is filtered on too late non-stocked and stocked order lines. A list is created (1,2,…) until the maximum number of days too late. Using a COUNTIF-function, the frequency per days too late is found. A cumulative percentage is calculated, which is also given in the table.

Coping with non-SKUs
Table 5
From the order lines data (2021) a list with the distinct item numbers of the order lines is created. These are all items that are sold in 2021. This list is combined this list with the item statuses from the item dataset. This dataset contains all items (247,698), with columns as given in Figure B-1. The total number of items per status is determined by a COUNT-function. Then, the number of items per item status is determined by a COUNTIF-function.

"For the non-stocked items, 76% have an MOQ of 0 or 1" / "85% of the non-stocked items have an MOQ smaller than or equal to 10"
A filter is set on column "Voorraadartikel" = "NONSTOCKED". Then, by looking at the number of items per MOQ, a percentage of 76% / 85% of the items is found.

Keeping an item in stock or not
Figure 8
From the table Order lines the items and the sold quantities for the DC are taken, from the table Items, the sold quantities for the stores are taken. Then, from the table Items, all items with the stocking and item statuses are taken. Per item, the sold quantities are summed by the SUMIF function in Excel. Figure 8(a) is then calculated by counting the number of sold quantities for stocked items, using the function =COUNTIF(Sales/Order lines<=x), for x=0 op to and including 41. Then, the percentage is taken and plotted.

For the non-stocked items, the same principle is used, however, the other way around (>=x in the COUNTIF), since the goal is to find items that might be better off stocked instead of non-stocked.

Table 6
Using Excel VBA, the number of different shipments per order is found (code is available on request). Also, this is done per forwarder, since the costs are very different. Then, using a COUNTIF-function, the numbers are found.

Appendix C Details Analysis Inventory Management

The data gathered about the classification is through a simulation function in Slim4. The current settings are simulated.

Table C-1: Inventory classification on Revenue

Classification (Revenue)	# SKUs	Stock (items)	Revenue	Order lines
A	7.5%	55.1%	70.0%	36.7%
B	15.5%	20.6%	20.0%	31.9%
C	77.0%	24.4%	10.0%	31.4%
Total	100%	100%	100%	100%

Table C-2: Inventory classification on Order lines

Classification (Order lines)	# SKUs	Stock (items)	Revenue	Order lines
A	12.2%	33.6%	59.0%	65.0%
B	14.4%	21.2%	19.5%	20.0%
C	73.4%	45.2%	21.5%	15.0%
Total	100%	100%	100%	100%

Table 9

The assumption is made that all stocked order lines that are too late are late due to a stock out. Since the fill rate is the percentage of demand that can be fulfilled directly from stock, this is easy to determine. The stocked items are listed distinctly, and the sum of the total ordered quantity and quantity delivered on time per item is calculated. The volume fill rate is then the on time ordered quantity divided by the total ordered quantity. The number of on time order lines and total order lines is counted per item and from this the order line fill rate is calculated. Using a COUNTIF/SUMIF-function, the fill rates per classification are determined.

"By conducting data analysis, it is found that only 0.5% of the order lines are cancelled"

The dataset contains the status of the order line (SalesStatus). 0.5% of the order lines have the status "Cancelled", while 99.5% have status "Billed".

Table 10

The descriptive statistics function in Excel is used to determine these data. The table Items (Figure B-1) is used.

"However, 95.1% of the items have an MOQ smaller than or equal to 100. 69.5% of the items have an MOQ that is smaller than or equal to 1."

Calculated by cumulative percentage of items with MOQ ascending.

"92.5% of the IOQs are equal to the item's MOQ. Of the 7.5% of the items that have a different IOQ than an MOQ, 96.3% do have a multiple of the MOQ ($MOQ \bmod IOQ = 0$)"

Using the table Items (Figure B-1), columns MOQ and IOQ.

"For the following analysis, the EOQ is calculated based on the sales of the past twelve months (January 2021-January 2022)"

Using the table Items (Figure B-1), columns "Afzet_12_mnd", "orderCost", and "price".

Appendix D Details Analysis Reliability of Replenishment Lead Times

Calculation methods

To find the actual replenishment lead times (from the moment the order is placed until the order is booked and processed), the purchase order lines have to be linked to the receipt packing slips. The date the receipt packing slip is created/booked is the date the purchase order is booked at the DC. Then, using that date and the creation date of the purchase order the realised replenishment lead time can be measured.

Different methods are used:

Only considering fixed order days

If only fixed order days are considered, the realised replenishment lead time is determined by starting counting only at the date the purchase order is created if the creation date is also an order day (e.g., both need to be on a Tuesday). If the purchase order is created on e.g. Monday, but the fixed order day is on Wednesday, the counting starts two days later.

Only considering fixed delivery days

If only fixed delivery days are considered, the replenishment lead time in the system is 'changed', by determining the time between the creation date of the purchase order and the delivery day. This delivery day is the first option after the replenishment lead time in the system is finished. Then this new replenishment lead time is compared to the realised replenishment lead time.

Considering fixed order and delivery days

If both order and delivery days are considered, the order date including fixed order days is used to determine the delivery date including fixed delivery days.

Analysis three largest suppliers Non-stocked and Stocked

The average replenishment lead times for the three largest suppliers for non-stocked and for stocked items based on sales order lines from 2021 are analysed further (from Table 1 and Table 2). Table D-1 gives the system and the realised replenishment lead times of the largest suppliers from Table 1 and Table 2. The realised replenishment lead times are, however, measured from the moment the order is placed until the moment the order is processed at the DC.

Table D-1: Average replenishment lead times over items ordered in 2021 in days

	Supplier	A	B	C	D	E	F
Overall	Days late	3.5	6.0	2.4	4.3	5.2	2.2
Stocked	Days late	7.0	6.1	2.1	4.2	5.2	3.2
	% Order lines	1.0%	0.3%	1.5%	13.7%	9.6%	8.0%
	Reliability	90.4%	80.0%	91.3%	92.2%	92.0%	90.3%
Non-stocked	Days late	-53.8	6.0	3.0	5.3	3.8	-4.7
	% Order lines	5.1%	4.5%	4.2%	0.9%	0.7%	1.3%
	Reliability	100.0%	41.4%	50.7%	59.8%	43.9%	80.4%

Supplier A has high replenishment lead times for all items (118 days). For non-stocked items the purchase orders arrive sooner than the replenishment lead time in the system. The shipment reliability is also high, which makes sense. For stocked items, the reliability is only 90.4%, probably since many of these items are stored at an external warehouse.

The purchase orders of supplier B are on average 6 days late. This is equal for stocked and non-stocked items, which makes sense because this supplier does not have fixed ordering and delivery days. The main item status that is ordered at Supplier B is 130 (non-stocked, visible on web shop). The average realised replenishment lead time of this status is more than two times as high as the lead time in the system, which explains the low reliability of non-stocked items supplied by Supplier B. For stocked items, the reliability is also too low (80% over 2021). Since both for stocked as non-stocked items the realised replenishment lead times are significantly higher than the replenishment lead times in the systems, the replenishment lead times that are in the system for this supplier should be checked on feasibility and correctness. Again, the realised replenishment lead times are based on the date the order is processed at the DC. There is no certainty that the cause is at the supplier.

Supplier C is on average 2.4 days late. This supplier has a fixed ordering (Tuesday) and delivery day (Friday). This seems to be an obvious cause of the low non-stocked reliability (50.7%), since the stocked reliability is around the average. The stocked items might be improved by setting safety lead time, to be able to cope with the uncertainties of the lead time of the supplier and the processing time at the DC. If the fixed ordering and delivery day is considered for the replenishment lead time, the purchase order is booked 1.2 days early, which means that this is an important cause.

