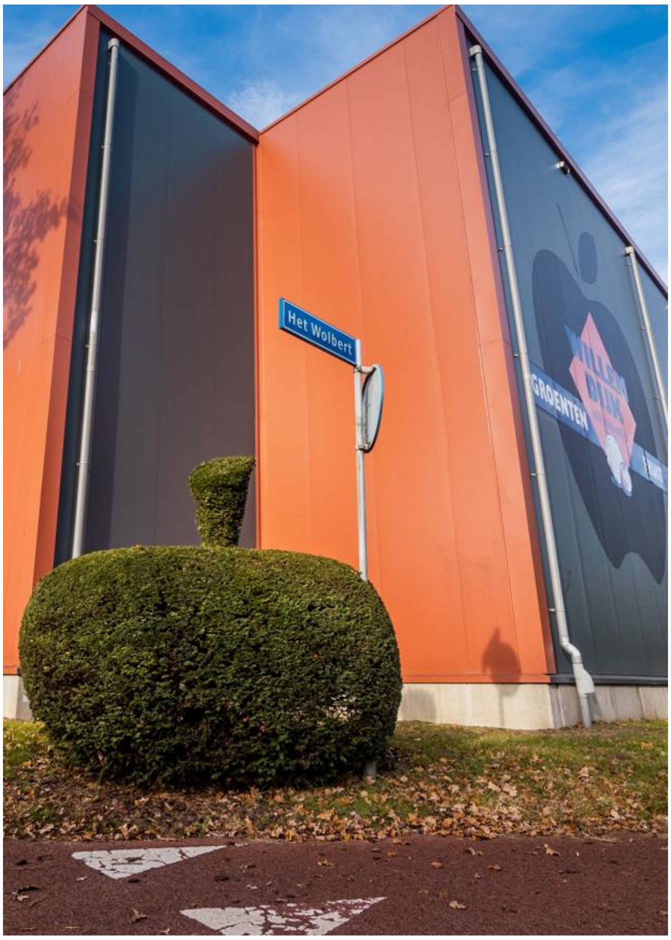

ALIGNING ORDER QUANTITIES WITH A NEW INVENTORY POLICY AT WILLEM DIJK

An academic approach to an industry with fast-deteriorating products

Niels Veldhuizen
Bachelor Thesis Industrial Engineering & Management

Aligning order quantities with a new inventory policy at Willem Dijk

Bachelor Thesis Industrial Engineering and Management
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Management summary

Introduction

Willem Dijk AGF B.V. (WD) is a wholesaler in the fruit, vegetables, and potatoes (FVP) sector, operating from Enschede, the Netherlands. WD is specialized in same-day purchasing and delivery of products, ensuring a high shelf life of its products for its customers, a unique selling point in the industry. Same-day dispatch results in low inventory levels (ILs) but many inbound and outbound logistical movements. The FVP industry distinguishes itself from other industries in terms of high obsolescence risk, stark purchase price deviations, supply deficits and demand affected by the weather. WDs customer base spans from wholesalers and supermarkets to market stalls, primarily in the Northern and Eastern parts of the Netherlands and Western Germany.

Problem Statement

Many products of WD are dispatched and transported to their customers on the same day of purchase. This makes the purchasing, inbound and outbound logistics and order picking process dependent on each other. The purchasing department currently bases order quantities of products on the weather and the price and purchasing happens from 05:00 until 09:00 hours. Then, the products are transported to WD, unloaded from the truck, checked for quality, transported to the warehouse, order picked for the customers and transported to WDs customers. Many products are purchased daily whilst their reinspection period (RP), the period between a product arriving at WD and the first time when a product is reinspected on the quality, is significantly longer, making daily purchase questionable. These frequent purchases result in many supplier visits every morning and a low availability of products in the warehouse in the morning, reducing the efficiency in the warehouse and postponing the end time of employees in the warehouse. Wages after 19:00 hours are 25% more expensive than the ordinary wage. The absence of a well-defined inventory policy based on a demand forecasting model leads to operational inefficiencies. This leads to the problem statement:

How to reduce the inbound logistical costs and improve the efficiency in the warehouse at WD by implementing an inventory policy?

Approach

In this thesis, we create insights in the in the holding costs and the lost sales of the product. We will use an appropriate model to deal with these costs accordingly. This model aims for the optimal inventory level (OIL) by trading-off the freshness of products against the inbound logistical costs and the efficiency in the warehouse. The model includes several factors like the RP of products, demand forecasting through exponential smoothing, current inventory level (CIL), transportation costs and purchase and selling price fluctuations. The model calculates the expected profit at the CIL and the OIL for the upcoming period, and if turns out that the expected profit of the OIL minus the transportation costs, is bigger than the expected profit at the CIL, purchasing will happen. When a purchase happens, the order quantity will be based on the whole RP of a product to reduce the amount of inbound logistical movements and improved availability of products in the warehouse in the morning. This model is adopted into a dashboard in Excel, and can help WD with the transition from a primarily experience-based purchasing strategy to a more data-driven one, possibly improving operational efficiency and reducing costs.

Results

The implementation of a new inventory policy according to a newsvendor problem model leads to an IL that balances of operational efficiency and freshness, reducing the frequency of daily supplier visits and thereby lowering logistical costs. The product groups subject to analysis saw a decrease of logistical costs of €37,578.06 and an overall increase in the product availability in the morning with 304.6% in comparison with the current purchasing policy. Unfortunately, the financial result of the improved product availability in the morning cannot be estimated. However, it is assumed that a higher product availability will improve the efficiency in the warehouse. Also, this makes starting earlier in the warehouse possible and this expedites the end time as wages after 19:00 hours are 25% higher than ordinary hours.

Conclusion and recommendations

The adoption of the model for inventory control at WD can lead to significant operational improvements and cost reductions. However, the enterprise resource planning (ERP) system in use by WD does not provide the demand and sales data of products, making it currently not possible to implement the model. Also, the demand is assumed to be normally distributed but this has to be verified before implementing the model. Nevertheless, there are significant chances for WD if it starts collecting data in combination with further research on this topic. This can ensure that WD maintains its competitive edge in the FVP industry by optimizing inventory management and improving overall operational efficiency.

Contents

1. Introduction

This chapter gives the introduction to the research conducted at WD in Enschede. Section 1.1 introduces the reader to the company. Section 1.2 describes the problem identification at WD and Section 1.3 states the research questions necessary to cope with the problem.

1.1. Company Introduction

WD is a wholesaler in the FVP industry. WD daily purchases products at auctions and wholesalers, primarily located in the western part of the Netherlands and purchases products several times a week in Dutch provinces, like Limburg and Friesland. WD also acquires seasonal products. These purchases are done through importers and originate from, e.g., Spain, New Zealand and Brazil. Goods are purchased without a predefined buyer, meaning all goods procured will be added to the inventory. The purchasers estimate the demand for products based solely on their experience, so, no demand forecasting models are used. Approximately 70 to 75 percent of the goods are sold on the day of purchase. Upon arrival of the products in Enschede, employees unload the goods and prepare the order for customers. WDs customers base ranges from wholesalers and supermarkets to market stalls. It is a typical business-to-business enterprise. WD's customers are mainly located in the northern and eastern part of the Netherlands and in Western Germany. In Western Germany, WD is the most significant player in the FVP wholesale industry.

The industry WD is operating in, is an unusual branch. From the moment of harvest, the products start decaying in quality instantly. Hence, swift action is crucial. WD delivers its orders within 24 hours after the customer places an order to guarantee a high shelf life to its customers. The unique selling point of WD is that it dispatches a large portion of the purchased products on the same day, ensuring a high shelf life for the customer. This means that the ILs of WD are relatively low for the industry it operates in.

1.2. Problem identification

This section describes the problem identification. Paragraph 1.2.1 contains the problem context and Paragraph 1.2.2 displays the problem cluster.

1.2.1. Problem context

In this section, the problem context is described. The description of the problem is done according several characteristics where the FVP industry is known for.

Perishable market

"Perishability or deterioration is defined as damage, spoilage, vaporization, dryness, etc. of items" (Nahmias, 1982). As described in Section 1.1, deterioration in the FVP industry makes it essential to act swift from the moment of harvest to decrease the chance that the product will become obsolete and to guarantee the quality of the product for its end-users, the consumers. Usually, products start decaying after a certain period, and after that, in quality and value fastly. Champignons, e.g., only have a shelf life of five days from harvest to consumption. These fast-deteriorating products do not go to a wholesaler but directly to WD, otherwise the shelf life will be too short for the consumer. Also, the shelf life of products can differ throughout the year. Figure 1 displays the physical flow of products. Products with a longer shelf life are purchased at wholesalers and products with short shelf life are purchased at the farmer. Having a lot of different (fast-)deteriorating products in inventory requires intensive inventory policy and many logistical movements.

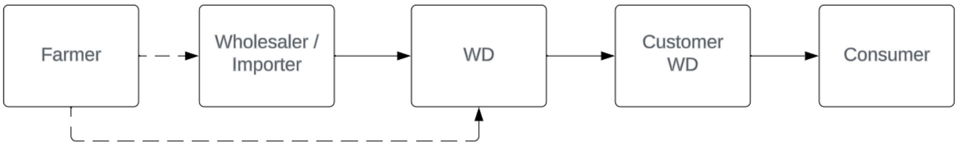

Figure 1. The physical flow of products purchased at WD

Seasonal

A large portion of the supply of the FVP industry is seasonal. Exceptions exist for fruits and vegetables harvested on both hemispheres, like tomatoes, apples and bananas. However, some products can only be harvested in certain parts of the world during a particular time frame, making the products seasonal.

Purchase price fluctuations

There are several reasons why the FVP is subject to stark price fluctuations. Firstly, the shelf life of some products is short, and therefore, every stage from the farmer to the consumer tries to deal with as little inventory as possible. If the demand suddenly rises, stock-outs are likely to happen. On the other hand, if demand suddenly drops, products are likely to go obsolete and the price will decrease significantly. Properly adapting to these fluctuations can increase the profit notably.

1.2.2. Problem cluster

The difference of RPs of products result in some products being in the warehouse for only a day while other products can be in the warehouse for up to three months. Due to the large number of products and seasonality, it is hard to adapt purchases to each product's perishability constantly.

Currently, approximately 35 to 40 suppliers are visited every day. Many products are purchased daily whilst the necessity of daily purchases is doubtful. For example, products with a RP of three days are often purchased daily. The high amount of daily supplier visits originates from the high shelf life WD wants to ensure for its customers. Averagely, a truck visits 3.5 suppliers every morning and visiting a supplier takes approximately 25 minutes. This results in 1.5 hours visiting suppliers daily for every truck a day. The combination of these factors result in high logistical costs.

WD offers approximately 1000 products to its customers. This high number gives a distorted image, as many of these products are substitutes of each other. Tomatoes, for example, come from different suppliers throughout the world are regarded as another product due to the different origin. For that reason, products are placed in product groups.

Products have a specific RP. The RP is defined as the shortest period that a product can become obsolete after entering the warehouse at WD. When a product is not sold during this period, the quality of the product is checked. Currently, the purchasing department adapts order quantities of products to products with a short RP but put less emphasis on adapting the order quantity of products with a medium or long RP. This means that products with a longer RP than two days are ordered frequently whilst its necessity is doubtful.

Table 1. Average end time in warehouse in 2023

Day	End time
Monday	23:23:53
Tuesday	20:50:24
Wednesday	22:10:40
Thursday	21:33:01
Friday	20:29:37
Average	21:40:34

The first shift in the warehouse starts around 09:30 hours and the last shift stops around 23:00 hours. The end time is dependent on the workload of the day and the day of the week. Table 1 above shows the average end time in the warehouse for each day of the week. During the day, employees get their ordinary wage. After 19:00 hours, the wage increases by 25%. For that reason, it is financially beneficial to get as much work done as possible before 19:00 hours.

Due to the little emphasis on products with a longer RP than two days, many products are purchased daily. These daily purchases result in a low amount of products available in the morning. This decreases the efficiency. Currently, there is the notion that employees in the morning do not work as efficiently as possible because there are no products to be picked. By improving the product availability in the morning, the employees in the warehouse can start earlier and work more efficiently resulting in earlier end times. Ending earlier results in a decrease of wages after 19:00 hours, the more expensive hour window. So, we make the assumption that if the products availability in the morning increases, the order-picking efficiency increases and the expensive hours expenses decrease. Figure 2 below depicts the problem cluster.

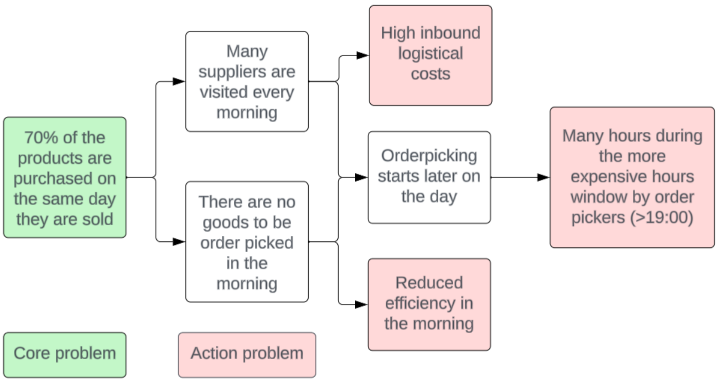

Figure 2. Problem cluster

To conclude, WD currently has no inventory policy. An inventory policy for products that have a RP longer than two days reduces the inbound logistical movements, improve the efficiency of the order picking process in the warehouse and reduce the amount of expensive hours. Figure 2 shows that there is one box that does not have another factor influencing it so introducing an inventory policy is the objective of this thesis. The problem statement is as follows:

70-75% of the goods are purchased on the same day they are sold

1.3. Research questions and sub-research questions

Now that the problem is described and problem statement is given, the type of research needs to be defined. There are two types of research, qualitative and quantitative. “Qualitative research includes an array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social, a quantitative research” (Cooper & Schindler, 2014). The goal of this thesis is to find a solution to WDs operational problem, therefore, this will be a qualitative research. Followingly, the main research question and sub-research questions can be described. (sub-)research questions are questions to split up the problem statement, thereby making it more accessible (Heerkens & van Winden, 2017). The research question can be answered after solving the sub-research questions and is given below.

What effects would implementing an inventory policy have on the inbound logistics, efficiency in the warehouse and the wage expenses in the warehouse?

SQ: What are the characteristics of the purchasing, selling, logistical and order picking process?

Researching the characteristics of the purchasing, selling, logistical and order picking process can provide valuable insights for the set-up of the model in Chapter 4. Section 2.1 and 2.2 give the answer to this sub-research question.

SQ: Which key performance indicators (KPIs) should be measured to evaluate results properly?

To calculate the effect of implementing a new inventory policy, several KPIs need to be introduced. These KPIs will be used to calculate the current situation and the expected situation after implementation of the inventory policy. In this way, the improvement can be measured and a consideration can be made whether to implement the new inventory policy or not. Section 2.3 introduces the reader to the KPI used in this thesis.

SQ: What kind of inventory policy can be used to represent the situation at WD?

This sub-research question is a follow-up question from the characteristics of the industry and the process. Searching for relevant researches and literature can start when the characteristics of the sub-processes are known. Chapter 3 introduces several inventory policies to the reader and Section 3.2 will introduce the model that will be used in the rest of the thesis.

SQ: How should the indices, parameters and variables be defined to apply the inventory model to the situation at WD?

Now that the inventory policy is defined, we will apply the model from the literature to the situation at WD. Defining the model is done in Chapter 4. When the indices, parameters and variables are applied to WD, the model can be set-up.

SQ: What distribution does the demand of products follow and what forecasting method applies best for demand forecasting?

Defining the inventory policy will be the basis of the model. For calculating the effects of the model, we need to have a demand distribution of the demand of products. If WD wants to use the model, also an adequate estimation should be made about the upcoming period. This is essential, the expected demand will otherwise still be grounded on experience rather than on data. So, a forecasting method will be used to estimate the demand in the best manner. This will be introduced in Section 5.1 and 5.2.

SQ: According to which variables can products be grouped?

As stated in Paragraph 1.2.1, products at WD can be seasonal and are relatively perishable. To research the effect of implementing an inventory policy, first, the groups that need to be researched should be known. If products are placed into specific product groups, analyzing a product group can happen instead of analyzing single products. This research question is answered in Section 5.3 and 5.4.

Now that the company is introduced, the problem cluster is given and the sub-research questions are defined to answer the research question, the answering of the sub-research questions can start. The following chapter of this thesis begins with answering the first two research questions.

2. Current situation

This chapter outlines the current situation at WD. In Section 2.1, all the relevant sub-processes are described to understand the general process. Then, Section 2.2 portrays the characteristics of the relevant sub-processes. Section 2.3 introduces the reader to the KPIs. Then, Section 2.4 concludes chapter. In this chapter, the following two sub-research questions will be answered:

What are the characteristics of the purchasing, selling, logistical and order picking process?

Which KPIs should be measured to evaluate results properly?

2.1. Current sub-processes

Fulfilling the wishes of the customer involves a lot of logistics. At WD, the order picking process in the warehouse and the outbound logistics are dependent on the purchasing process and the inbound logistics. In this section, all the subprocesses at WD will be explained from the moment of harvest to the delivery at the customer. Figure 1 in Paragraph 1.2.1 displays the physical process of the product from the moment of harvest to the delivery at the customer. Figure 3 below shows process of WD from the purchase to the delivery to the customer.

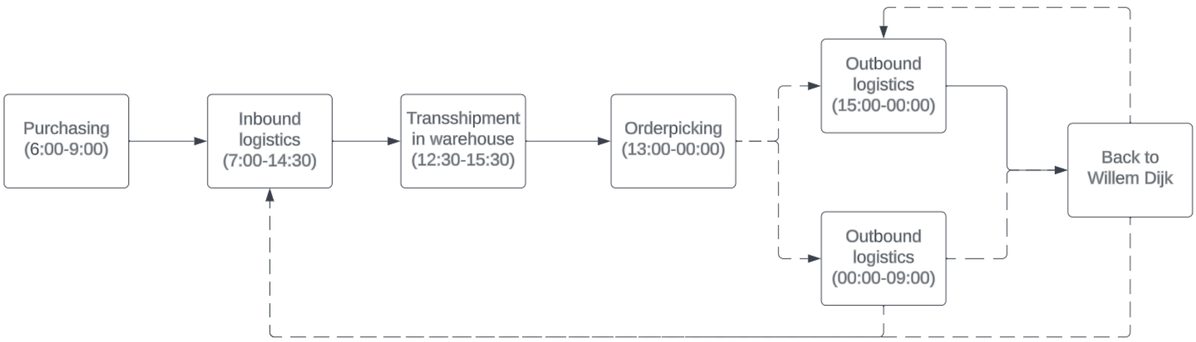

Figure 3. Process at WD

Negative consequences of current process

The FVP market requires swiftness. As depicted in Figure 3, arrival of the goods at the location of WD happens until 14:30 hours and the first outbound logistics start from 15:30 hours. Currently, 70-75% of the goods that are sold to customers are purchased on the same day. The main reason for the large amount of purchases at the supplier on the same day as selling to the customer is the short shelf life for some product groups and the high quality that WD wants to ensure. Due to this, there are a lot of daily inbound logistics. This is expensive.

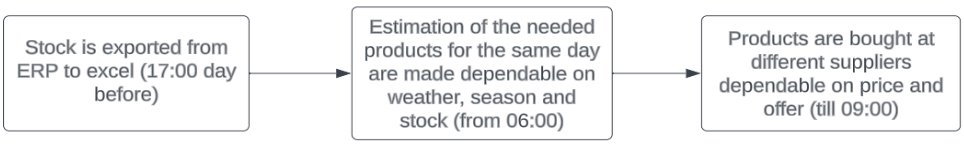

Figure 4. Process at purchasing department

Purchasing

Purchasing products at WD comprises national products, importing standard products and exotic products like fruit juices. Currently, around 17:00 hours, a file with the "sellable inventory" is exported from the ERP system. The calculation of sellable inventory is shown in Equation 1, and an explanation about the sellable inventory is provided in Section 3.5. Shortly, purchased goods are goods that yet need to become physical inventory but are already purchased and sold goods are goods that are in the physical inventory but not order picked yet. Based on the "sellable inventory" file from the day before, the purchasing department starts at 5:00 hours in the morning. Purchasers base purchases on the sellable inventory and their experience. Purchasing stops at 09:00 and no purchases happen after this time. Many products are purchased daily. Figure 4 shows the purchasing process. Figure 5 below shows the definition of the flow from a supplier via a distribution centre to the customer and vice versa.

$$Sellable\ inventory = physical\ inventory + purchased\ goods - sold\ goods \tag{1}$$

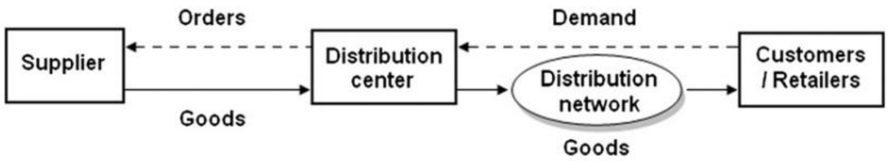

Figure 5. Flow from supplier to customers/retailers (Ignaciuk & Bartoszewicz, 2012)

Order quantities of the same products can significantly vary during periods as products are subject to various factors. Firstly, especially in auctions, purchase prices can fluctuate substantially. High prices make profit implausible and make purchases of this product more unlikely or decreases the order quantity. Secondly, suppliers are not always able to comply with demand of a certain product. In that case, a substitute for this product needs to be purchased. Figure 6 demonstrates a histogram with the order quantities for Elstar apples throughout 2022. Figure 6 shows the order quantities that are larger than 20 trade units (TU), because the data acknowledges return orders also as purchases. The reason for having a minimum of 20 TU is because orders of this size are unlikely and return orders of this amount also are unlikely. It can be seen, that order quantities can vary largely. Figure 7 shows a histogram of the amount of Elstar TU purchased per week.

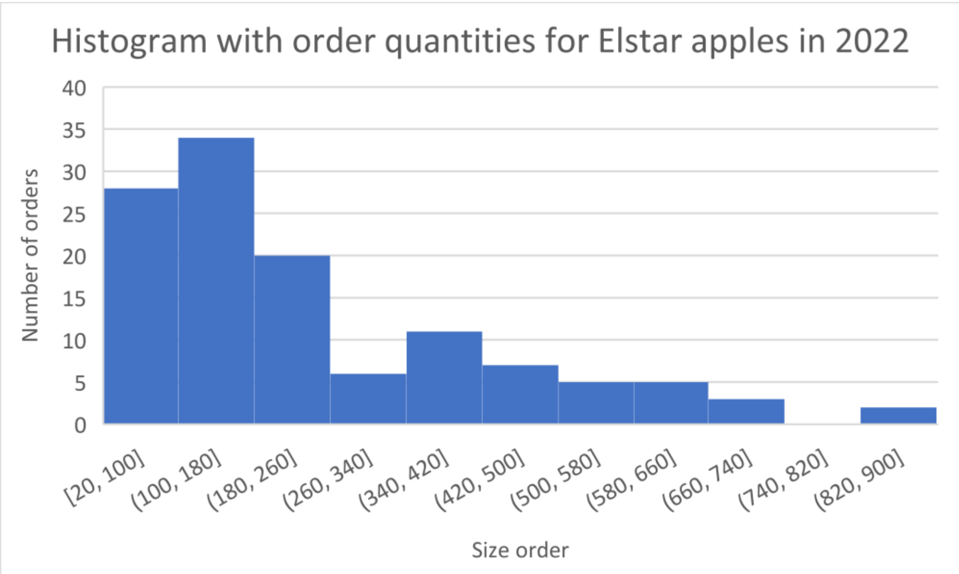

Figure 6. Order quantities for Elstar apples in 2022

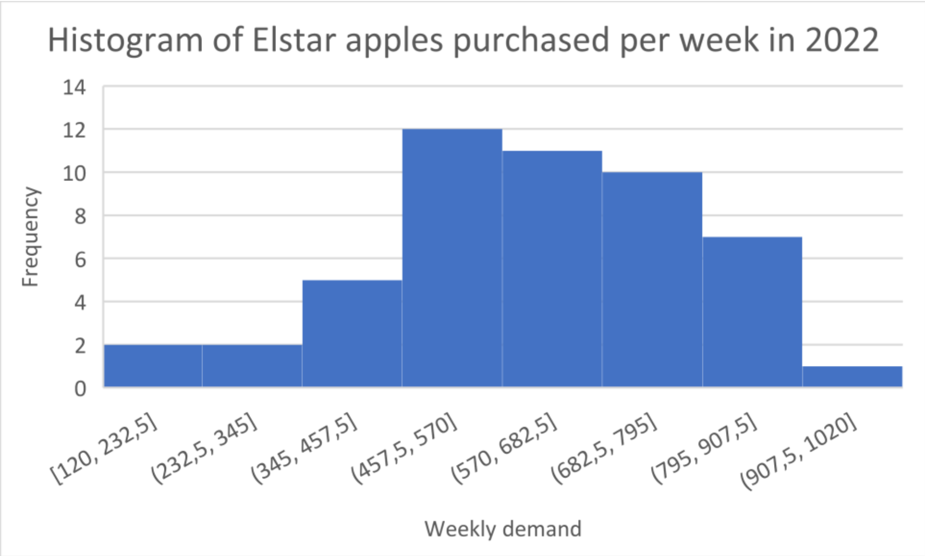

Figure 7. Weekly order quantity Elstar apples in 2022

Sales

The customers of WD mainly consist of supermarkets, grocery shops, FVP-processing companies, smaller wholesalers and market stalls. As stated in Section 1.1, WD is known for its high quality of products and the long shelf life. This means that WD has relatively high prices.

A large portion of the customers order every day from Monday to Friday. For the customer, it is convenient to order as late as possible. In this way, the inventory left over can be known more precise and the products needed for the upcoming day can be estimated more precisely. Customers can order until 17:00 hours or 1.5 hours before the departure of their truck, this is for the customers where the truck departs before 18:00 hours. Figure 8 shows a histogram of demand for Elstar apple TU per day for every Monday – Friday in 2022. Figure 8 shows that the daily demand can deviate substantially. Section 5.2 provides detailed information about the distribution of the demand of a product and the reasons why it is assumed that demand is normally distributed.

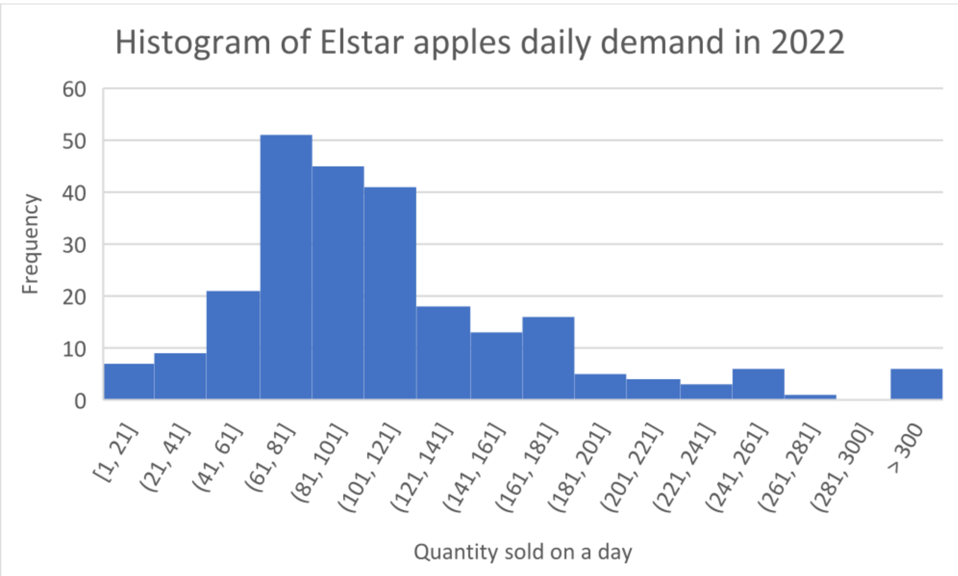

Figure 8. Histogram of daily Elstar apple demand

Inbound logistics

The inbound logistics is the logistical process from the suppliers to WD. The logistical planners at WD adapt these routes to the suppliers that need to be visited by WDs trucks that morning. Some places like Venlo, Breda, Barendrecht and Westland are visited daily. Other provinces like Flevoland, Gelderland, Friesland and North Holland are visited approximately three times a week. Frequently, trucks visit suppliers for small order quantities. These minor supplier visits can accumulate to late arrival of the trucks in Enschede and increased logistical costs. Usually, the trucks arrive between 12:30 and 14:30 hours in Enschede. Then, the unloading of the products starts, the quality of products is checked and the products are placed in the warehouse.

Order picking

Customers place orders during the day. After placing an order, order pickers start picking the order. First, the urgent orders are picked. When all the orders of a particular route are ready, the truck can be loaded and departs. The first order pickers start around 9:30 hours, but the order picking process normally happens between 12:30 and 22:00 hours. This end time can be extended up to 00:00 hours on Monday, Tuesday and Thursday, as shown in Table 1. The order pickers are dependent on the availability of products in the warehouse. This is the reason why implementation of an inventory policy can influence the efficiency of the order picking process and can make the order pickers start earlier.