Supplier D has fixed ordering days on Monday and Thursday and fixed delivery days on Tuesday and Thursday. For non-stocked items, the cause of the low reliability is probably that there are fixed ordering and delivery days. Incorporating this into the lead times or not using these fixed days will probably improve the reliability for non-stocked items. The average days too late would decrease from 4.3 to 2.6 days. Considering that almost 14% of the stocked order lines in 2021 were items supplied by Supplier D, ordering and delivering every day could be also a choice for the stocked items, which can reduce the inventory significantly, while remaining or even improving the reliability to the customer.

There are no fixed ordering and delivery days for supplier E. Overall, the average replenishment lead time that is in the systems is 1.7 days. However, the realised average replenishment lead time is 5.8 days. This is a significant difference. Although there is, on average, a significant difference between the replenishment lead times in the system and the realised lead time, for stocked items the reliability over 2021 was 92.0%, which is above average (90.7%). For non-stocked items the reliability was 43.9%, which is significantly lower than the average (71.6%). This is probably due to safety stocks on the stocked items. This does, however, mean that considering a safety lead time at least for the non-stocked items could increase the reliability significantly as well.

Supplier F has a fixed order (Wednesday) and delivery (Thursday) day. Supplier F has an average agreed upon lead time of 20.2 days. The non-stocked reliability is 80.4%, which is significantly higher than the average of 71.6%. Remarkable is that this is while there is one ordering and one delivery day on Thursday. Therefore, although improvement is still necessary, this supplier seems to be performing very well, relative to the others.

Appendix E Literature research

The used databases are Scopus and Business Source Elite. Furthermore, the reference list of found items is inspected and books that were possibly interesting for the topic and that are known by the author are inspected.

Decision to stock or not

From Google Scholar a literature review is found, which also lead to useful articles (Rego & Mesquita, 2011).

Table E-1: Literature search SKU or non-SKU (date of search 07/02/2022)

Database	# Of articles	Search string
Business Source Elite	8(1)	("classification" OR "criteria" OR "criterion" OR "decision" OR "decision model" OR "decision rule") AND ("non-stock" OR "non-stocking" OR "non-inventory" OR "non-SKU")
SCOPUS	7(1)	
Google Scholar	8260(4)	

Decision Rule using EOQ (Silver, Pyke, & Thomas, 2017)

Silver, Pyke, & Thomas (2017) describe a set of factors that can influence the decision to stock or not stock the item, (1) the system cost, (2) the unit variable cost of the item, (3) the cost of a temporary backorder, (4) the fixed setup cost, (5) the carrying charge, (6) the frequency and magnitude of demand transactions, and (7) the replenishment lead time. However, creating a general model to handle all these factors would be "of limited value to the typical practitioner because of its complexity" (Silver, Pyke, & Thomas, 2017, p. 372).

A decision rule is created, under the following assumptions:

1. The unit variable cost and the fixed setup cost is the same under stocking and non-stocking.
2. In the derivation, a non-integer order quantity is allowed.
3. The replenishment lead time is negligible; therefore, no backordering cost is considered.

Then, the item should not be stocked if either of the following two conditions holds:

$$c_s > \frac{A}{E(i)}$$

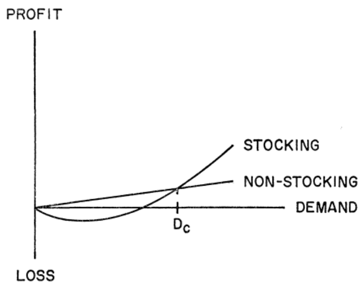
Or

$$E(t)vr > \frac{E(i)}{2A}\left(\frac{A}{E(i)} - c_s\right)^2$$

Where c_s is the system cost of having the item stocked, A is the setup (ordering) cost, $E(i)$ is the expected interval between demands, $E(t)$ is the expected size of a demand transaction, v is the unit variable cost, and r is the carrying charge. If the decision is to stock the item, the EOQ should be used. An extension is described where the unit variable cost and the setup cost depend on whether the item is stocked or not.

The Inventory Cut-off Level (Fenske, 1968)

Fenske (1968) determines the total profit under non-stocking and under stocking and gives three methods to determine the Cut-off level. The first method is trial and error, by calculating the non-stocking and stocking profit until the input demand gives (almost) equal results. The second method is the graphical approach: finding the intersect of the two profit functions in a graph (FigureE-1(a)). The third method is the analytical approach: firstly, the optimal total costs are determined for stocking and for non-stocking. Then, by using the fact that $profit = revenue - costs$, the total profit under stocking and under non-stocking is determined. Lastly, the two profit functions are equated and solved for the demand. The result is given in Figure E-1(b). Where s is the setup or ordering costs, h is the holding costs (not as percentage of the price), g is the percentage of sales lost if the item is not stocked, r is the selling price per unit, p is the production variable cost per unit (0 in case of retail or wholesale), and n is the average size of an order received from customers. The breakeven point can give two results, as the total profit has multiple intersects. The highest point is the minimum demand that needs to present for the item to prefer stocking the item over non-stocking.



$$D_c = \frac{1 - \frac{A}{2s} \pm \left[1 - \frac{A}{s}\right]^{1/2}}{\frac{A^2}{sh}}$$

$$A = -\left[g(r-p) - (1-g)\frac{s}{n}\right]$$

Figure E-1: (a) Graphical breakeven-analysis, (b) Formulas for breakeven-demand (Fenske, 1968)

To Stock or Not To Stock (Shorrock, 1978)

According to Shorrock (1978), there are two essential points to be considered: (1) Whether or not the item must be stocked to enable a particular lead time to be achieved. If a company wants to promise a delivery time of 10 days, but the procurement lead time is more than 10 days, the item should be stocked. (2) Whether or not it will be cheaper to order economic quantities and hold these in inventory rather than order directly against each demand.

The model developed for the second essential point is as follows: if more than a critical number of calls (demands) are received, it will be cheaper to stock the item. The critical number for an item is: $Critical\ number\ of\ item\ demand = 2 * \sqrt{\frac{ACI}{2S}}$. Where A is the yearly demand, C is the unit cost per item, I is the inventory carrying charge (holding cost) as a % of the unit cost, and S is the order cost per replenishment order.

Non-stocking alternative for Low Demand Items (Park, 1980)

Park (1980, p. 1) states that "it is important to classify and screen out the items that need not be stocked." Under the assumption that demand occurs one at a time and follows a Poisson process and a replenishment time that is exponential, not stocking the item is optimal if:

$$\left(\frac{W_z}{W_h}\right) \leq \frac{1}{e^{\rho}-1} \quad \text{or} \quad W_h e^{-\rho} + W_z[\rho - (1-e^{-\rho})] \geq W_z \cdot \rho \qquad \text{(Park, 1980)}$$

Where W_z is the backorder cost per item per time unit, W_h is the inventory carrying cost per item per time unit, and ρ is the expected demand during lead time.

It is important to note that the assumption of this model is that demand occurs one at a time and that if the item is kept in stock, an $(S-1, S)$ policy is used.

Interaction between stocking and replenishment policies (Johnson J. , 1962)

The idea behind the model is that in inventory management, costs that are occurring just because the item is stocked are often considered fixed and independent of the inventory. Therefore, these are taken out of the calculations. The model of Johnson (1962) uses the expected annual operating costs, with input the item value and the annual demand. The model considers the following cost factors:

1. C_1 – "Administrative" Inventory Cost per year
2. C_2 – Inventory "variable" cost per dollar of inventory per year
3. C_3 – Normal replenishment cost per demand

4. C_4 – Back-order cost per number of backorders of non-stocked items per year
5. C_5 – Cost of expediting stock replenishment per hastening demand per year
6. C_6 – Cost of implementing change from stocked to non-stocked status and vice versa per change

Then, given the yearly demand and the value of the product, the optimal decision is given to either stock or non-stock (see Figure E-2).

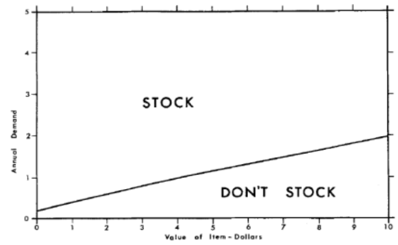


Figure E-2: Optimal stocking threshold (Johnson J. , 1962)

Stock Levels for Slow-Moving Items (Croston, 1974)

The model considers an item which is normally replenished at fixed review intervals to maintain the stock at some level R (Croston, 1974). The probability of a demand occurring in a specific review interval is assumed to be $\frac{1}{p}$, because the average interarrival interval between demands is p review intervals. Each demand will give rise to a replenishment on a routine basis at the end of the time interval in which it has occurred, at a cost of C_r. The model assumes that if the item is not stocked, a special delivery takes place at C_n costs, the stock is always available at the supplier at zero lead time. Also, all orders are backordered and there are no lost sales. C_n could include some kind emergency order costs and/or the notional cost of customer dissatisfaction. If the item is stocked but the stock level is insufficient to meet the demand, the total costs for meeting that demand would be $C_r + C_n$. Then, the average cost per demand is:

$$C_d = bp(C_8 + RLh) + C_r + C_n\left(1 - b\int_0^R f(x)dx\right)$$

Where b is a bivalent variable (1 if the item is stocked, 0 otherwise), L is the unit cost of the item, h is the percentage holding cost per review interval, C_8 is the standard cost per review interval for having the item in the system, and $f(x)$ is the probability density that a demand will occur of size x. Then, the decision whether or not to stock the item can be obtained by minimising C_d with respect to b and R.

Decision rule to keep either 0 or 1 in stock (Tavares & Almeida, 1983)

A model is developed by Tavares & Almeida (1983) to compare the decisions of keeping either 1 unit in stock or 0. The following assumptions are made:

1. The process of demand follows a Poisson process with parameter λ and the number of units demanded at each occurrence is 1.
2. When there is a need of the item that is not in stock, a special order can be placed to reduce its usual lead time l to a negligible duration with extra cost p, which includes the additional delivery and penalty costs.

Then, the expected number of demand occurrences in study horizon T is $n = T\lambda$. The total cost for having 0 stock policy is then $F(0) = T\lambda(c + p)$. The total cost for having 1 stock policy is $F(1) = T_1 h + cn + pn_0$, where T_1 is the expected length of time with 1 unit in stock, h is the holding cost per unit during a time unit, c is the purchase price of the item, and n_0 is the expected number of occurrences taking place during zero stock periods. Then, the threshold $\lambda_0 = \frac{h}{p}$. If $\lambda_0 < \frac{h}{p}$ the 0 stock policy is not preferable.

The following models are found in literature but are not useful for this study:

ABC/FMR-classification (Oberle, 2010)

Oberle (2010) describes the ABC/FMR analysis to decide between Make-to-Stock and Make-to-Order. The analysis "allows inventory controllers to decide which products should be stocked, called "Make to Stock" items, versus which products need to be expedited to customers without an intermediary stock ("Make to Order" item)" (Oberle, 2010, p. 6). The model uses four main criteria: differential between the offer lead time and the procurement lead time, the life cycle of the product, the value of the product, and the number of orders per month for a specific product (Oberle, 2010).

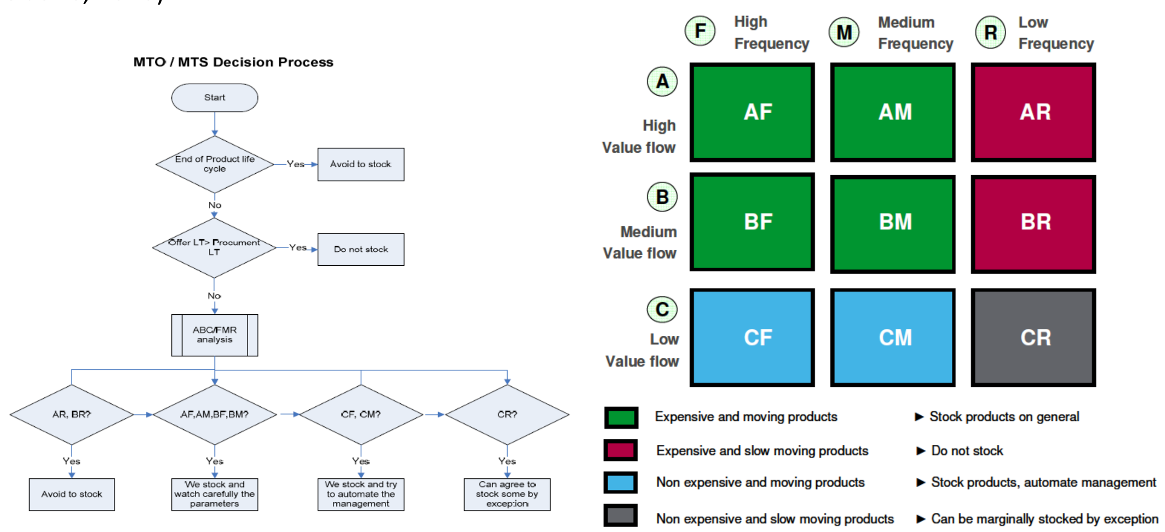


Figure E-3: (a) MTO/MTS decision process, (b) ABC/FMR matrix (Oberle, 2010)

Figure E-3(a) gives the decision process, in which a step is the ABC/FMR analysis (Figure E-3(b)). The first decision, whether the product life cycle is at the end of its life cycle, is a logical step. If the product is at its end, stock should be avoided. Otherwise, the question is if the desired/offered lead time towards the customer is greater than the lead time from the supplier. If this is the case, the company can order and deliver the product within their offered lead time, without stocking the item. Therefore, in this case, the item is not stocked. If this is not the case, the ABC/FMR analysis needs to be performed. The ABC classification is based on product value flow or annual dollar volume (Ongkicyntia & Rahardjo, 2017). The FMR-classification is based on the frequency of demand, where F is high frequency and R is low frequency demand. The model states that AR and BR items (expensive, but slow-moving products) should be avoided to stock. The AF, AM, BF, and BM items should be stocked and managed carefully, while CF and CM should also be stocked, but can be managed less carefully. The CR items can be stocked by exception.

ABC/OSX-classification (Richards, 2011)

The ABC/OSX-classification is an extension of the standard ABC-classification. "A warehouse manager can extend the normal classification to include non-moving and obsolete stock together with identifying stock which may not require storage in the warehouse but can be despatched direct from the supplier to the end customer where the lead time is in line with the customer's requirement" (Richards, 2011, p. 123). In the classification, O means obsolete or non-moving stock, S means special or one-off purchases, and X means non-stock or non-standard items (Figure E-4). The challenge is, however, in finding the right percentages to perform the classification.

Classification	Description
A	Fast-moving stock
B	Medium-moving items
C1	Slow-moving items
C2	Very slow-moving but required for cover
O	Obsolete or non-moving stock
S	Special or one-off purchases
X	Non-stock or non-standard items

Figure E-4: ABC/OSX-classification (Richards, 2011)

A way of determining whether or not there is an excess of slow-moving stock in the warehouse is to calculate the stock turn (Richards, 2011): $Stock\ turn = \frac{Cost\ of\ goods\ sold}{Average\ cost\ of\ goods\ stored}$. Richards (2011) states that the higher the stock turn, the better the company is performing. However, no general goal can be determined, since this depends among others on the sector the company is in.

Framework based on consumption and functionality (Botter & Fortuin, 2000)

The model developed by Botter & Fortuin (2000) is based on spare part management; however, the underlying idea could be useful for this study. The model classifies the items on consumption (demand) and on functionality (criticality for uptime). Then, it is up to management to decide which items to stock and which not. From the framework in Figure E-5, it could be wise to not stock items in e.g., the category DY and DZ.