Outbound logistics

The outbound logistics is the logistical process from WD in Enschede to the customer. The first outbound routes depart at 15:30 hours, and the last depart at 4:00 hours. A large portion of the customers order daily but some customers do not order on a daily basis. Therefore, the outbound routes differ from day to day. These outbound routes are planned by the logistical planners. The outbound routes that depart at 15:30 hours come back the same evening and sometimes depart again between 00:00 and 04:00 hours. The late departures are mainly for customers in the Netherlands. These truck will go to suppliers after their last delivery at customers. These truck will then, with fresh products, go to WD in Enschede.

In conclusion, the outbound logistical process and order picking and are currently dependent on the purchasing and inbound logistical process. In the next section, the characteristics of the process are described.

2.2. Characteristics of sub-processes

In this section, the following research question will be answered.

What are the characteristics of the purchasing, logistical and order picking process?

First in, first out

WD's purchases are based on the estimated demand of products by the purchasers based on their experience. If fresh products arrive before the old products are sold, the old goods are sold first. So, the policy is first in, first out (FIFO).

No inventory policy

Currently, there is no inventory policy at WD. As described in Section 2.1, the purchasing department extracts a file with the sellable inventory before 17:00 hours the day before and starts purchasing the day itself from 5:00 to 9:00 hours. The amount of products purchased depends on the current sellable IL, weather, season, price and availability. Essentially, the experience of the purchaser. Due to the fact that WD does not have an inventory policy and many products are purchased every day, it has a low inventory compared to other FVP companies. This increases the number of logistical movements.

Fast movers versus slow movers

There are many purchasable goods at WD. However, some significant product groups account for a large portion of the demand. Figure 9 displays the ten fastest movers at WD.

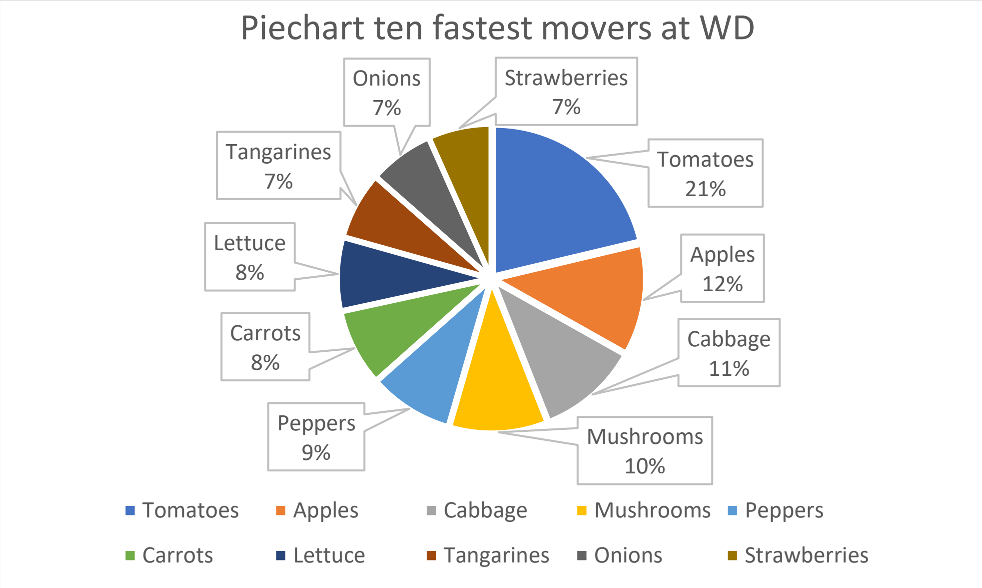

Figure 9. Pie chart with ten most popular products at WD, 50% of total demand

The demand of the largest 26 product groups, all the product groups accounting for more than one percent of the total demand, accumulates to 83% of the total demand. Table 2 shows the product groups' demand share, cumulative demand share and RP. Section 5.3 and 5.4 will elaborate on the product(s) (groups) that will be analysed.

Table 2. Demand of the 26 fast-moving product groups with their RP

Kind	Number	TU share in %	Cumulative TU	Cumulative TU in %	RP
Tomatoes	147546	10.38%	147546	10.38%	3D
Apples	82125	5.78%	229671	16.15%	5D
Cabbage	75349	5.30%	305020	21.45%	5D
Mushrooms	72440	5.09%	377460	26.54%	1D
Peppers	62236	4.38%	439696	30.92%	3D
Carrots	56471	3.97%	496167	34.89%	1W
Lettuce	53750	3.78%	549917	38.67%	1D
Tangarines	49350	3.47%	599267	42.14%	4D
Onions	47535	3.34%	646802	45.49%	1W
Strawberries	46201	3.25%	693003	48.73%	1D
Melons	44516	3.13%	737519	51.86%	3D
Oranges	44436	3.12%	781955	54.99%	2D
Cucumber	43859	3.08%	825814	58.07%	2D
Potatoes	43088	3.03%	868902	61.10%	1W
Bananas	42743	3.01%	911645	64.11%	1D
Grapes	42172	2.97%	953817	67.08%	2D
Spices	31962	2.25%	985779	69.32%	1D
Pears	27543	1.94%	1013322	71.26%	5D
Pickles	24855	1.75%	1038177	73.01%	2D
Parsley	23739	1.67%	1061916	74.68%	3D

Nectarines	22563	1.59%	1084479	76.26%	2D
Endive	21317	1.50%	1105796	77.76%	2D
Zucchini	21192	1.49%	1126988	79.25%	3D
Peaches	20714	1.46%	1147702	80.71%	1D
Beans	17302	1.22%	1165004	81.93%	3D
Plums	15863	1.12%	1180867	83.04%	2D
Rest	241136	16.96%		100.00%	
Total	**1422003**				

2.3. KPI selection

Paragraph 2.3.1 and 2.3.2 will describe the KPIs. Paragraph 2.3.3 will summarize the KPIs and by this, the third research question is answered.

Which KPIs should be measured to evaluate results properly?

2.3.1. Logistical costs

The high amount of inbound, 35 daily suppliers visits, and outbound logistics, 100+ daily customer visits, play a major role in the financial result of WD. Currently there are already two employees working on optimizing the logistical routes. Also, there are several reasons why reducing the outbound logistics is hard:

- Variance in number of daily purchases from customers;
- High service that WD ensures to its customers;
- Contracts, for up to a year, where WD has to guarantee delivery.

WD also has a lot of inbound logistics. As stated in Section 1.2, there are currently 35 to 40 suppliers that are visited daily. The number of daily supplier visits is influenced significantly on the strategy of WD and the purchasing department. This large amount results in high logistical inbound costs. Currently, WD wants to ensure an as high shelf life for the customers. Due to this, the purchasing department buys products often and does not consider the increase of logistical movements. These factors result in daily purchases at the purchasing department for many products groups. The management of WD wants to decrease the costs of the operational process at WD and indicate that changing the inventory policy to the RP is a possibility. The relation is depicted in the Figure 10 beneath.

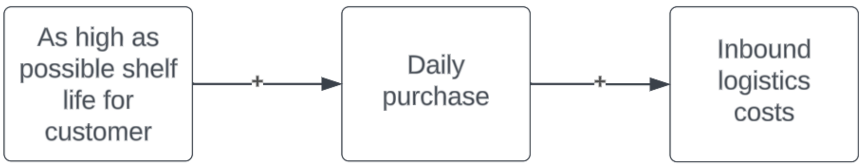

Figure 10. Positive relation between the high shelf life of customers and high inbound logistics costs

As stated in Section 1.2, visiting a suppliers takes 25 minutes on average. The costs of a truck at WD is 80 Euros per hour on average. This makes the average cost of visiting a supplier:

$$25 \, minutes * 80 \frac{Euro}{hour} = 33.33 \, Euro \tag{2}$$

Reducing the number of inbound logistical movements, therefore, can significantly impact the financial result of WD. A reduction of only one supplier on every Monday-Friday means an annual decrease of:

$$52\ weeks * 5 \frac{days}{week} * 33{,}33 \frac{Euro}{day} = 8665.80\ Euros$$

(3)

This is the result if only a reduction of one visit a day at the supplier is obtained. A larger reduction of the number of inbound shipments can impact the finances more positively. Implementing a new inventory policy that adapts the order quantity to the RP of a product, reduces the inbound logistical costs greatly.

2.3.2. Situation 2nd to 4th of October 2023

The situation of the 2nd, 3rd and 4th of October of 2023 was unique WD. On the 3rd of October, all the German customers were closed as it was German Unity day. So, German customers placed their order on October 2nd for their upcoming selling day, October the 4th. Normally, German customers order before 17:00 hours at WD for delivery before 8:00 hours the next day. Now, German customers order before 17:00 hours at WD for delivery before 8:00 hours on Wednesday, 1.5 days later. WD did not adapt the purchasing process, only the ordering moment of customers expedited.

So, on Tuesday morning, order pickers picked the orders of German customers instead of Monday evening. On Tuesday, the orders of the Dutch companies came in. There was still some products in inventory left to be picked and trucks with fresh products started to arrive at WD. These were mainly the goods that could not be in the warehouse for longer than 24 hours, like mushrooms, bean sprouts, cabbage lettuce and the products where a stockout was likely to happen.

To conclude, picking the orders of the German customers could happen Tuesday morning instead of Monday evening. After 19:00 hours the wages are 25% higher. After the order picking for German customers was finished on Tuesday morning, picking orders from Dutch customers could be done from the inventory left over. Figure 11 below shows the special situation. Table 3 below gives the results of this unique situation and explanation is given below the table. The data of Table 3 can be found in Appendix A.

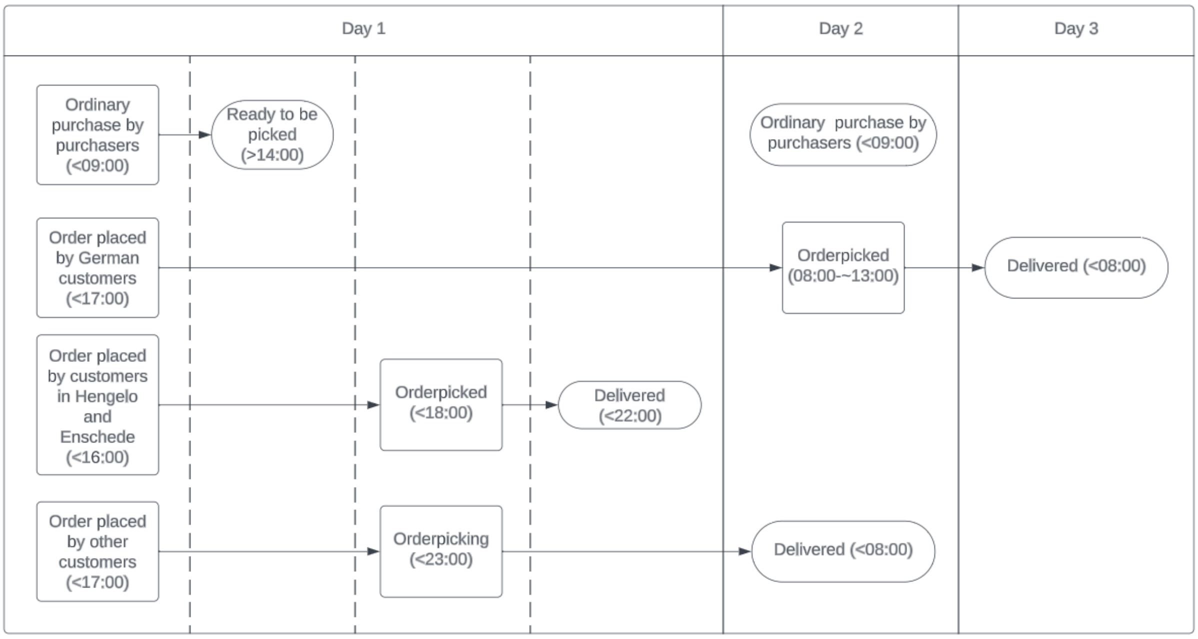

Figure 11. Situation WD from 2nd to 4th of October 2023

Table 3. Result of five successive Mondays &Tuesdays from September 4th 2023 to October 3rd of 2023

Dates	TU	TU/hour	Paid hours	Productivity (Index)	Wage expense (Index)	Cost per packed TU (Index)	End time Monday	End time Tuesday
4 & 5-9-2023	19399	56	395.75	106.06	111.43	99.67	01:25	22:00
11 & 12-9-2023	17537	54	371.0	102.27	104.46	103.36	00:40	22:00
18 &19-9-2023	17436	54	338.0	102.27	95.17	94.71	21:50	21:20
25 & 26-9-2023	16619	49	359.25	92.80	101.15	105.61	22:50	20:25
2 & 3-10-2023	15633	51	311.75	96.59	87.78	97.43	19:50	19:20
Average	17325	52.8	355.15				22:55:00	21:36:00

- TU/hour: This is the average efficiency of the days in the warehouse;
- Paid hours: This is the total wage expense these days. More expensive hours are taxed more 25% higher;
- “End time Monday” & “End time Tuesday” are inputs and give a slight indication of the more expensive hours expenses that day;
- “Productivity” and “Wage expense” are index numbers with the average of these five weeks as reference;
- $Cost\ per\ packed\ TU = \left(\frac{TU}{Paid\ hours}\right) * 100$

(4)

Unfortunately, these numbers are not that representative for WD. Firstly, German customers were closed one day, and therefore, the workload or TU that needed to be picked was significantly lower than normal. Therefore, the end times give a slight indication of the earlier end time but do not give the definite answer of the earlier end time, due to the lower workload was. Secondly, the situation of German customers being closed on Tuesday only occurred once since the new ERP system, and therefore, drawing conclusions from it should be done very cautiously. The cost per packed TU, on the 2^{nd} and 3^{rd} of October 2023, was 2.57% lower than the average over these 5 weeks. Again, this could be the result of less expensive hour wages but could also be the result of the lower amount of TU. In conclusion, there is not enough data to give any definitive answers regarding the efficiency, end times and expensive hours when order pickers start earlier on the day. For that reason, the financial result of higher inventory levels for the efficiency in the warehouse cannot be calculated.

However, the chance of an product being in inventory in the morning can be calculated if some assumptions are made. This can be used as KPI. Although no reduction of costs can be calculated due to the higher availability in the morning, it can be interpreted as a useful KPI both for this thesis and the management of WD. The assumptions that are necessary to calculate this KPI are stated and explained in Chapter 5.

2.3.3. KPI selection and substantiation

Paragraph 2.3.1. describes the effect that a reduction of inbound logistics movement will have. Paragraph 2.3.2 describes the unique situation of the 2^{nd} to the 4^{th} of October in 2023. From the 2^{nd} to the 4^{th} of October, no conclusion can be drawn that picking earlier results in more efficient work and earlier end times. This will decrease the amount of more expensive hours. WD is currently working on displaying the efficiency throughout the day, but this is not implemented in the ERP system yet. However, we assume that the efficiency in the warehouse will increase and the number of expensive hours will decrease if the product availability in the morning is increased. This is due to the following reasons:

- As stated in Paragraph 1.2.2, it is reasonable to think that the efficiency increases if the product availability increases;
- Employees and staff of WD indicate that efficiency currently is low in the morning;

This leaves the following two KPIs for this thesis:

- Reduction of inbound logistical movements;
- Chance of a product being in inventory in the morning;

For the first KPI, the financial result can be calculated. For the second KPI, this is not possible. However, an increase of product availability can be calculated and this can be interpreted by the management of WD.