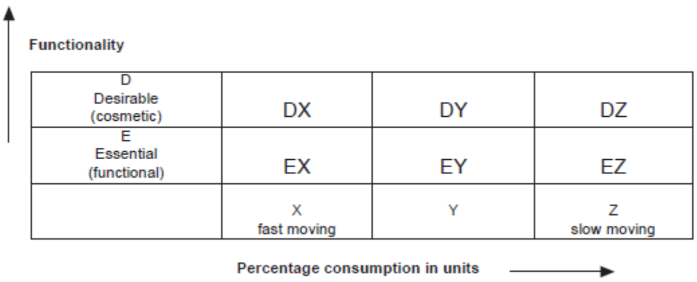


Figure E-5: Framework based on consumption and functionality (Botter & Fortuin, 2000)

Inventory management Classification of SKUs

Table E-2: Literature search Inventory Classification (date of search 21/02/2022)

Database	# Of articles	Search string
SCOPUS **Business Source Elite**	41(6) 13(1)	("inventory" OR "inventory management" OR "inventory control") AND ("classification" OR "Ranking") AND ("SKU" or "stock keeping unit")

Appendix F Derivation Total cost functions

Table F-1: Notations used in Total cost Derivations

Notation	Definition
	Input variables
MOQ	Minimum Order Quantity
IOQ	Incremental Order Quantity
h	Yearly holding cost per item as percentage of purchase price
c_p	Purchase price per item
c_{sell}	(Average) selling price per item
c_O	Ordering cost per order
c_{Sh}	Shortage cost per item per day short as percentage of purchase price
c_{PD}	Cost per extra delivery
$p_{PD,S}$	Probability of an extra delivery under stocking
$P_{PD,NS}$	Probability of an extra delivery under non-stocking
R	Review period in days
L	Lead time in days
$E[J]$	Expected Order line size
$E[D]$	Expected yearly demand
	Auxiliary variables
EOQ	Economic Order Quantity (calculated using Equation (2))
Q	Used order quantity (based on EOQ, IOQ and MOQ)
$E[BO]$	Backorders at an average point in time
s	Reorder point
SS	Safety stock
$E[D_{R+L}]$	Expected Demand during review period plus lead time
	Output variable
$E[C_h]$	Expected total yearly holding cost
$E[C_O]$	Expected total yearly ordering cost
$E[C_{Sh}]$	Expected total yearly shortage cost
$E[C_{PD}]$	Expected yearly partial delivery cost
$E[TC_S]$	Expected cost per year under stocking
$E[TC_{NS}]$	Expected cost per year under non-stocking
$E[P_S]$	Expected profit per year under stocking
$E[P_{NS}]$	Expected profit per year under non-stocking

We know that the total cost under stocking is equal to the sum of the holding, the ordering, the shortage, and the partial delivery cost:

$$E[TC_S(D)] = E[C_h] + E[C_O] + E[C_{Sh}] + E[C_{Pd}]$$

To calculate the yearly holding cost, we need to know what the average stock level is. It is well-known from theory that inventory consists of cycle and safety inventory. The expected safety inventory is constant, since this is only present to cope with uncertainties. Since we assume that demand follows a Compound Poisson process, we determine the reorder point and use that to find the safety stock $SS = s - E[D_{R+L}]$ (determination of reorder point will be discussed separately). The cycle inventory is not constant, but the expected cycle inventory is half the order quantity (also well-known from theory, see Figure F-1), since in principle an R, s, Q policy uses a fixed order quantity. Using h as yearly holding cost per item as percentage of the purchase price, the total yearly holding cost C_h is then equal to the average inventory times the holding cost:

$$E[C_h] = \left(s - E[D_{R+L}] + \frac{Q}{2}\right) hc_p \tag{24}$$

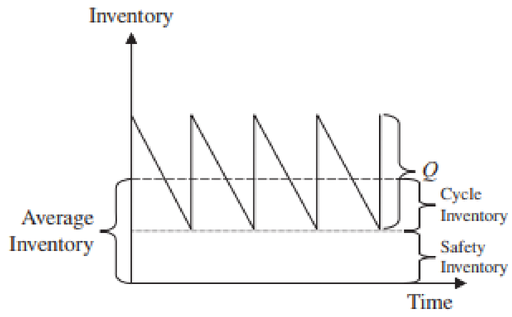


Figure F-1: Safety and cycle inventory to determine average inventory (Chopra & Meindl, 2016, p. 315)

To determine the total ordering cost per year, the number of orders must be determined. Since an R, s, Q policy is used, there is a fixed order quantity. So, the total expected yearly demand must be divided by the order quantity, which gives us the expected number of orders. Then, the yearly total ordering cost is the expected amount of orders times the cost per order:

$$E[C_O] = \frac{E[D]}{Q} c_O \tag{25}$$

The shortage cost is determined by multiplying the expected backorders at an arbitrary point in time by the shortage cost per year per unit per time unit by the purchase price. The determination of the expected backorders is treated separately.

$$E[C_{Sh}] = E[BO] c_{Sh} c_p \tag{26}$$

The partial delivery costs are determined by multiplying the chance of a partial delivery with the cost of a partial delivery times the number of order lines.

$$E[C_{PD}] = \frac{E[D]}{E[J]} p_{PD,S} c_{PD} \tag{27}$$

Then, the total cost is:

$$E[TC_S(D)] = \left(s - E[D_{R+L}] + \frac{Q}{2}\right) hc_p + \frac{E[D]}{Q} c_O + E[BO] c_{Sh} c_p + \frac{E[D]}{E[J]} p_{PD,S} c_{PD} \tag{28}$$

Safety stock – Compound Poisson demand

To determine the expected safety stock under Compound Poisson demand, the expected number of arrivals (order lines) during the review period plus the lead time is needed. Also, the expected order line size is needed, for which the average of the historical demand is used. Then, the expected number of arrivals is equal to the expected number of arrivals per year times the review period plus the lead time: $\mu = \lambda \frac{R+L}{365}$. Then, using the cumulative probability distribution function of a Poisson random variable with mean μ:

$$F(x;\mu) = \sum_{i=0}^{x} \frac{\mu^i e^{-\mu}}{i!} \tag{29}$$

We need to find the minimum value of x, for which the cumulative distribution function is equal to or greater than the target service level. Then, the reorder point is determined by multiplying x by the expected order line size $E[J]$: $s = x * E[J]$.

We can use trial and error or a program to find the minimum reorder point that satisfies the target VFR. Figure F-2 gives VBA code that determines the reorder point given a certain target fill rate and demand. Then, using the fact that $s = SS + \mu E[J] \rightarrow SS = s - \mu E[J]$, we easily get the expected safety stock.

```
Function FindReorderPointPoissonVFR(Lambda As Long, VFR As Double)
Dim i As Long
Dim RealVFR As Double

Application.ScreenUpdating = False
Application.Calculation = xlManual

i = 0
Do While RealVFR < VFR
    i = i + 1
    RealVFR = Application.WorksheetFunction.Poisson_Dist(i, Lambda, True)
Loop
FindReorderPointPoissonVFR = i

Application.ScreenUpdating = True
Application.Calculation = xlAutomatic

End Function
```

Figure F-2: VBA Code to determine reorder point for Poisson demand and VFR

Expected backorders under stocking – Poisson demand

Axsäter (2006) first determines the distribution of the inventory position (the inventory level plus incoming orders). Using a continuous review policy and an inventory system with discrete compound Poisson demand, an order Q is triggered immediately after a customer has arrived and the inventory position IP is smaller than or equal to the reorder point s. Using this property, Axsäter (2006) proofs that the inventory position is then uniformly distributed in the interval $[s + 1, s + Q]$. However, as mentioned, this is only true for a continuous review policy. Under a periodic review policy, the order is not placed immediately after the inventory position is smaller than or equal to the reorder point after a customer has arrived, but only if the review period is passed. However, for simplicity, we will approximate by assuming that a continuous review policy with fixed order quantity is used but using the lead time plus the review period instead of only the lead time.

Then, it can be assumed that the inventory position is also uniformly distributed in the interval $[s + 1, s + Q]$ for a discrete demand distribution. In this case, demand is Compound Poisson distributed with mean $\mu = \lambda E[J]$, where $E[J]$ is the expected order line size and λ is the number of demand arrivals per time unit.

Axsäter (2006) shows that at a random time $t + L$ before a possible delivery the inventory level is equal to the inventory position at time t minus the demand during the lead time L. Using our assumption of $L \rightarrow R + L$, we get:

$$IL(t + R + L) = IP(t) - D_{R+L} \qquad (30)$$

Since IP is uniformly distributed, IL has the following distribution, where IL is the inventory level at time $t + L + T$ before a possible delivery (Axsäter, 2006):

$$P(IL = i) = \frac{1}{Q} \sum_{k=\max(s+1,i)}^{s+Q} P(D_{R+L} = k - i) \qquad i \leq s + Q \qquad (31)$$

If the inventory level is smaller than 0, there is a backorder. Therefore, the expected number of backorders is equal to

$$E[IL|i < 0]$$

Obviously, this is equal to

$$E[IL|i < 0] = E[BO] = E[IL|i \geq 0] - E[IL] \qquad (32)$$

Since

$$E[IP] = \frac{1}{2}(s + 1 + s + Q) = s + \frac{Q + 1}{2} \tag{33}$$

$E[IL]$ is easily obtained from Equation (30) as

$$E[IL] = s + \frac{Q + 1}{2} - E[D_{R+L}] \tag{34}$$

Furthermore, from probability theory is known that:

$$E[IL|i \geq 0] = 1 * P(IL = 1) + \cdots + (s + Q) * P(IL = s + Q) \tag{35}$$

From which $P(IL = i)$ can be obtained through Equation (31). This is easier to determine, since $i \leq s + Q$ is bounded. However, again, this cannot be determined by a simple formula. Therefore, a VBA code is written to determine the expected backorders (Figure F-3).

```
Function FindExpectedBackorders(lambda As Double, custsize As Double, LeadTime As Double, ReviewPeriod As Double, s As Integer, Q As Integer)
Dim mu, ExpectedIL, sum, EILPlus As Double
Dim i, j As Integer
Dim ProbIL() As Variant


mu = lambda * custsize

ExpectedIL = s + (Q + 1) / 2 - mu * (LeadTime + ReviewPeriod)

ReDim ProbIL(s + Q, s + Q)
EILPlus = 0
For i = 0 To s + Q
    sum = 0
    For j = WorksheetFunction.Max(s + 1, i) To s + Q
        ProbIL(i, j) = WorksheetFunction.Poisson_Dist(j - i, mu * (LeadTime + ReviewPeriod), False)
        sum = sum + ProbIL(i, j)
    Next j
    EILPlus = EILPlus + i * sum / Q
Next i

FindExpectedBackorders = EILPlus - ExpectedIL

End Function
```

Figure F-3: VBA Code to determine expected backorders under Compound Poisson demand

Appendix G Input parameter determination

Due to confidentiality issues, parts of this Appendix are left blank.

Holding cost

Holding inventory costs money. They are a main input for determining the economic order quantity (Equation (2)). Generally, holding costs are determined by including (1) working capital costs, (2) storage costs, and (3) obsolescence risk costs (Slack, Brandon-Jones, & Johnston, 2013) (Durlinger, 2016). The capital costs can be determined by the WACC (Weighted Average Cost of Capital), which is calculated based on the financial structure of the organisation (Durlinger, 2016). To determine the storage costs, an easy method is to look at what a logistics service provider would charge per pallet place over time. Another way is to determine the cost of personnel, warehouse, checking, et cetera that are present in the organisation. The risk related costs are mainly insurance costs (Durlinger, 2016). Often, "holding cost is estimated as a percentage of the cost of a product" (Chopra & Meindl, 2016, p. 271). Durlinger (2016) suggests differentiating the percentage over the SKUs, since some products have higher risk and/or higher value per volume.

According to Chopra and Meindl (2016) the following major components are part of the holding costs:

1. Cost of capital – WACC can be used to determine the cost of capital.
2. Obsolescence (or spoilage) cost – estimate of the rate the at which the value of the inventory drops due to decreasing market value.
3. Handling cost – should include only incremental receiving and storage costs that vary with the quantity of the product. Fixed handling cost, independent of quantity, should be included in the ordering costs.
4. Occupancy cost – incremental change in space cost due to changing cycle inventory.
5. Miscellaneous cost – e.g., theft, security, damage, or tax.

To determine the holding cost at Jarola, Durlinger's (2016) approach is used, which means that the holding cost consists out of the WACC, the storage cost, and the risk cost. Durlinger's (2016) suggestion to differentiate over e.g. volume of an SKU is not researched; however, this is a suggestion for further research.

Working capital costs

The WACC can be calculated, however, this percentage is also a predetermined percentage available at the controller. No change is needed in the WACC, so the current WACC of **10%** will be used.

Storage costs

To determine the storage costs, an easy method is to look at what a logistics service provider (LSP) would charge per pallet place over time and look at what the average purchasing value of a pallet is. Then, by dividing these, the storage cost as percentage of the purchasing price per year is determined. A similar method is to look at the total yearly storage cost at the LSP (for storage and inbound handling) and divide this over the total average purchasing value of inventory located at the LSP over the same time unit. Another way is to determine the cost of personnel, warehouse, checking, et cetera that are present in the organisation per year and divide this by the average total purchasing value of the inventory.

$$Storage\ cost\ \% = \frac{Storage\ cost\ at\ LSP\ per\ year}{Average\ purchasing\ value\ of\ inventory\ located\ at\ LSP} \tag{36}$$

$$Storage\ cost\ \% = \frac{Yearly\ cost\ of\ personnel, warehouse, etc.}{Average\ total\ purchasing\ value\ of\ inventory} \tag{37}$$

Both methods are described:

Method 1

Jarola holds some of its inventory at logistics service providers (LSPs). One of these is. Basically, the costs for storage and entry can be divided by the purchasing value of inventory stored at this LSP. However, the items stored at this LSP have a very high purchasing value with respect to the other items. Therefore, the value of the inventory at this LSP is based on the number of units stored at this LSP times the average purchasing value of a unit in all inventory. Table F-2 shows the determination of the storage cost per item per year. The result is 6.7%.

Table G-1: Determination of average value of a unit in inventory

Warehouse/Location	Units in inventory	Total value of inventory	Average value / unit
Buiten Wulp 1			
Lutten			
staging			
Wulp 1			
Wulp 5			
Total			

Table G-2: Storage cost determination

Description	Amount	Unit
Pallets at LSP		Pallets
Costs per pallet		Euro per calendar day
		Euro per calendar year
Total costs LSP storage		Euro per calendar year
Entry costs at LSP		Euro per pallet entry
Entries at LSP (2021)		Pallet entries
Total costs LSP entry		Euro per year
Total costs LSP		Euro per year
Purchasing value (Table)		Euro
Storage cost	**6.7%**	**Per item per year**

Method 2

The financial department has an overview of costs per cost centres. In consultation with responsible people within the organisation, the costs per cost centre are assigned to ordering, holding, or other cost (other is obviously not used). Doing so, the total holding cost for January and March 2022 are €. Assuming that this can be multiplied by 4 to create a yearly cost, we get €. (Since the new DC was not considered in the cost of 2021, that cost is not representative for the coming years.) Dividing this by the total value of inventory of € (see Table), we get a yearly storage cost of 6.5% per item per year.