2.4. Conclusion

This chapter describes the sub-processes with its characteristics. If an inventory policy is introduced, purchases at suppliers will happen more rational resulting in a reduction of the number of inbound logistics, and with that, a decrease of the logistical costs. Inventory policies will further be discussed in Section 3.1, Section 3.2.

In this chapter, the following research questions are answered:

What are the characteristics of the purchasing, selling, logistical and order picking process?

Which KPIs should be measured to evaluate results properly?

The two KPIs that will used to measure the effect of implementing a new inventory policy are:

- Reduction of inbound logistical movements;
- Chance of a product being in inventory in the morning;

3. Theoretical framework

This chapter describes the theoretical framework for this thesis. Section 3.1 describes various inventory policies and Section 3.2 describes the newsvendor problem. Section 3.3 expresses the inventory position, definition of demand and various forecasting methods. Section 3.4 discusses lead time and Section 3.5 elaborates on the application of this theory on WD. Section 3.6 gives the conclusion of this chapter. The following sub-research question is answered in this chapter.

What kind of inventory policy can be used to represent the situation at WD?

The literature for the following research question will be introduced in this chapter.

What distribution does the demand of products follow and what forecasting method applies best for estimating results?

3.1. Inventory policies

Managing inventory sets rules to determine the best levels of inventory based on certain factors and desired targets (Axsäter, 2015). This requires finding a compromise between reducing the amount of perishable items and maintaining service and quality for customers, all while keeping a check on the overall costs. According to Chopra and Meindl (2016), the decision-making aspects of inventory policies include:

- When to reorder?
- How much to reorder?

Deciding when to reorder products depends on when to review inventory. These can be regular checks or ongoing evaluations. How much to reorder can be both variable and fixed, for variable quantities the objective is to reach a certain IL, for fixed order quantities this is based on ideal order quantities. Also, the (R, s, Q) policy is explained and Table 5 shows what each variable means.

Table 4. Different inventory policies

Review \ Order quantity	Fixed	Variable
Periodic	(R, Q), (R, s, Q)	(R, S)
Continuous	(s, Q)	(s, S)

Table 5. Definition variables regarding inventory policies

Variables	Definition
R	Review period
Q	Order quantity
S	Order-up-to-level
s	Reorder level

The (R,Q) policy

The (R, Q) policy undergoes regular reviews, where a predetermined quantity Q is systematically ordered at intervals of R (Nahmias & Olsen, 2015). When the demand is substantially higher than normal, and thus, the inventory is significantly lower than normal, a multiple of the predefined quantity Q can be ordered. This policy is also called a (R, nQ) policy, as Nahmias and Olsen (2015) highlighted. The ordered quantity is based on the average demand during period R, assuming a consistent demand in each period. While this model is straightforward and easy to implement, it is considered the least adaptive inventory policy as it cannot slightly adapt the order quantity to the demand during the review period. If the demand turns out to be high enough, a multiple of the order quantity is ordered.

The (R,S) policy

Similar to the (R, Q) policy, the (R, S) policy undergoes periodic reviews at intervals of R (Winston, 2004). However, instead of ordering a fixed quantity, this policy involves ordering up to a designated level, denoted as S. Order quantity S is determined by subtracting the inventory from the order-up-to-level. Unlike the (R, Q) policy, this model adapts to variable demand. Among its advantages are the synchronisation of replenishments and the ability to expect order times with certainty. Nevertheless, Winston outlines that it incurs higher holding costs than continuous review policies.

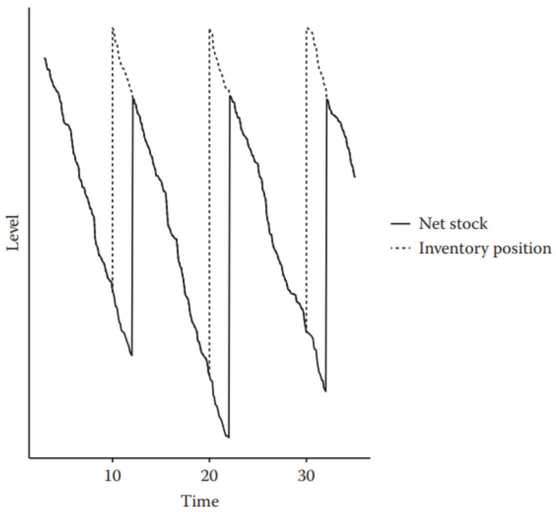

Figure 12. (R, S) policy (Silver et al., 2017)

The (s, Q) policy

The (s, Q) policy operates as a continuous review strategy in inventory management. Upon reaching a specified reorder level, a predetermined quantity is ordered to minimise the overall cost. This policy demonstrates higher responsiveness to inventory fluctuations than the (R, S) policy while mitigating the risk of stockouts.

The (s, S) policy

Similar to the (s, Q) policy, the (s, S) policy functions as a continuous review strategy and places an order when the IL falls below or equals the specified reorder level s, as described by Winston (2004). It then orders a predetermined order quantity, similar to the (R, S) policy. This policy evaluates the on-hand IL and places an order for the difference between the IL and the specified order-up-to-level S. A drawback is the complexity of determining both variables, as Nahmias and Olsen (2015) explained.

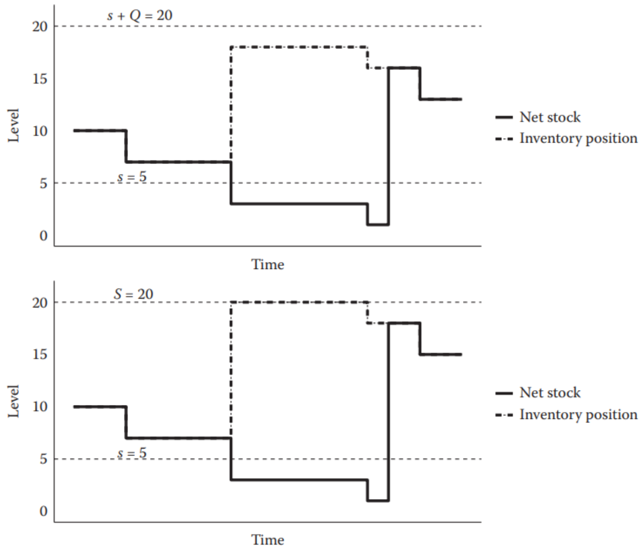

Figure 13. Continuous review systems with fixed order quantity (Q) above and order-up-to-level (S) below (Silver et al., 2017)

The (R, s, Q) policy

The (R, s, Q) policy integrates characteristics from both the (R, Q) and the (s, Q) policies, resulting in a periodic review. At intervals of R, this policy evaluates the inventory position. When the inventory position falls below the defined reorder level s, an multiple of quantity Q, denoted as n*Q, is placed. This order is structured to elevate the inventory position to a value within the range of s and s + Q (Janssen et al., 1996). This policy boasts a higher level of responsiveness than the (R, Q) policy, as it triggers orders based on the reorder level without requiring continuous review, differentiating it from the (s, Q) policy.

WDs policy

When determining an inventory policy, it is crucial to consider the characteristics of purchases and the products. Firstly, purchasing at WD only happens once per period. Therefore, reviewing will be periodic. Demand of products at WD significantly fluctuate dependent on the season and the day, also taking perishability into account, order sizes or order-up-to-levels change from day to day. The goal of this thesis is to calculate the OIL, this is similar to the order-up-to-level S. However, this S changes every day, and therefore, WD does not comply with all the characteristics of the (R, S) policy. In the next section, the newsvendor problem will be introduced.

3.2. Newsvendor problem

The newsvendor problem originates from a newsvendor selling newspapers with a uncertain demand. The decision that needs to be made by the newsvendor is to buy the optimal order quantity to maximize the profit with the uncertain demand. The profit is affected by the overstocking and understocking costs of newspapers, obsolete and lost sales costs respectively. The newsvendor goes to the printing house of the newspaper before he sells the newspapers. So, the decision about the order quantity of newspapers is made before the period begins. After that, he is not able to buy more newspapers. Therefore, the choice that is made in the morning cannot be changed and affects the lost sales and the obsolete costs of that period, that day. Demand of newspapers is uncertain, as the content of the newspaper and the number of people passing by can largely influence the demand. Those factors can both not be influenced by the newsvendor.

The newsvendor problem is a single-period problem. A significant amount of businesses faced problems with similar characteristics as the newsvendor problem. Several examples of the newsvendor problem across industries are given below:

- Retail. Clothing retailers often deal with seasonal collections with high demand uncertainty and long lead times. This means that and expectation about the demand should be made and often reordering is not an option.
- Manufacturing. If the start-up costs of a certain process is high, an elaborate trade-off between the holding costs and the set-up costs should be made. This decision is based on the expected demand during the period during and after the start-up period until the next expected start-up.
- Agriculture. A farmer harvest its perishable goods and brings it to the market. Similar to WD, the demand is uncertain, and a trade-off between lost sales and holding costs is made.

Correctly identifying the overstocking costs includes the inventory costs and the associated capital that cannot be used for other investments and obsolete costs. Understocking costs can be the lost sales and / or the reputational damage for not being able to sell. Understanding these cost structures can help to determine an optimal order quantity (OOQ). The newsvendor problems' calculation of the OOQ is:

$$OOQ = \mu + z * \sigma \tag{5}$$

Where μ is the mean, z is the safety factor and σ is the standard deviation. This formula will be further explained in Chapter 4.

To conclude, the newsvendor problem, is a single-period problem. This is different from WD, as WD has the daily option to order the products, making it multi-period. So, it does not match all the criteria of the situation at WD. However, it can be used under assumptions introduced in Chapter 5. The next section introduces the reader several attributes of demand.

3.3. Demand

This section introduces several attributes of demand. Paragraph 3.3.1 defines the inventory position, Paragraph 3.3.2 gives the definition and explanation of demand and Paragraph 3.3.3 introduces several forecasting methods.

3.3.1. Net inventory and inventory position

It is important to introduce several definitions of ILs. There are two main types of interpreting the IL (Silver et al., 2017):

$$net\ inventory = on\ hand\ inventory - backorders \tag{6}$$

$$Inventory\ position = on\ hand\ inventory + ordered\ products - backorders - commited \tag{7}$$

The committed items are items that are already assigned to something. This can be for a production company that has to have products in inventory to assign to a production line or for maintenance but also for customers that have delivery guarantee of products. Section 3.5 will identify the inventory position for WD.

3.3.2. Sales data and demand data

First, the demand for certain products should be understood to define the demand distribution. The demand for a product is defined as:

$$Demand \ = sales + lost\ sales \tag{8}$$

Many companies do not take lost sales into account (Axsäter, 2015). In such instances, the assumption is made that the demand of a particular product equals to the sales of that product. There are some techniques to estimate the lost sales. In these cases, historical ILs play a crucial role. It is based on the notion that if the inventory does not reach zero in a given period, the demand for that period is equal to the sales of that period. Conversely, if the demand drops to zero, it can be concluded that demand at least equals the IL at the beginning of the period. The frequency of a stockout is used to calculate the demand of a product. The demand for a product at WD will also be defined in Section 3.5.

3.3.3. Forecasting methods

The goal of any forecasting method is to predict the systematic component of demand and estimate the random component (Chopra & Meindl, 2016). This paragraph will introduce several forecasting methods.

Moving average

In the context of the moving average, the average is computed over a consistent historical span, spanning over x periods, with each preceding period carrying an equal weight (Axsäter, 2015). Equal weight brings out linear trends, making purchases adaptable to past sales patterns. The demand distribution derived from moving average offers several advantages:

- **Reduced sensitivity to outliers**: This method is less influenced by outliers or extreme values than alternative approaches, given that all periods contribute equally to the estimated demand.
- **Ease of use and robustness**: The moving average method is straightforward to apply, enhancing the robustness of the model. The simplicity of the moving average contributes to its effectiveness.
- **Effective seasonality measurement**: Moving average correctly captures and measures seasonality, providing insights into the cyclical patterns within the demand distribution.

The formula is as follows:

$\hat{a}_t$ = estimate of average a after observing the demand in period *t;*

$x_{t,T}$ = forecast for period T > *t* after observing the demand in period *t;*

$$x_{t,T} = \hat{a}_t = \frac{x_t + x_{t-1} + \cdots + x_{t-N+1}}{N}, where\ t < T \tag{9}$$

Exponential smoothing

Exponential smoothing serves to forecast upcoming data points by relying on past observations, like exponential smoothing (Axsäter, 2015). This technique proves particularly advantageous when dealing with data subject to exponential trends or seasonal patterns. Exponential smoothing gives greater significance to recent data points, progressively lowering the influence of older observations. This method has several advantages:

- **Appropriate for exponential demand trends**: Exponential smoothing is well-suited for scenarios where the demand displays an exponential trend, effectively capturing and projecting such patterns.
- **Effective for short-term forecasting**: Given its emphasis on recent observations, exponential smoothing is particularly effective for short-term forecasting, providing more significant weight to the most recent data points and adapting swiftly to trends.

The formula is as follows:

$$x_{t,T} = \hat{a}_t = (1 - \alpha)\alpha_{t-1} + \alpha x_t, where\ t < T \tag{10}$$

$$\alpha = smoothing\ constant\ (0 < \alpha < 1) \tag{11}$$

$$x_t = demand\ in\ period\ t \tag{12}$$

Again, Section 3.5 will provide the reader to the determination whether exponential smoothing or the moving average is applicable for demand forecasting at WD.

3.4. Lead time

Lead time is defined as the duration between ordering and replenishment. Lead time is a very important factor for many companies as almost every company is dependent on deliveries of other companies. This dependency can be anything, from start-up times of product to the travel time between the supplier and the customer. Accurate lead time management largely influences a companies' supply chain. Therefore, it is one of the, if not the, most important factors for having effective and efficient operations. Several examples of lead time will be given:

- Delivery of a maintenance product from the supplier to an oil drilling platform. Maintenance lead time;
- Time for an ambulance to reach a person in a specific area. Healthcare lead time;
- Requesting a permit at a municipality. Service lead time;

Lead time is, specifically for the food industry, notorious for its importance as perishability plays an important role in having efficient and profitable operations. Explanation of the application of lead time to WD will be described in Section 3.5.