Using Equation (36), a storage cost of **6.7%** per item per year is found. Using Equation (37), a storage cost of **6.0%** per unit per year is found. The difference between these two methods is not significant.

Obsolescence risk costs

The risk related costs are mainly insurance costs (Durlinger, 2016). Some other costs must be considered as well, e.g., damage, theft, etc. To determine the yearly risk cost as percentage of the purchasing price, the money that is reserved for obsolete plus the insurance cost per year must be divided by the average total purchasing value of the inventory. A risk cost of 2% is found by using the following equation.

$$Risk\ cost\ \% = \frac{Interest + Activa}{Contribution\ to\ indirect\ cost\ centre} = 2\% \tag{38}$$

Since the determination of the risk cost does not include insurance cost, this is doubled to 4.0%.

Cost price additions

For some items, an addition for handling and depreciation is used. Some items have handling cost for e.g., packing single items in a bag of 25 pieces. On top of the standard holding cost percentage based on WACC, storage, and risk, this addition is added to the holding cost per item. If an addition is used, this is on average 38.1% of the purchase price. However, this is largely due to the handling cost (51.5% on average). Only considering depreciation, the addition is on average 8.5%. Currently, only 33 items have an addition for handling and only 56 items have an addition for depreciation. From the responsible department is found that the cost price additions are currently not up-to-date and therefore need improvement to become more accurate. However, for the time being these additions are used during the research.

Total holding cost

Then, the total yearly holding cost per item as percentage of the purchase price is equal to the sum of the above defined factors:

$$h = WACC\ \% + Storage\ cost\ \% + Risk\ cost\ \% + Addition\ \% \tag{39}$$

Using a WACC of 10%, a storage cost of 6.7% (6.0%), and a risk cost of 4.0%, the total holding cost per year as percentage of the purchase price is equal to 20.7% (20.0%). This percentage is rounded to **20%.** This is indeed lower than the currently used percentage of 25%, which is as expected. Per item/supplier it might be that an addition is added.

Ordering cost

According to Slack, Brandon-Jones, & Johnston (2013), order costs are calculated by considering (1) the cost of placing the order (including transportation costs from the supplier) and (2) the price discount costs. "The ordering cost includes all incremental costs associated with placing or receiving an extra order that are incurred regardless of the size of the order" (Chopra & Meindl, 2016, p. 272). According to Chopra and Meindl (2016) the following components are part of the ordering costs:

1. Buyer time – incremental time of the buyer placing the extra order.
2. Transportation costs.
3. Receiving costs – e.g., checking the order, administrative costs, et cetera.
4. Other costs – organisation-specific ordering costs.

According to Durlinger (2016), the ordering cost consists of three components: (1) the personnel cost, (2) the transportation costs of the supplier, and (3) the checking and booking of the incoming products. Again, Durlinger (2016) suggests differentiating the ordering costs over e.g. the suppliers instead of using a constant.

To determine the ordering cost, again Durlinger's (2016) approach is used. Following Durlinger's (2016) suggestion to differentiate over the supplier, the ordering cost will be determined in two parts: the transportation costs per supplier and the other costs independent of supplier.

The ordering cost (excluding transportation)

The ordering cost (excluding transportation) is determined by summing all costs that are incremental with the number of orders related to ordering products. E.g., the purchasing department is not considered in the cost determination, however, the receiving team is. Using the same approach as Method 2 in the determination of the storage cost, a total cost of € is found (again, for January, February, and March 2022). From the data over 2021, the average number of purchase order lines is

7.8. In Q1 2022, purchase orders are placed, which means that, using the average, purchase order lines are expected to be placed. Using these, the order cost per order line is € = **€10.05.**

Transportation cost

The found order cost is equal to the currently used order cost. It is however important to note that this is without the transportation cost. As mentioned, a cost price is used which is the purchase price plus possible additions. Furthermore, for some suppliers the goods are picked up at the supplier and the costs are paid by Jarola, while some compensation is paid to Jarola by the supplier. For quartile 1 of 2022, the cost made for picking up goods at suppliers is €. The compensation that was paid to Jarola was €. Furthermore, transportation cost is processed through the cost price (€). Therefore, the other transportation cost that are not processed or compensated yet are €. This is = €4.58 transportation cost per order line for items that do not have an addition through the cost price.

This means that a distinction must be made for items that have transportation cost through a cost price and items that do not: items that **do** have transportation cost through a cost price should use an order cost of (rounded) €10 + Addition (different per item). Items that **do not** have transportation cost through a cost price should use an order cost of €10.05 + €4.58 = €14.63, which is rounded to €15,-.

In the ideal case, all items should have a fitting cost price addition, which means that if that addition is zero, deliveries are free. If deliveries are free, the ordering cost is lower which means that orders should be placed more often. This can have a positive influence on the inventory costs. To cope with extra transportation cost specifically for non-stocked items (e.g., if the minimum order amount cannot be ordered and an extra shipping cost is incurred) an extra field is created in the model.

To conclude, the total ordering cost per order line is either **€10,- plus the additions** for items with additions or **€15,-** for items without additions. It is however recommended to create a clear overview per supplier or item what the actual transportation cost are.

Appendix H Details Evaluation Model SKU vs Non-SKU

Due to confidentiality issues, parts of this Appendix are left blank.

Evaluation

Table H-1: Cost and profit resulting from advices

		Current	Advice (without discontinue)	Advice (with discontinue)
Number of items	Stocking	2,332	4,774	3,119
	Non-stocking	8,630	6,188	4,481
	Total	10,962	10,962	7,600
Profit	Stocking			
	Non-stocking			
	Total			
Cost holding	Stocking			
	Non-stocking			
	Total			
Cost ordering	Stocking			
	Non-stocking			
	Total			
Cost shortage	Stocking			
	Non-stocking			
	Total			
Cost partial delivery	Stocking			
	Non-stocking			
	Total			
Total cost	Stocking			
	Non-stocking			
	Total			

Sensitivity Analysis

Table H-2: Sensitivity Analysis model Stock versus Non-stock – Holding cost

From	To	Profit		Profit and discontinue	
		$h = 18\%$	$h = 22\%$	$h = 18\%$	$h = 22\%$
Stocked	**Non-stocked**	783	807	225	243
Non-stocked	**Stocked**	3,318	3,147	1,894	1,801
Stocked	**Discontinue**	0	0	814	845
Non-stocked	**Discontinue**	0	0	2,526	2,550
Total		4,101	3,954	5,459	5,439
% Of items advised to change		37.4%	36.1%	49.8%	49.6%
Effect on profit		+6.6%	+6.7%	+8.5%	+8.7%
Effect on costs		-27.3%	-26.1%	-40.4%	-39.3%
Effect on shipment reliability		0.5%	0.5%	0.6%	0.6%

Table H-3: Sensitivity Analysis model Stock versus Non-stock – Ordering cost

From	To	Profit		Profit and discontinue	
		$c_o = 10$	$c_o = 12.5$	$c_o = 10$	$c_o = 12.5$
Stocked	Non-stocked	818	808	275	256
Non-stocked	Stocked	3,093	3,172	1,962	1,913
Stocked	Discontinue	0	0	756	787
Non-stocked	Discontinue	0	0	1,919	2,257
Total		3,911	3,980	4,912	5,213
% Of items advised to change		35.7%	36.3%	44.8%	47.6%
Effect on profit		+4.5%	+5.5%	+5.5%	+7.0%
Effect on costs		-24.6%	-25.7%	-34.2%	-37.1%
Effect on shipment reliability		0.5%	0.5%	0.5%	0.6%

Table H-4: Sensitivity Analysis model Stock versus Non-stock – Partial Delivery cost

From	To	Profit		Profit and discontinue	
		$c_{Pd} = \{5,30\}$	$c_{Pd} = \{1,20\}$	$c_{Pd} = \{5,30\}$	$c_{Pd} = \{1,20\}$
Stocked	Non-stocked	778	817	226	246
Non-stocked	Stocked	3,547	2,867	1,896	1,825
Stocked	Discontinue	0	0	832	821
Non-stocked	Discontinue	0	0	2,559	2,502
Total		4,325	3,684	5,516	5.394
% Of items advised to change		39.5%	33.6%	50.3%	49.2%
Effect on profit		+6.9%	+6.4%	+8.9%	+8.3%
Effect on costs		-27.1%	-26.3%	-40.2%	-39.3%
Effect on shipment reliability		0.5%	0.5%	0.6%	0.6%

Table H-5: Sensitivity Analysis model Stock versus Non-stock – Service level Stocked items

From	To	Profit		Profit and discontinue	
		$SL = 90\%$	$SL = 80\%$	$SL = 90\%$	$SL = 80\%$
Stocked	Non-stocked	754	819	199	256
Non-stocked	Stocked	3,582	3,089	2,081	1,757
Stocked	Discontinue	0	0	827	825
Non-stocked	Discontinue	0	0	2,557	2,523
Total		4,336	3,908	5,664	5,361
% Of items advised to change		39.6%	35.7%	51.7%	48.9%
Effect on profit		+7.9%	6.2%	+9.8%	8.0%
Effect on costs		-28.8%	-25.9%	-41.2%	-39.2%
Effect on shipment reliability		0.5%	0.5%	0.6%	0.6%

Appendix I Details Evaluation Inventory Optimisation

Classification and Target Service Levels

Settings

Table I-1: Settings of the simulations

Sim	Classification	Cross method: Rev	OLs A	OLs B	OLs C	Target service levels: Rev	OLs A	OLs B	OLs C
Current	Double ABC on revenue (70/20/10%) and order lines (65/20/15%)	A	A	A	A	A	97%	97%	97%
		B	A	B	C	B	97%	90%	90%
		C	A	B	C	C	85%	85%	85%
1	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) Service level classification CA is changed to 97%.	A	A	A	A	A	97%	97%	97%
		B	A	B	C	B	97%	90%	90%
		C	A	B	C	C	97%	85%	85%
2	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) Classification symmetrical Consistent service levels	A	A	A	A	A	97%	97%	97%
		B	A	B	B	B	97%	90%	90%
		C	A	B	C	C	97%	90%	85%
3	Double ABC on revenue (70/20/10%) and order lines (70/20/10%) Classifications equal distributions Classification symmetrical Consistent service levels	A	A	A	A	A	97%	97%	97%
		B	A	B	B	B	97%	90%	90%
		C	A	B	C	C	97%	90%	85%
4	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) Service levels are made consistent according to crossing method.	A	A	A	A	A	97%	97%	97%
		B	A	B	C	B	97%	90%	85%
		C	A	B	C	C	97%	90%	85%
5	Double ABC on revenue (70/20/10%) and order lines (65/20/15%) ABC-classification made consistent according to service level.	A	A	A	A	A	97%	97%	97%
		B	A	B	B	B	97%	90%	90%
		C	A	C	C	C	97%	85%	85%

Details Simulations 1 up to and including 5

Table I-2: Results simulations classification and service levels – Weighted average service level

Sim	Revenue	Order lines	Demand	Sum of difference
Current	94.9%	92.6%	94.7%	
1	95.1% (+0.1%)	93.6% (+1.1%)	95.4% (+0.8%)	+2.0%
2	95.2% (+0.2%)	94.1% (+1.7%)	95.7% (+1.0%)	+2.9%
3	95.3% (+0.4%)	94.6% (+2.2%)	95.9% (+1.2%)	+3.8%
4	94.8% (-0.1%)	94.0% (+1.6%)	95.5% (+0.9%)	+2.4%
5	95.1% (+0.1%)	93.6% (+1.1%)	95.4% (+0.8%)	+2.0%

Table I-3: Results simulations classification and service levels – Units in inventory and value of inventory

Sim	Average units in inventory					Average value of inventory				
	Total	A	B	C	Diff	Total	A	B	C	Diff
Curr		57.8%	16.8%	25.4%			56.9%	9.6%	33.5%	
1		58.5%	16.5%	25.0%	1.8%		57.0%	9.6%	33.4%	0.2%
2		58.3%	20.7%	21.0%	2.1%		56.9%	21.1%	21.9%	0.3%
3		61.3%	22.2%	16.5%	2.5%		58.6%	21.6%	19.8%	0.6%
4		58.5%	16.8%	24.7%	1.8%		57.4%	9.8%	32.9%	-0.4%
5		58.5%	10.4%	31.1%	1.8%		57.0%	17.4%	25.5%	0.2%

Table I-4: Results simulations classification and service levels - ABC distributions after crossing

	Distribution Revenue			Distribution Order lines			Distribution SKUs		
Sim	A	B	C	A	B	C	A	B	C
Current	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%	15.4%	12.7%	71.9%
1	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%	15.4%	12.7%	71.9%
2	78.6%	14.9%	6.5%	68.0%	19.8%	12.2%	15.4%	18.6%	65.9%
3	80.0%	14.5%	5.4%	72.1%	19.2%	8.7%	17.4%	21.6%	61.0%
4	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%	15.4%	12.7%	71.9%
5	78.6%	12.5%	8.9%	68.0%	8.4%	23.6%	15.4%	10.2%	74.3%

Simulations for Shipment reliability
In Simulation 1, only the target service level of CA-items is changed from 85% to 97%. In the data for 2021, 54,924 order lines are order lines with CA-items, which is equal to 6.6% of the total order lines in 2021. Of the 54,924 order lines, 4,642 are considered to be too late, which means a reliability of 91.5%. Since the target service level is increased to 97%, we now assume that an order line is late only if a random number generated by Excel is larger than or equal to the target service level. The same approach is used for the other simulations, where the target service level is adapted for the class that is changed.

Other simulations
Other simulations are performed with the goal to further increase the weighted average service levels. First, the goal is to do so, without changing the values of the target service levels (97%, 90%, 85%), but by changing the classification distributions. Since Simulation 3 resulted in the highest service levels, this will be used as basis. From the results of Simulation 3 can be seen that the only weighted average service level below 95% is for the order lines. After doing more simulations with as main goal to increase the weighted average service level over the order lines, while keeping the other two weighted average service levels at least above 95% and the increase in inventory value and items to a minimum, the closest distributions are 65/20/15% for the revenue classification and 77/13/10% for the order line classification. The weighted average service levels for these settings are 95.3% (revenue), 95.0% (order lines), and 96.0% (demand). The increase in inventory units is 2.8% and for value 0.4%. The increase in inventory value is not significant, however, the increase in units is.

Table I-5: Overview of settings for simulations Classification and Target Service levels – Set 2

Sim	Classification
14	Double ABC on revenue (65/20/15%) and order lines (80/15/5%), Sim4 as base
15	Double ABC on revenue (65/20/15%) and order lines (77/13/10%), Sim4 as base

The next option is to slightly change the target service levels. Three simulations are done, where in every simulation one of the service levels is increased with 1%. Increasing the service levels causes significant increases in the inventory (value and unit), while the increase in weighted average service levels is not that significant compared to changing the ABC-classification distributions.