3.5. Defining WDs characteristics

IL

At WD, purchases are made in until 9:00 hours in the morning and upon acquisition, the goods become immediately sellable to customers. WD does not directly manage backorders. If a product is out of inventory, the purchasing department can put the product into the ERP system as "product needed" for the following day, corresponding to the next period. Therefore, WD's inventory status cannot drop below zero. Consequently, the inventory status at WD is as follows:

$$Sellable\ inventory = physical\ inventory + purchased\ goods - sold\ goods \tag{13}$$

The purchasers have two options in the morning: to buy or not to buy. If a purchase happens, the order quantity will be defined as following:

$$Order\ quantity = OIL - sellable\ inventory + backorders \tag{14}$$

Instances of customer backorders are very uncommon. Consequently, and for the sake of simplicity in the model, the backorders will be omitted from this thesis, giving the following formula:

$$Order\ quantity = OIL - sellable\ inventory \tag{15}$$

Demand

As defined in Section 3.3, the demand of a product can be calculated followingly:

$$Demand\ = sales\ + lost\ sales \tag{16}$$

The ERP system of WD only displays the CIL. So, there is no historical data about the frequency of the stockouts. Making assumptions about the frequency of the stockouts cannot be grounded, and therefore, the assumption is made that the demand of a product group equals to the sales of a product group, so:

$$Demand\ = sales \tag{17}$$

Forecasting method

The characteristics of both the moving average and exponential apply to the demand of products within the FVP sector. The moving average approach is characterised by its simplicity, accurate measurement of seasonality and lower sensitivity to outliers compared to exponential smoothing. The reduced sensitivity proves beneficial for the period after historical high outliers like Easter and Christmas. On the other hand, at WD, we assume that the supply of goods also influences our sales data. Supply deficits are unlikely to fully recover within a week. Therefore, exponential smoothing captures the estimated demand better in cases of supply deficit. Consequently, exponential smoothing excels in recognising supply patterns from the supplier. Reasoning does not give the answer whether to use the moving average or exponential smoothing method as forecasting method at WD. For that reason, both the moving average and exponential smoothing method will be applied with historical demand of WD in Section 5.1 to see which method fits best.

Lead time

At WD, purchased goods become sellable inventory immediately. This is shown in Equation 13. The ERP system of WD adds a purchase at a supplier immediately to the sellable inventory. Customers of WD can order these products from that moment and these products will be transported with the first shipment to the customer. If a product is not in inventory, the product will be purchased the day after and shipped to the customer. Purchasing happens until 9:00 hours and selling start around 12:00. If a product sells better than expected, products cannot be ordered for the same period but will be ordered the upcoming period. As ordering products as a result can only be done the next period, and it will always be delivered that same period, we assume the lead time to be null.

3.6. Conclusion

This chapter introduces the applicable literature to the reader. Several inventory policies are introduced but none of them fully covered the situation at WD. Subsequently, we determined that the model that is most applicable to WD is the newsvendor problem. Chapter 4 will use the newsvendor problem to establish an inventory policy for WD. Then, the IL, demand definition, forecasting method and lead time are introduced and the application to WD is described. This chapter contains the answer to the following research question:

What kind of inventory policy can be used to represent the situation at WD?

Forecasting methods are introduced in this chapter. However, not a forecasting method is chosen yet and this research question will further be answered in Section 5.1 and 5.2.

What distribution does the demand of products follow and what forecasting method applies best for estimating results?

Now that the kind of model is defined and multiple characteristics are introduced like demand distribution and forecasting methods, the model can be set-up. This will be done in the next chapter.

4. Problem formulation

Defining the model is done in this chapter. This will be according the newsvendor problem, introduced in Section 3.2. The newsvendor problem is a decision-making model in inventory management where a company must make a decision for the IL for perishable goods before the period starts. Demand uncertainty is the challenge for estimating an adequate IL. This model aims at balancing conflicting goals, namely meeting demand and minimizing the lost sales. The objective of the newsvendor problem is to maximize the expected profit by minimizing the expected costs. This can be calculated given several variables like the purchase and selling prices, residual and lost sales costs with the demand distribution of the product. The following research question is answered in this chapter.

How should the indices, parameters and variables be defined to apply the inventory model to the situation at WD?

4.1. The objective of the model

The goal of this thesis is to implement an inventory policy at WD. Currently, the policy at WD is that products with a RP of three, four and five days are still ordered daily. Substantiation for the product(s) (groups) subject to analysis is described in Section 5.3 and Section 5.4. The goals of the inventory policy are as follows:

- Reduction in the number of inbound logistical movements;
- Higher availability of products in the morning to improve the efficiency.

Reaching the objective is possible by ordering larger order quantities. Therefore, if a purchase of a product groups subject to analysis happens, the order quantity should not be based on the OIL for the upcoming period, but for the OIL for the RP. This increases the order quantities, and thus, reduces the number of inbound logistical movements and increases the IL in the morning.

With the newsvendor problem, profit is maximized at the OIL. The OIL can be calculated with the mean μ, the standard deviation σ, the profit margin, overstocking costs, $co_{i,t}$, and the understocking costs, $cu_{i,t}$. Consequently, the maximum profit can be calculated if the variables are put in the notations given in Section 4.2 below. Then, the expected profit under the CIL can also be calculated. The expected profit under the CIL is the same or less than the expected profit under the OIL. The transportation costs are calculated in Paragraph 2.3.1. If the expected profit of the CIL is smaller than the expected profit of the OIL minus the transportation, purchase is beneficial.

When it is beneficial to purchase, the goal of this thesis should be taken into account, namely, reducing the number of inbound logistical movements and having more products in inventory in the morning. This can only be obtained if products of the day before are still in inventory. So, when the expected profit for the CIL of the upcoming period is lower than expected profit for the OIL of the upcoming period minus the transportation costs, purchasers should buy the OIL for the entire RP of a product group, minus the CIL. The number of inbound logistics movements reduces and the chance of products available to be picked in the morning increases by doing this. Figure 14 below shows the purchasing strategy of the new inventory policy.

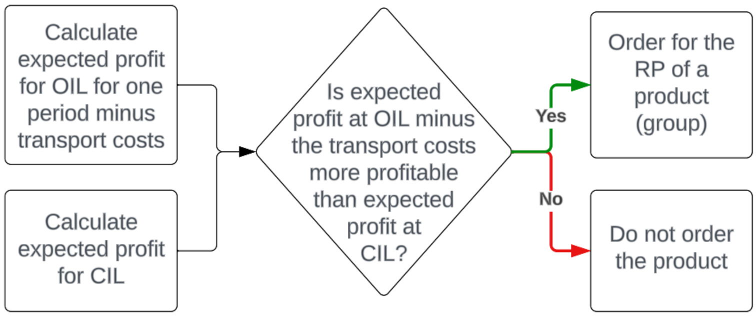

Figure 14. Purchasing strategy with new inventory policy

It may seem odd that the expected profit for the OIL for one period is compared to the expected profit for the CIL, but that the OIL for one period is never ordered. There are a few reasons for this strategy:

- Obsolescence is expensive. The order quantity is based on the whole RP, but the consideration is made between the OIL of one period and the CIL. In this way, first all the older products are sold and when the inventory is substantially low, meaning that almost all old products are sold, new products are ordered;
- In this way, also the number of inbound shipments decrease. First, the OIL for the entire RP is ordered. When the CIL drops to a point that for the next period reordering is profitable, even regarding transportation costs, reordering happens again for the entire RP.

4.2. Defining the model

Indices

During a certain period, WD can purchase a product at a supplier. We define products as i, and this is part of the set products I, so, $i \in I$. The purchase of a product can only occur once every day, from Monday – Friday. We define that a day is a period and denote it as t, t being in the set of $t \in T$.

$i \in \{1,2,\dots,I\}$	The set of products
$t \in \{1,2,\dots,T\}$	The set of periods

Parameters

Then, we define all the parameters of the of the newsvendor problem model. In Paragraph 3.3.3, several forecasting methods are introduced. Section 5.1 describes that calculating the expected demand, $\mathbb{E}(D_{i,t})$, will be done by using exponential smoothing with a smoothing constant of 0.30. In Section 5.2, also the assumption is made that the demand of products at WD follow a Normal distribution. For that reason, the standard deviation of product i during period t is defined and is $\sigma_{i,t}$. The $I_{i,t}$ can be looked up in the ERP system of WD, and gives the inventory of product i at in the beginning of period t. Both the overstocking and the understocking costs are defined by parameters, $p_{i,t}, s_{i,t}$ and $o_{i,t}$, purchase price, selling price and obsolete value, respectively. The overview of notations is given below. Then, we also have the costs of visiting supplier for product i, defined as TC_i.

$\mathbb{E}(D_{i,t})$	Expected demand of product i in period t;
$\sigma_{i,t}$	Standard deviation of the demand of product i in period t;

$N_{i,t}$	Normal distribution of the demand of product i in period t;
RP_i	RP of product i;
$CIL_{i,t}$	CIL of product i at the beginning of period t;
$r_{i,t}$	Residual value of product i in period t;
$p_{i,t}$	Purchase price of product i in period t;
$s_{i,t}$	Sale price of product i in period t;
TC_i	Transportation cost of product i;

Variables

This section introduces the notation of the variables. These variables can be calculated given the values of the parameters and applied to both the OIL and the CIL at WD. By this, the expected profit of the CIL and the expected profit of the OIL is calculated. The use and explanation of variables is done in sub-sections for clarity.

$co_{i,t}$	Overstocking costs of product i in period t;
$cu_{i,t}$	Understocking costs of product i during period t. Understocking costs comprehends the costs of lost sales and the costs of potential reputational damage;
$CR_{i,t}$	Critical ratio of product i in period t;
N_{i,J_t}	Normal distribution for product i during period J_t, where J_t is period t to $t + RP_i - 1$
$z_{i,t}$	Safety factor of product i in period t;
$f_{i,t}$	Standard Normal density function of the demand of product i in period t;
$F_{i,t}$	Standard Normal cumulative distribution function of the demand of product i in period t;
$CSL_{i,t}$	Customer service level of product i in period t;
$OOQ_{i,t}$	Optimal Order Quantity of product i in period t;
OOQ_{i,J_t}	Optimal Order Quantity of product i in period J_t;
$OIL_{i,t}$	OIL of product i in period t;
OIL_{i,J_t}	OIL of product i in period J_t;
$L_{i,t}$	Standard loss function of product i in period t;
$EUS_{i,t}$	Expected understocking costs per product i in period t;

$EOS_{i,t}$	Expected overstocking costs per product i in period t;
$ETC_{i,t}$	Expected total costs for product i in period t;
$EP_{i,t}$	Expected profit for product i in period t;

Obsolete value and lost sales costs

The costs of having too many products in inventory, overstocking costs, will be calculated according to the formula of $co_{i,t}$. Then, the obsolete value of product i during period t, $r_{i,t}$, will be subtracted from the purchase price of product i during period t, $p_{i,t}$. This obsolete value can be estimated by WD on the experience of personnel. If WD runs out of products, the understocking costs are calculated by subtracting the purchasing price, $p_{i,t}$, from the selling price, $s_{i,t}$.

$$co_{i,t} = p_{i,t} - r_{i,t} \tag{18}$$

$$cu_{i,t} = s_{i,t} - p_{i,t} \tag{19}$$

Critical Ratio of the OIL

When the values of the $co_{i,t}$ and the $cu_{i,t}$ are obtained, the critical ratio of product i in period t can be calculated, notated as $CR_{i,t}$. The critical ratio displays the trade-off between the overstocking and understocking costs of a product and is necessary for calculating the OIL.

$$CR_{i,t} = \frac{cu_{i,t}}{cu_{i,t} + co_{i,t}} \tag{20}$$

The $CR_{i,t}$ is not used for calculating the OIL. Therefore, we have to introduce the customer service level (CSL). The CSL is a metric that displays the chance that a company can meet all the demand during a period. In the newsvendor problem, the critical ratio weighs off the overstocking costs and the understocking costs. If we set the critical ratio of product i in period t to be equal to the optimal value for the CSL for product i in period t, we obtain $CR_{i,t} = CSL^*_{i,t}$. Now that the critical ratio is set to the optimal value of the CSL, we can calculate the safety factor of the critical ratio. This will be done in the subsection "Standard Normal cumulative distribution function".

The critical ratio can be calculated with the purchase and selling price and the obsolete value of that period. The critical ratio can only be calculated for periods where the prices are known, and therefore, the critical ratio for period t is the same as the critical ratio for period J. This is denoted as:

$$CR_{i,t} = CR_{i,J_t}, where\ J\ is\ period\ t\ to\ t + SL_i - 1 \tag{21}$$

Demand distribution multiple periods

A Normal distribution has parameters μ and σ, where the μ is the mean and the σ is the standard deviation. It is assumed that the demand follows a Normal distribution. Then, the parameters need to be defined. We will define the μ as the estimated demand of product i in period t, $\mathbb{E}(D_{i,t})$, and the standard deviation σ is defined as the standard deviation of the demand of product i in period t, $\sigma_{i,t}$. Then, we get demand distribution of product i in period t:

$$N_{i,t} \sim N\left(\mu_{i,t}, \sigma_{i,t}^2\right)$$

(22)

For adding two random variables that are normally distributed, independence of both variables should be substantiated. Section 2.1 explains that WD has a lot of customers that order every day from Monday to Friday as this also includes products with a short RP. For that reason, ordering happens every day nonetheless, and therefore, also products with a RP of three to five days are ordered every day. Customers of WD aim at giving an as high as possible shelf life to their customer, the consumer, and in this case it holds the same costs as reordering is likely to happen every day. Customers of WD want to have an as long as possible shelf life for their customers, the consumers, if it holds the same costs. So, we make the assumption that the customers of WD order products with a RP of three to five days also only for the upcoming period. Therefore, the consecutive days' distribution is independent. Equation 23 and 24 show random variables X and Y, both normally distributed. Equation 25 shows Z, the sum of both independent variables.

$$X \sim N(\mu_X, \sigma_X^2)$$

(23)

$$Y \sim N(\mu_Y, \sigma_Y^2)$$

(24)

$$Z = X + Y, \text{ then } Z \sim N(\mu_X + \mu_Y, \sigma_X^2 + \sigma_Y^2)$$

(25)

Now that independence is defined we can define the demand distribution for the RP of product i. We define the demand distribution during the RP with J, J is t to $t + SL_i - 1$. We define it as follows;

$$N_{i,J_t} = N\left(\sum_{t}^{t+SL_i-1} \mu_{i,t}\,, \sum_{t}^{t+SL_i-1} \sigma_{i,t}^2\right)$$

(26)

Safety factor of IL

Calculating the safety factor is important for determining the OIL. The notation of the safety factor of product i in period t is given below:

$$z_{i,t}(x) = \frac{x - \mu}{\sigma}$$

(27)

Implementing $\mu = \mathbb{E}(D_{i,t})$ and $x = I_{i,t}$ or $OIL_{i,t}$, gives

$$z_{i,t}(I_{i,t}) = \frac{I_{i,t} - \mathbb{E}(D_{i,t})}{\sigma_{i,t}} \; and \; z_{i,t}(OIL_{i,t}) = \frac{OIL_{i,t} - \mathbb{E}(D_{i,t})}{\sigma_{i,t}}$$

(28)

It is important to note, that the safety factor for the CIL can be calculated, as $I_{i,t}$ is a parameter. However, we need a formula to obtain the value of the safety factor for the OIL. As this is optimal, we will denote $z_{i,t}\left(OIL_{i,t}\right) = z_{i,t}^*$. Next sections will define that we can obtain the value of $OIL_{i,t}$ by using the standard Normal cumulative distribution function, given value $z_{i,t}^*$.

Standard Normal density function

The standard Normal density function gives the probability density of any given value within a standard Normal distribution. It indicates the distribution likelihood of a specific range of values within a distribution. The mean of the standard Normal density function is 0 and the standard deviation is 1. We aim to express the costs and expected profit for the OIL and CIL for a specific safety factor. For that, we need the probability density at that value of the safety factor. Equation 29 shows the notation.

$$f_{i,t}(z_{i,t}) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z_{i,t}^2}{2}}$$

(29)

Standard Normal cumulative distribution function

The standard Normal cumulative distribution function calculates the probability that a random variable, in this case x, takes a value less or equal to a specific value in a Normal distribution. This notation will also be used for expressing the expected profit for any IL. This is denoted as follows:

$$F_{i,t}(x) = P(X \leq x) = \int_{-\infty}^{x} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx$$

(30)

Given that the mean μ is the expected demand of product i in period t, $\mathbb{E}\left(D_{i,t}\right)$, and the standard deviation σ is the standard deviation of product i in period t is $\sigma_{i,t}$, the cumulative probability can be obtained by putting in x. Implementing this in the formula gives the following:

$$F_{i,t}(x) = P(X \leq x) = \int_{-\infty}^{x} \frac{1}{\sigma_{i,t}\sqrt{2\pi}} e^{-\frac{(x-\mathbb{E}(D_{i,t}))^2}{2\sigma_{i,t}^2}} dx$$

(31)

Now, that the standard Normal cumulative distribution function is defined, we can retrieve the value of $z_{i,t}^*$, the safety factor of the OIL. This value can be obtained by putting in the critical ratio of product i in period t in the inverse function of the standard Normal cumulative distribution.

$$z_{i,t}^* = F_{i,t}^{-1}\left(CR_{i,t}^*\right), \text{because we defined that } CR_{i,t} = CSL_{i,t}^*$$

(32)

Order quantity

Now that the calculation of z is defined, we will introduce order quantities. The standard form of an order quantity is as follows:

$$O = \mu + \sigma * z$$

(33)

OIL

With the definition of this, the OIL can be calculated. As described in Section 3.2, we slightly deviate from the original newsvendor problem as there can still be inventory left at WD. This means that the CIL should be taken into account. For this reason, we will calculate the OIL and subsequently subtract the inventory to obtain the OOQ. With $\mu = \mathbb{E}(D_{i,t}), \sigma = \sigma_{i,t}, O = OQ_{i,t}$ and $z = z_{i,t}$, the OIL of product i in period t is obtained:

$$OIL_{i,t} = \mathbb{E}(D_{i,t}) + \sigma_{i,t} * z_{i,t}^{*} \tag{34}$$

$$OOQ_{i,t} = OIL_{i,t} - I_{i,t} \tag{35}$$

The goal of this thesis is to introduce an inventory policy that will order quantities based on the estimated demand for several days instead of the estimated demand for the upcoming period. Obsolescence is a big factor in the FVP industry, and therefore, it is beneficial in terms of finances that WD reduces the risk of obsolescence. Therefore, the consideration whether to purchase a product will be dependent on the expected profit associated with the CIL and the OIL for the upcoming period. So, the profit regarding the CIL and the OIL for the upcoming period should be known. In this way, the IL will first drop to the point where reordering, plus the transportation costs, is more profitable than not reordering. When this happens the inventory is sufficiently low to assume that obsolescence of products in the upcoming period is unlikely to happen and ordering happens. If a purchase minus the transportations costs is expected to be profitable than not ordering, we will order the product for the whole RP, so we set the period of the OIL to J. Figure 14 shows purchasing strategy. The OIL for J periods is as follows:

$$OIL_{i,J} = \mathbb{E}(D_{i,J}) + \sigma_{i,J} * z_{i,J}^{*}, \text{where } J \text{ is } t \text{ to } t + SL_i - 1 \text{ and } z_{i,J}^{*} = z_{i,t}^{*} \tag{36}$$

It can be noted that by retrieving OIL_{i,J_t} all the variables are calculated for period J_t, except for the $z_{i,t}^{*}$. The purchase price and selling price of a product can only be known for the upcoming period. This influences the overstocking and understocking costs, influencing the critical ratio subsequently. Therefore, it is not possible to calculate the critical value for period J_t. Due to the lack of data regarding prices in following periods, we assume that $z_{i,J}^{*} = z_{i,t}^{*}$. Section 7.5 discusses the safety factor further.

Once again, this model is multi-period where the original newsvendor problem is a single-period model. WD can have inventory left, and so, we subtract the inventory from the $OIL_{i,j}$ to obtain the optimal order quantity. The IL is a parameter that can be looked up in WDs ERP system and gives the current value for the IL. For the order quantity, only the IL needs to be known. Therefore, the I_{i,J_t} does not have to be known and the IL of WD, $I_{i,t}$, can be subtracted from the $OIL_{i,J}$. Equation 37 shows the notation.

$$OOQ_{i,J} = OIL_{i,J} - I_{i,t} \tag{37}$$

Standard loss function

The standard loss function gives a value that will be used for calculating the costs associated with actual demand deviating from the mean demand. This can be used in this model, as we want to calculate the standard loss function for the OIL and the CIL. The notation of the standard loss function is as follows:

$$L(z_{i,t}) = f(z_{i,t}) - z_{i,t} * \left(1 - F(z_{i,t})\right)$$

(38)

After introduction of the standard loss function, the expected understocking and the expected overstocking can be calculated. The notation is as follows:

$$EUS_{i,t} = \sigma_{i,t} * L(z_{i,t})$$

(39)

$$EOS_{i,t} = \sigma_{i,t} * \left(z_{i,t} + L(z_{i,t})\right)$$

(40)

Expected total costs

When the value of all these variables are known, the expected total costs at any given IL can be calculated. This is according the following formula:

$$ETC(z_{i,t}) = co_{i,t} * EOS_{i,t} + cu_{i,t} * EUS_{i,t}$$

(41)

Expected profit

Now that the expected total costs are known, the expected profit can be calculated with the following formula:

$$EP_{i,t} = cu_{i,t} * \mathbb{E}(D_{i,t}) - ETC(z_{i,t})$$

(42)

It should be noted, that this formula only has one variable, the $ETC(z_{i,t})$. The understocking costs, $cu_{i,t}$, and the expected demand, $\mathbb{E}(D_{i,t})$, are both parameters. Because the $ETC(z_{i,t})$ is the only variable, the optimal expected profit can be obtained by minimizing the expected total costs.

Determination of order quantity

The objective of the model implemented in a dashboard is to show whether to purchase or not. If it turns out that ordering is expected to be profitable, the model displays the order quantity. The order decision is dependent on the expected profit associated with the OIL and the expected profit associated with the CIL. When both expected profits are known, the considerations whether to buy or not can be made by weighing transportation costs against the extra profit. Notation is given in Equation 42.

$$OQ_{i,t} = \begin{cases} OIL_{i,J} - I_{i,t}, if \ \left(EP_{i,t}(OIL_{i,t}) - EP_{i,t}(IL_{i,t})\right) > TC_{i,t} \\ 0 \ else \end{cases}$$

(43)

Optimal multi-period newsvendor problem for upcoming period

In this model, the newsvendor problem is changed into a multi-period model. Therefore, it can be questioned whether adding transport costs and inventory still gives the optimal solution. $ETC(z_{i,t})$ is the only variable, and is affected by Equation 18, 19, 27, 29, 31, 37, 39 and 40. All these equations are not affected by the IL at WD. Because the addition we used for making the newsvendor problem multi-period does not influence the $ETC(z_{i,t})$, we still find an optimal solution for just the upcoming period. Section 7.3 elaborates further on the validity the model.

4.3. Conclusion

In this chapter, we elaborately set-up the model according to a newsvendor problem for WD. Normally, a newsvendor problem is singe-period, but to make it useful for the situation at WD, we transformed it to a multi-period model. This chapter defines the indices, parameters and variables for the model. By this, the following research question is answered.

How should the indices, parameters and variables be defined to apply the inventory model to the situation at WD?

Now that the model is obtained, the result should be calculated to check the impact of the new inventory policy. For calculating the result, first, further elaboration on the demand distribution, forecasting methods and the practical implication at WD need to be described. Also, the product(s) (groups) subject to analysis will be introduced in the following chapter, Chapter 5.

5. Model at WD

This chapter outlines several necessary factors for the model for WD that is defined in Chapter 4. Section 5.1 will determine the best forecasting method for WD according to historical data. Then, Section 5.2 will give the substantiations why a Normal distribution is assumed for the demand distribution of products at WD. Section 5.3 and 5.4 define the product groups that will be subject for analysis for the KPIs. Followingly, Section 5.5 reasons why we use the RP. Lastly, for calculating the effect on the KPIs, a new purchasing is set-up and this can be found in Section 5.6. With all this information, the model can be put in a dashboard in Excel. Section 5.7 shows the input and output sections. Section 5.8 summarizes this chapter. In this chapter, the following sub-research questions are answered.

What distribution does the demand of products follow and what forecasting method applies best for estimating results?

According to which variables can products be grouped?

5.1. Choosing a forecasting method

The nature of the FVP industry is distinguished by seasonality, demand variability and supply deficits. Paragraph 3.3.3 describes exponential smoothing and moving average as forecasting method. Moving average and exponential smoothing both have their advantages and drawbacks, making it challenging to choose a forecasting method based on reasoning. The fundamental difference between these forecasting methods is whether to weigh the most recent observation more heavily or no. Choosing a forecasting method can have a significant impact on the outcome of this thesis. For that reason, thorough analysis will be done. The data that will be used shows that demand depends per week of the day, so Monday to Friday. Therefore, the estimated demand will be calculated for every day in the week individually. The product group subject to analysis is tomatoes. The product group tomatoes accounts for 10.38% of the total demand. The product group tomatoes have a RP of three days.

In statistics and data analysis, the Mean Squared Error (MSE) is a measurement for evaluating the effectiveness of regression models. It measures the correlation between a dependent and an independent variable. In this thesis, the historical demand is the independent variable as this cannot be influenced. Then, we also need to have a dependent variable. The goal is analyze the best forecasting method, so we will use both forecasting methods with different values as dependent variables and measure the MSE with the historical demand as independent variable. The MSE formula sums the squared differences between these variables and divides it by the number of observations. The formula of the MSE is depicted in Equation 44. A low MSE suggests a low error, and thus, an accurate estimation. This indicates that the forecasting method predictions' approach the actual demand.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \bar{Y}_i)^2 \tag{44}$$

The Mean Absolute Deviation (MAD) is a statistical metric used to quantify the variability within a dataset. MAD provides the centrality and deviation in the dataset, giving insights into the average deviation from a dataset's mean. This is irrespective of their directional aspect, a necessary condition if demand is normally distributed. MAD is often used if the magnitude of an error is assumed to be linear rather than quadratic. The formula is as follows:

$$MAD = \frac{\sum_{i=1}^{n} |Y_i - \bar{Y}_i|}{n}$$

(45)

Lastly, the formula is introduced for taking the average demand of a dataset. This is:

$$Average\ Demand\ (AD) = \frac{1}{n}\sum_{i=1}^{n} Y_i$$

(46)

To make the MSE of the moving average and exponential smoothing a more interpretable number, the MSE will be divided by the AD. Equation 47 shows this.

$$\left(\frac{Mean\ Squared\ Error}{Average\ Demand}\right) * 100$$

(47)

First, it is important to determine which of the statistics is most important for deciding which forecasting method should be used if methods show contradictory results. The demand at WD is assumed to follow a Normal distribution. Therefore, the impact of a larger error grows exponentially rather than linearly. For that reason, MSE/AD is the most important measurement of the two.

Table 6. Average result of Monday – Friday in 2022 for moving average and exponential smoothing for the tomato demand

Number of periods*	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
3	150.0	209.6	for **α=0.10**	144.4	207.4
4	139.6	212.4	for **α=0.15**	140.4	205.4
5	153.2	221.4	for **α=0.20**	137.4	203.6
6	154.4	229.0	for **α=0.25**	134.2	201.6
7	150.8	229.6	for **α=0.30**	131.6	199.2

**The forecasting values in Table 6 are the averages of Monday – Friday.*

Table 6 shows that the forecasting method exponential smoothing with an smoothing constant of 0.30 approaches the historical demand best both for the MSE/AD and MAD test. It should be noted that the difference between the best value for exponential smoothing and the best value of the moving average method for the MSE/AD test is 5.7% lower, not a major difference. Due to the results of Table 6, the assumption is made that all products and product groups follow the forecasting method exponential smoothing, with $\alpha = 0.30$. The forecasting formula is, as given in Paragraph 3.3.3, as follows:

$$x_{t,T} = \hat{a}_t = (1 - \alpha)\alpha_{t-1} + \alpha x_t$$

(48)

Figure 15 below shows the weekly tomato demand in 2022 and the result of the forecasting method that is defined above. The MSE/AD of Thursday in 2022 was 136 as can be found in Appendix A. This is the closest number to the average MSE/AD for Monday – Friday, as can be seen in Table 6. Therefore, this figure depicts the relationship between the historical demand and exponential smoothing, with a smoothing constant of 0.30, best.