Table I-6: Overview of settings for simulations Classification and Target Service levels – Set 3

Sim	Classification
16	Sim5 as base, service level of B-items to 91%
17	Sim5 as base, change service level of C-items to 86%
18	Sim5 as base, change service level of A-items to 98%

Table I-7: Results simulations classification and service levels – Weighted average service level

Sim	Revenue	Order lines	Demand	Sum of difference
Current	94.9%	92.6%	94.7%	
14	95.5% (+0.4%)	95.4% (+1.3%)	96.2% (+0.5%)	+2.2%
15	95.3% (+0.2%)	95.0% (+0.9%)	96.0% (+0.3%)	+1.4%
16	95.5% (+0.3%)	94.8% (+0.7%)	96.0% (+0.3%)	+1.3%
17	95.4% (+0.2%)	94.7% (+0.6%)	95.9% (+0.2%)	+1.0%
18	96.1% (+1.0%)	95.3% (+1.3%)	96.7% (+1.1%)	+3.4%

Table I-8: Results simulations classification and service levels – Units in inventory and value of inventory

Sim	Average units in inventory					Average value of inventory				
	Total	A	B	C	Diff	Total	A	B	C	Diff
Current		57.8%	16.8%	25.4%			56.9%	9.6%	33.5%	
14		69.5%	19.1%	11.4%	3.2%		59.9%	17.2%	22.9%	0.8%
15		66.0%	16.5%	17.5%	2.8%		61.6%	19.9%	18.5%	0.4%
16		61.1%	22.4%	16.5%	2.7%		58.4%	21.9%	19.7%	0.9%
17		61.2%	22.2%	16.6%	2.6%		58.5%	21.6%	19.9%	0.7%
18		62.4%	21.6%	16.0%	5.6%		59.9%	20.9%	19.2%	3.9%

Table I-9: Results simulations classification and service levels - ABC distributions after crossing

	Distribution Revenue			Distribution Order lines			Distribution SKUs		
Sim	A	B	C	A	B	C	A	B	C
Current	78.6%	7.9%	13.5%	68.0%	17.6%	14.4%	15.4%	12.7%	71.9%
14	82.4%	12.8%	4.8%	80.7%	14.5%	4.8%	22.9%	24.5%	52.5%
15	81.1%	11.9%	7.1%	78.0%	12.8%	9.2%	20.8%	16.1%	63.1%
16	80.0%	14.5%	5.4%	72.1%	19.2%	8.7%	17.4%	21.6%	60.9%
17	80.0%	14.5%	5.4%	72.1%	19.2%	8.7%	17.4%	21.6%	60.9%
18	80.0%	14.5%	5.4%	72.1%	19.2%	8.7%	17.4%	21.6%	60.9%

Holding and Ordering cost

To see what influence the ordering cost has on the inventory, all ordering cost is set to €15,-, with a holding cost parameter of 25%. The results are given in Table I-10, including a sensitivity analysis. The results are that increasing the ordering cost parameter to €15, - results in a significant increase in inventory (units and value) of more than 5%. Obviously, the number of purchase order lines decreases significantly as well. If all ordering cost are set to €15,- and the holding cost parameter is decreased to 20%, the inventory increases significantly with 14.6% (units) and 13.7% (value), while the number of purchase order lines decreases significantly with 18.2%.

Table I-10: Results simulations ordering cost parameter

Ordering cost (h=25%)	€15 (w.r.t. €10, €25, h=25%)	€13 (w.r.t. €15)	€17 (w.r.t. €15)
Inventory units	+5.1%	-2.6%	+6.5%
Inventory value	+6.4%	-6.4%	+8.3%
# Of order lines	-10.6%	0.1%	-0.2%

The transportation cost is very dependent on the supplier. In principle, all suppliers should therefore be analysed to find the realised transportation cost per order line. However, this has to be done manually and is very time consuming. To overcome this, six suppliers are analysed based on realised transportation cost for quartile 1 in 2022. It is found that three of these six suppliers deliver for free. The other three suppliers have a realised transportation cost of €X, €Y, and €Z per order line. Obviously, only changing the ordering cost has no influence for the first three suppliers, since the transportation costs are zero. For the other three suppliers, the number of expected order lines that needs to be placed at the supplier is expected to reduce by 26.1%, 10.9%, and 3.9%. However, this does lead to a higher average inventory, an increase in units of 35.6%, 11.9%, and 1.3% and in value of 27.7%, 31.3%, and 2.1% is found after simulating. Also changing this parameter to 20% leads to an even larger decrease in number of expected order lines for the coming year of 29.7%, 11.8%, and 11.8%. Also, the inventory is expected to increase even more by 46.9%, 12.7%, and 4.1% for those suppliers. This makes sense, since decreasing the holding cost parameter means that it is cheaper to hold inventory, which leads to a higher order quantity.

Decreasing Inventory

The inventory is placed in the categories as follows:

- The physical Iron stock is determined by the minimum of the inventory on hand and the iron stock: $IOH_{Iron} = \min\{Iron, IOH\}$
- The physical Safety stock is determined by the minimum of the inventory on hand minus the physical iron stock and the safety stock: $IOH_{Safety} = \min\{IOH - IOH_{Iron}, Safety\}$
- The physical Cycle stock is determined by the minimum of the inventory on hand minus the physical iron stock minus the physical safety stock and the cycle stock, which is equal to the order quantity (the maximum is taken instead of the average):
  $IOH_{Cycle} = \min\{IOH - IOH_{Iron} - IOH_{Safety}, Cycle\}$
- The physical other stock is the leftover physical stock: $IOH_{Other} = IOH - IOH_{Iron} - IOH_{Safety} - IOH_{Cycle}$.

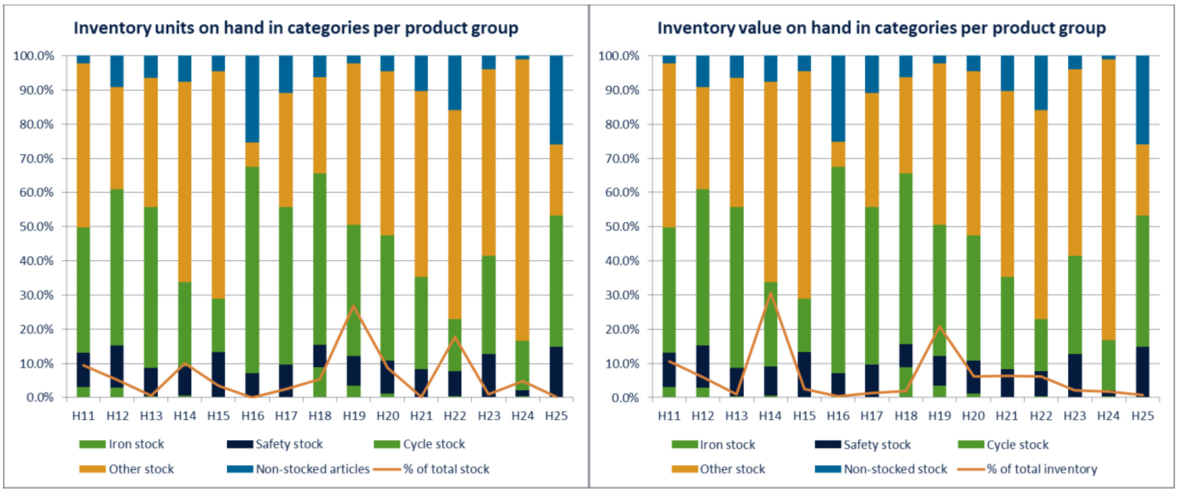


Figure I-1: Inventory per category per product group, (a) in units, (b) in value

Looking at the inventory on hand per product group (a description per product group is given in Appendix A), the main inventory (based on units) is in product group H19 – Pressure pipes and fittings. However, the product group with the largest part of other stock is H24 – Tools. A product group with significant non-stocked inventory is H16 – Sanitary. If the value is the main goal to decrease, the inventory of product group H14 – Electrics and Lights should be the main focus, however, also H24 – Tools can be a good focus.

Appendix J Translation table Confidential information

Due to confidentiality issues, this Appendix is left blank.