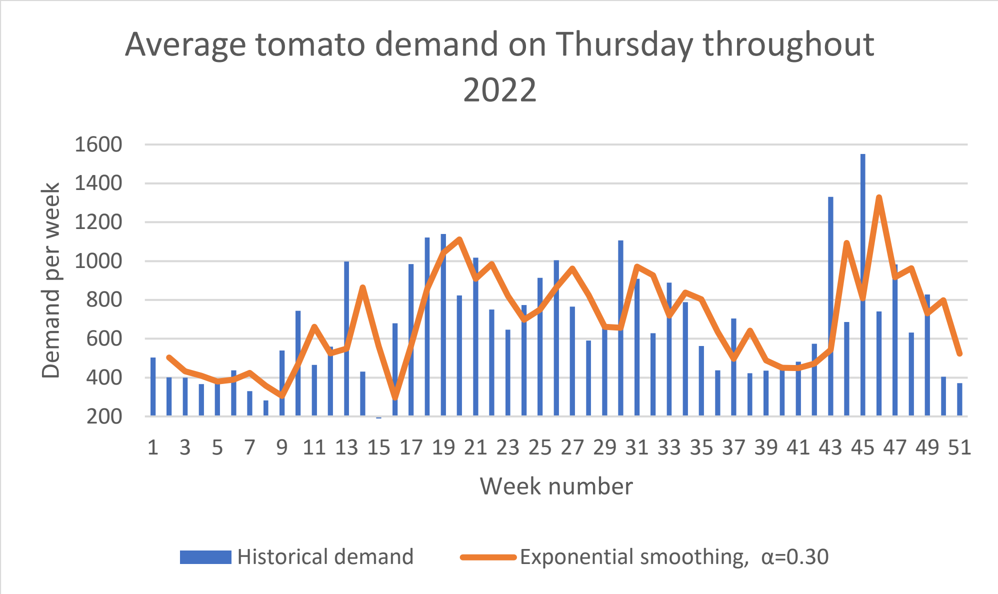

Figure 15. Weekly tomato demand throughout 2022 with exponential smoothing, $\alpha = 0.30$

5.2. Demand distribution at WD

Section 5.1 describes that exponential smoothing as forecasting with a smoothing constant of 0.30 is the best estimator for the expected demand. Now that the estimated demand is defined, still a distribution needs to be defined to define the standard deviation appropriately. Elstar apples is a product that is not subject to seasonal supply as its RP, more than a month, is longer than possible supply deficits. Figure 16 shows a histogram with the daily demand of Elstar apples. Figure 16 gives the impression that historical data follows a Normal distribution. According to Figure 16, we will make the assumption that the distribution of the demand of products, that are sold year-round, follow a Normal distribution. WD is aware of the fact that there three stark outliers in the year, Easter, Christmas and Pentecost. So, these data points may be neglected as the purchasing department will adapt the order quantities of these outliers. Due to the fact that the estimated demand of different days of the week, Monday to Friday, can differ substantially, the standard deviation of each weekday, Monday to Friday, is calculated separately on the historical demand of 2022.

In conclusion, it is assumed that the demand of products groups follow a Normal distribution. In the next section, several conditions are introduced to define the product groups subject to analysis.

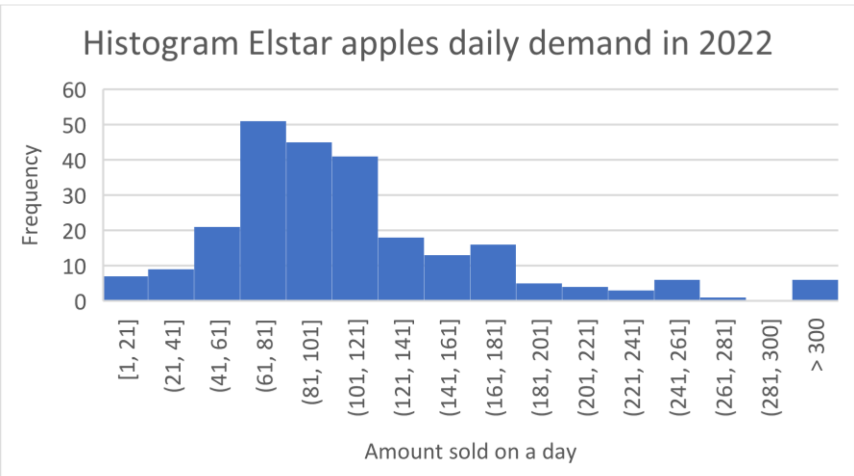

Figure 16. Histogram with daily Elstar apples demand in 2022

5.3. Products groups subject to analysis for inbound logistics

In this section, several conditions for product groups are defined. If product groups comply to these conditions, they are used for calculating the result on the inbound logistical movements KPI. For the availability of products in the morning, complying with these conditions is not required.

Firstly, analysed products need to be available the whole year. There are products that are harvested in different places in the world throughout the year to supply it the whole year. Also, there can be supply (chain) deficits, especially when the products are harvested overseas and transported to WD. In these situations, substitutes for this product are purchased. So, the first criteria is that a product should be available throughout the year. Also, the sum of the demand of products within a product group displays the average demand, as single product's demand can vary largely due to supply deficits.

The management summary introduces RPs. In this thesis, product groups with a RP of three, four or five days will be analysed. Purchases of products groups that have a longer RP than five days already happens for longer than one period. Product groups that only have a RP of one or two days will not be subject to analysis. Due to the short RP, demand can drop significantly and large amounts of products go obsolete. This is costly, and so, not beneficial.

Lastly, we will only observe product groups that account for more than 2% of the total demand for 2023. If the specific product group demand is less than 2% of the total demand, it is unlikely that daily purchase is necessary.

These criteria leave nine product groups of the original 93 product groups. All the product groups, with their RP and their demand share, are depicted in Table 7 below.

Table 7. Information of product groups subject to analysis

Product group	**Demand**	**RP**
Tomatoes	7.467%	3 days
Apples	5.945%	5 days
Mandarins	5.331%	5 days
Paprika	4.068%	3 days
Cabbage	4.500%	5 days
Melon	3.996%	3 days
Oranges	3.795%	4 days
Pear	2.784%	5 days
Carrot	2.429%	5 days
Total	44.97%	

The current ERP system of WD, ADS, does not store the address where a purchase is coming from. Also, many products groups are purchased at multiple suppliers as there are day-to-day price differences and surpluses and deficits can happen anywhere in the FVP supply chain. As there is no possibility to research the number of times a supplier is visited daily, we assume that the suppliers of this product group are visited every single working day. This means every week in the year from Monday – Friday.

Lastly, the new ERP system does not show the historical sales of any product or product groups. Before the implementation of ADS at WD in February 2023, another system was in use. This was not an ERP system but rather a system barely for the purchases, sales and the inventory management. This system was useful for the purchasing and sales department as inventory and historical purchase and selling prices could be seen and was called DiTo. However, it was too old to operate. Data from the old system was still available but could not directly be exported to Microsoft Excel.

For extracting this data, first, the files needed to be exported to a PDF-file, then splitting it into sub-parts in PDF. Then, converting these sub-parts into an Excel file. The conversion to Excel led to many interchanges of cells and contained around 40000 rows of data. Checking this was time-consuming. Due to time constraints, only the data of the biggest product group in terms of demand, tomatoes, is analysed. There are eight product groups that meet the same criteria as tomatoes, and therefore, the assumption is made that product groups meeting the same criteria as tomatoes will have the same result as tomatoes. In the next section, the product groups subject to analysis for the availability of products in the warehouse will be discussed.

5.4. Products groups subject to increase in IL in the morning

The previous section describes the product groups that are subject to analysis for the inbound logistical KPI. This section sets the conditions that a products should meet to calculate product availability in the morning in the warehouse of WD and also elaborately describes the current purchasing strategy.

Section 5.3 describes the current ordering policy for different RPs at WD. Products that have a RP of one or two days are purchased daily. So, it is unlikely that these products will be available in the warehouse in the morning.

Products with a RP longer than five days are already purchased for longer than one period. Also, when the IL of these products drop to a significant low level, these products can be ordered and will be available the next period. Therefore, these products will always be in inventory in the morning. Table 8 below shows the RP's and their percentage of the total demand.

Table 8. Percentage of total share for RPs

RPs	% share of total demand	Number of products
1 day	19.80%	19
2 days	20.95%	24
3 days	20.42%	12
4 days	10.20%	7
5 days	16.50%	6
1 week	10.31%	13
1 month	0.68%	3
3 months	0.69%	4
1 year	0.46%	2

For this thesis, all the RP's are unnecessary. Therefore, this will be categorized in three groups. Products with a RP shorter than three periods, products with a RP of three, four or five days and products with a RP of longer than five periods. This is depicted in Table 9 below.

Table 9. Share of total demand for product groups regarding RPs

RP	% share of total
< 3 days	40.75%
3 - 5 days	47.12%
> 5 days	12.13%

All the products with a RP of three, four or five days account to 47.12% of the total demand. Under the assumption that products with a RP of five periods or shorter are ordered every day from Monday to Friday, availability of products in the morning at WD is assumed to be 12.13%, depicted in Table 9. Increasing the availability of products with a RP of three to five periods will significantly impact the availability of products in the morning.

For the inbound logistical movement KPI it is necessary to determine the percentage of the demand of a product to the total, to identify the necessity of daily purchase. This is not relevant for this KPI, as products with a smaller demand share can be ordered for their RP, but due to the fact that daily purchase is unlikely, it cannot be justified that the number of inbound logistics will decrease, with the same rate as product groups with more than 2% of the total demand share, if the new inventory policy is introduced. The next section explains further characteristics of the RP and justifies the use of it in this thesis.

5.5. Practical interpretation of the RP definition

As stated in Section 5.3 and 5.4, only product(s) (groups) with a RP of three to five days are analysed in this thesis. Naturally, if the order quantities are adapted to the expected demand during the RP instead of the upcoming period, the number of products going obsolete will also increase.

The RP is defined as the minimal amount of days that a product can be in the warehouse at WD. After this period, the quality of the product is checked, and if it is still okay, the RP is enlarged with the whole RP. This can happen multiple times. If the quality of a product decayed substantially in the warehouse, several things can happen:

- The product gets a discount. This can happen after the initial RP, but also if a product is several RPs in the warehouse;
- A product's obsolete value is zero. This can also happen after one or several RPs.

Extend the product due to a good quality with the same RP or giving discount on products happens most frequently. For that reason, we can substantiate that the RP always holds the minimum amount of periods that a product can be in the warehouse. This means, that the model labels products as obsolete faster than it does in reality. So, if the new inventory policy is implemented, obsolescence is lower than the model will show.

WD does not monitor the number of products that are fully obsolete after the initial RP nor the products that are sold with a discount. Logically, the percentage of obsolete products will increase if the order quantities of products, with a RP of three to five days, increase. In addition, the average quality of products for the customer can also decrease. However, the increase of obsolete products and decrease of the quality of products cannot be measured. In the discussion, further elaboration on this subjects can be found. Now that the RP is defined, we will introduce the practical effect if the new inventory policy will be introduced.

5.6. New ordering policy for WD

In Chapter 6, the financial calculations regarding a new inventory policy will be made. This inventory policy affects the order quantities. Consequently, it affects the purchasing process and the logistical process. However, financial calculations of the new situation can only happen if a new purchasing strategy throughout the week is initiated.

The objective in this thesis is to decrease the inbound logistical costs and the costs in the warehouse. The new order policy will order a product for the whole RP if a purchase happens.

It is unpractical to order products with a RP of three days on Friday, as a Monday will be the fourth day after purchase, resulting in obsolescence for the model. For products with a RP of four days, this also is not very practical as the Monday will be the last day of its RP. For products with a RP of five days, however, ordering on Friday is possible as products can also be sold on next Monday or Tuesday. This matter is discussed with the COO of WD. Table 10 below shows the and the new purchasing policy.

Table 10. New ordering policy for products with a RP of 3, 4 or 5 days

RP \ day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3 days	X		(X)	(X)			
4 days	X		(X)	(X)			
5 days		(X)	(X)		X		

X = definite purchase that day
(X) = purchase dependent on inventory left from definite purchase

5.7. Model

In the previous two chapters, we have defined what should be implemented in the dashboard. This section describes the input and output variables that the dashboard tool has.

The objective of this dashboard, is to make a decision about the order quantity. Making the decision is done by putting in the equations of the model into Excel. When all the input values are known, it gives the order quantity.

The yellow boxes in Figure 17 need to be filled in to get the results.

Inputs	
Product number (#)	
Period number (#)	
Purchase price (in €)	
Sale price (in €)	
Residual price (in €)	
Transport costs (in €)	
Inventory level (#)	
Inspection period of product (t)	

Figure 17. Input section of the tool

When the values are put in, still information should be known to calculate the order quantity. The dashboard will look up the RP of product i. Subsequently, the demand distribution of period J_t is calculated by looking up historical data with period t and the RP of product i, using Equation 26 of Chapter 4. Then, all the notations given in Chapter 4 are done and Excel will give the output, depicted in Figure 18 below.

How much to order?	
Order quantity	
Extra expected profit	

Figure 18. Output section of the tool

To make the result more interpretable, two graphs are added to the dashboard. One graph contains the estimated profit under different ILs and the other graph contains the estimated total costs under different ILs. These x-axis of these graphs is adapted to the OIL of one period. Also two pie charts are added to the dashboard. One contains the cost division under the CIL if no order is placed and the other figure contains the cost division under the CIL if an order is placed. Figure 21 in Appendix B shows the dashboard if no order is placed. Figure 22 in Appendix B shows the dashboard if an order is placed. In Figure 21, the IL is 650 units and in Figure 22, the IL is 550 units. The dashboard determines the quantity that needs to be ordered. In the next chapter we will calculate the effect.

5.8. Conclusion

This chapter provides information necessary for implementation of the tools and calculating the results on the KPIs. Section 5.1 defines that exponential smoothing with a smoothing estimator of 0.30 forecasts demand best. Section 5.2 substantiates the assumption of the Normal distribution. Section 5.3 and 5.4 state criteria for products that are analysed. Section 5.5 gives reasons why order quantities should be based on RPs and Section 5.6 outlines the new purchasing strategy under the new inventory policy. Then, the dashboard can be implemented and Section 5.7 shows the input and output sections of the dashboard. This chapter gives answers to the following sub-research questions:

What distribution does the demand of products follow and what forecasting method applies best for estimating results?

According to which variables can products be grouped?

Now all the sub-research questions are answered. So, in the next chapter, we will answer the main research question.

6. Results

All the sub-research questions are answered in previous chapters. This means that the main research question of this thesis will be answered in this chapter. The research question is as follows:

What effects would implementing an inventory policy have on the inbound logistics, efficiency in the warehouse and the wage expenses in the warehouse?

In Section 6.1, the results on the inbound logistical costs under the new inventory policy will be calculated. Subsequently, Section 6.2 provides calculations regarding the increase in inventory level in the morning. Lastly, Section 6.3 summarizes this chapter.

6.1. Financial results inbound logistics

The previous chapter makes the necessary assumptions to calculate the effects on the KPIs. With these assumption, the dashboard for WD is made.

As stated in Section 5.3, only the product groups tomatoes can be used to calculate the effect on the KPI. For calculating this result, first a few parameters should be determined. First, the gross profit margin of WD needs to be known. The notation of this is shown in Equation 49.

$$Average\ gross\ profit\ margin = \frac{turnover}{Purchase\ value} - 1 \approx \text{[redacted]} - 1 \approx \text{[redacted]} \tag{49}$$

For confidentiality reasons, gross profit margin cannot be published. Therefore, we have to assume a number to be the gross profit margin. We assume the gross profit margin to be 33%. This is the average gross profit margin of all the products over a year and we will use this number in the calculations.

For calculating the reduction of inbound logistical costs, also, the residual value for the product group tomatoes should be known. This is being discussed with the purchasing department, sales department and product quality department, and it is assumed to be 50% after the RP.

In Paragraph 2.3.1, we already defined that the average costs of visiting a supplier is €33.33. We will also use this in the calculation.

Then, in Table 10 in Section 5.6, we defined the purchasing strategy for product groups with a RP of three to five days. For product groups with a RP of three periods, the optimal purchasing strategy is to order twice a week. However, demand deviations can result in three, four or five purchases a week. Product groups with a RP of three periods are always ordered on Monday. On Tuesday to Friday, a purchase is done if a purchase the model expects a purchase to be beneficial.

The historical demand data for 2022 for tomatoes is known and Section 5.1 shows that exponential smoothing with a smoothing constant of 0.30 is the best forecasting method. Now that we have all the information that is needed, we use the dashboard for all the weeks without a missing day. These are 22 weeks in total and we determine for every Tuesday to Friday whether a purchase should happen or not. When filling in the data in 2022 for tomatoes, we found that with the new inventory policy, the number of purchases decreases with 53 over 22 weeks. So, the annual saving for tomatoes would be:

$$\frac{53\ trips}{22\ weeks} * 52\frac{weeks}{year} * 33.33\frac{Euro}{trip} = 4175.34\ Euro \tag{50}$$

As defined in Section 5.3, there are eight other product groups that meet the same conditions as tomatoes. Therefore, the annual savings with the new inventory policy are:

$$4175.34 \frac{Euro}{product\ group} * 9\ product\ groups = 37{,}578.06\ Euro$$

(51)

6.2. Increase product availability

The other KPI in use is the availability of products in the morning in the warehouse. Currently, the financial result of increasing the availability of products in the morning cannot be measured. However, we assume the efficiency in the warehouse to increase and the end time of employees in the warehouse to expedite as work can start earlier and happens more efficiently.

With the new inventory policy, we will calculate the effect of the availability of products in the warehouse in the morning under the new inbound logistical movements. Due to the larger order quantities, availability of a product in the morning in the warehouse increases. We will calculate this result.

We have assumed that WD currently purchases product groups with a RP of three to five days daily. So, it can happen that inventory is left over from the day before and can be picked. However, this will largely vary across product groups. For that reason, no estimation can be made whether beginning earlier in the morning is beneficial or not by daily operations at WD, and thus, starting earlier in the warehouse never happens.

The dashboard also makes it possible to calculate the availability of a product in the morning. Products with a RP of three days are always purchased on Monday. For that reason, it is not possible to have any inventory on Monday morning. During the 23 weeks, tomatoes were available 69 mornings. This makes the average product availability on Tuesday to Friday in the morning:

$$\frac{\frac{69}{22}}{4} * 100\% = 78.41\%$$

(52)

Products with a RP of four of five days are assumed to be more in inventory in the morning as order quantities can happen for longer periods. Now that we know that the average product availability of products with a RP of three to five days is at least 78.41%, we calculate the total product availability in the morning.

Currently, all products with a RP of up to five periods are purchased every day from Monday to Friday. Products with a RP of longer than five periods are assumed to always be in the warehouse. When looking at Table 15, we can see that currently 12.13% of the average demand is available in inventory in the morning.

Table 11. Share of total demand for product groups regarding RPs

RP	% share of total
< 3 days	40.75%
3 - 5 days	47.12%
> 5 days	12.13%

We will calculate the availability on Thursday – Friday. Monday is a hard day to have many products in inventory as no purchases happen on Saturday and Sunday. We have assumed that all products with a RP of longer than five days are always in inventory in the morning and no products with a RP of one or two days are in inventory in the morning. With the implementation of the new inventory policy, 78.41% of the products with a RP of three to five days are assumed to be in inventory in the morning. The new average product availability will be the average number of products in inventory in the morning to:

$$12.13\% + 47.12\% * 0.7841 = 49.08\%$$

(53)

This may not really look like much, but first only 12.13% of the demand was in inventory in the morning. Now that is increased by:

$$\frac{new\ availability\ \%}{old\ availability\ \%} - 1 = \frac{49.08}{12.13} - 1 \approx 304.6\%$$

(54)

An increase of 304.6% for product availability is a significant increase.

Another calculation that can be done is the products that are in the inventory in the morning respective to the maximum availability. This is the following sum:

$$\frac{New\ availability\ \%}{Maximum\ availability\%} = \frac{0.4908}{1 - 0.1980 - 0.2095} = 82.84\%$$

(55)

This means, that after implementation, 82.84% of the products that can be in inventory are in inventory in the morning. In Paragraph 2.3.2 and 2.3.3, we assume that having an increased inventory in the morning has several benefits:

- Efficiency by order pickers increases as more products are available;
- Employees in the warehouse can start picking orders earlier, so employees work less during more expensive hours.

In conclusion, the availability of products in the morning increases with 304.6% if the new inventory policy is implemented. However, the reduction of the costs cannot be calculated as the efficiency throughout the day is not recorded. So, the improved efficiency cannot be known and the result of starting earlier with order picking cannot be calculated either.

6.3. Conclusion

In this chapter, we have calculated the results of implementing a new inventory policy. This inventory policy will then be based on the newsvendor model introduced in Chapter 4. With the use of the dashboard, the reduced inbound logistical costs are estimated to be €37,578.06. Secondly, product availability with the new inventory policy in the warehouse is calculated. After implementing the new inventory policy, the total product availability at WD increases with 304.6% in the morning. By this, we answered the main research question of this thesis:

What effects would implementing an inventory policy have on the inbound logistics, efficiency in the warehouse and the wage expenses in the warehouse?

Now that the main research question is answered, we discuss the results, give recommendations to WD, notice the limitations and give advice about future research about this topic.

7. Conclusion

This final chapter concludes the research that has been performed at WD. Section 7.1. will give the answer to the research question, Section 7.2 will identify the limitations within this research. With the knowledge of the limitations, the thesis will be discussed in Section 7.3. Followingly, Section 7.4 gives recommendations to WD. Lastly, Section 7.5 will provide possibilities for future academical research.

7.1. Main findings

This section describes the main findings of this thesis. It is divided into two parts. Paragraph 7.1.1. gives the results for WD and Paragraph 7.1.2 elaborates on the use of this thesis for other companies.

7.1.1. Result for WD

The main motivation of this thesis is to help WD with their problem: the operational process is not as efficient as it should be. This problem is being researched and the core problem is that WD currently does not have an inventory policy. The purchasing process is not interwoven with the inventory policy and this directly affects the inbound logistical process and indirectly affects the order picking process in the warehouse. Implementing a new inventory policy will increase the order quantities. Products subject to analysis are products with a RP of three to five periods. These are currently being purchased daily but order quantities should be based on their RP. By increasing order quantities, the number of inbound logistics decrease and the availability of products in the warehouse in the morning increases. The inbound logistics is positively impacted in two ways:

1. Reduction in logistical costs;
2. Earlier arrival of inbound trucks at WD.

The reduction of inbound logistical costs are estimated to decrease with €37,578.06. The earlier arrival of inbound trucks positively affects the availability of products and efficiency of order pickers in the warehouse. However, the efficiency of order pickers throughout the day is not known at WD yet. Therefore, also no financial analysis about the effect can be done.

There are multiple reasons why the operational process in the warehouse is too expensive. Firstly, in the morning there are employees working in the warehouse, but often, no orders are too be picked. So, work in the morning happens less efficiently. Secondly, due to the late arrival of purchased products and inefficient work in the morning, employees have to work more after 19:00 hours. The expenses for these late hours are 25% higher than normal. Reordering happens when it turns out to be financially beneficial for the upcoming period. If the new inventory policy is implemented, product availability in the morning will increase by 304.6%.

In conclusion, the expected annual reduction of logistical costs after implementing the new inventory policy is €37,578.06 and the availability of products in the morning increases with 304.6% minimally. This increases the efficiency and reduces the amount of wage expenses during the more expensive time window.

7.1.2. Contribution to other companies

The FVP’s most important characteristics are obsolescence, large demand variability, price changes and supply deficits. When solving this problem at WD, several essential components were taken into account. These are obsolescence, large demand variations and price changes. So, this model could be adapted by businesses or industries with similar characteristics. The notation of the problem is done in a general way, making it adaptable for other businesses.

Another contributing factor in the model is that this model is a multi-period newsvendor problem. Usually, industries that are subject to the theoretical newsvendor problem deal with single-period problems. By making it multi-period, demand distributions of several periods could be defined the consideration whether to purchase or not could be included. This decision is dependent on the set-up costs, transport costs for WD and the estimated extra generated profit that would otherwise be missed out on.

Industries with (some) similar characteristics that can integrate (an adaption of) this model are:

- Clothing companies. If a season product appears to be a fast-runner and reordering is still an option. An example of this could be the Zara;
- A crop farmer with high set-up costs, like an asparagus farmer;
- An ice cream salesman considering whether or not to open his parlour that day dependent on weather forecasts (high set-up costs).

7.2. Limitations

This section describes the limitations of this thesis. During the execution of this research, several limitations have come across. The limitations were mainly the absence of data. The lack of data is described in the following paragraphs.

7.2.1. No financial projection about efficiency

WD does record the average efficiency in the warehouse daily and the efficiency of employees in a day. However, the efficiency throughout the day is not calculated. If this was recorded, a projection about the cost reductions with the implementation of the new inventory policy in the warehouse could be made. Also, the possibility of starting earlier with the order picking process to stop earlier, and thus reducing the more expensive wages, could be researched. Due to this, the increase of availability of products in the morning is positive but no calculations about cost savings can be made.

7.2.2. Data

The ERP system of WD does not store a lot of historical data. This is due to the fact that the system is in use for less than a year. Examples of the lack of data are the number of inbound logistical movements and the supplier, the absence of purchasing prices of products and the absence of sales data. The data that is analysed in this research, the demand for tomatoes in 2022, can be outdated and analysis of this can be less relevant or not relevant anymore.

An estimation about the number of inbound logistical movements needed to be done. This is done by the logistical planners and the COO, but is not a definitive answer. The number of inbound logistical movements of the product groups subject to analysis would be beneficial. In that way, the reduction of the logistical costs could be calculated in a more precise manner.

Obsolescence plays a major role in the FVP industry. However, the number of products going obsolete is not recorded by WD. This is one of the most important factors of companies operational in the FVP industry. Adapting the order quantities to the RP with the new inventory policy is beneficial in operational terms, but negative consequences due to reduction of average quality or higher levels of obsolescence are not calculated.

7.2.3. Demand distribution

Firstly, the demand of products is assumed to follow a Normal distribution. This is a substantiated assumption as the demand pattern of Elstar apples in Figure 8 and 16 appears to be normally distributed. However, there are multiple reasons why the current data is questionable, and so, the Normal distribution of products is also questionable. Secondly, the data that is analysed is sales data. Paragraph 3.3.2 describes the difference between demand data and sales data. The lack of lost sales can strongly influence the demand pattern. Thirdly, the reasoning behind stark outliers often is not recorded. Dismissing the stark outlying data that cannot be affected by WD may give a better estimation about the demand distribution, and so, predictions can be done more precise.

7.2.4. Multi-period newsvendor problem

This thesis deals with a newsvendor problem. Normally, a newsvendor problem is a single-period model where a trade-off is made between lost sales and obsolete costs. The original newsvendor problem, however, was not fully applicable to WD as WD needs to make a purchase decision based on the CIL. So, the newsvendor problem is adapted and made multi-period. By this, the consideration whether to purchase or not is made on the expected profit of the CIL and the OIL for that same period. If a purchase happens, the order quantity is based on the estimated demand of the RP of a product. So, the decision is based on the expected demand of the CIL and OIL of the current period and the OQ is based on the RP. However, it is possible to order products every period, so, sometimes it can be beneficial to postpone a purchase because it can also happen the day after. Also, it is not proven that ordering for the whole RP is the best parameter to base the order quantity on.

7.3. Discussion

This section reflects on the validity of this thesis and the application to other industries with the same characteristics.

As discussed in Paragraph 7.2.4, the model used in this study is a multi-period newsvendor problem with the CIL. At WD, this is the situation as the daily decision needs to be made whether to purchase a product or not, and therefore, is a reliable model to use for operational practices. The model also has some promising results. However, it has a few downsides because it currently does not take into account that ordering the period after the current period is possible. This is largely bypassed by including the CIL in the model, so that the expected profit for the upcoming period is maximized. For that reason, this model estimates the order quantities for products for WD in a good manner but is not optimal.

Due to the low RP of the products at WD, it can not be applied to many other industries. However, for other industries operating in the FVP industry, this model can be applied to their inventory policy. For other wholesalers and for supermarkets, the decision whether to purchase a perishable product or not depends on the CIL and the transportation costs of a product. Also, companies that offer fresh meals for their costumers, like HelloFresh, are also dependable on many perishable products and can use (an adaptation of) this model.

To conclude, this model gives good results but currently is not optimal. Other companies active in the FVP industry, or companies that offer fresh products, can use this multi-period newsvendor problem with a CIL to decrease the logistical costs, but this model is not widely adaptable to industries with products that hold products for longer periods.

7.4. Recommendations

Paragraph 7.2.1 and 7.2.2 describe the lack of data. The current ERP system at WD does not record a lot of data. As a matter of fact, the old purchasing, sales and inventory system recorded more data. The model that is set-up in this thesis does not work without data, and therefore, cannot be implemented at this moment.

The first recommendation is to look at the new ERP system with its functions once again. Currently, the ERP system shows a lot of real-time data. Inbound movements, CILs, current selling prices, etc. This makes the ERP practical in use by the warehouse employees. However, it would be helpful if some data would also be recorded. A few examples are the sum of the sales data of that day to improve the expected demand, the average buy and selling price of a product to determine the critical ratio in a better manner, the residual value of products to make the overstocking costs more representative, the efficiency of employees in the warehouse throughout the day to determine the effect of improved availability of products in the morning, the number of inbound logistical movements, etc.,

Also, currently the RP of products or product groups is static. Some products are more prone to deterioration in some periods of a year. If this is the case, always the lowest RP throughout the year is used. If the RP is dynamic, order quantities can be adapted to it and inbound logistical movements can be further minimized.

If this data is being stored, the data can be put in the model and should give the OIL of products. Although that there will be a chance that the purchase predictions by the model are worse than the prediction of the purchasing department, it can give other people in the company an insight into what drives the purchasing department whether to purchase or not. Moreover, if WD starts using the model and tries to optimize it according some trial-and-error, it is possible that the model can make accurate purchasing decisions in the future or reduce the amount of work of the purchasing department. There are also chances for the model. The model can give certain penalties to unwanted results and bonuses to wanted results. This could be that the model would cautiously weigh off the benefits of an inbound trip or reduced inventory the day after.

WD currently cannot implement the model as crucial data, like demand data, is missing. However, this thesis shows that ordering larger order quantities may have several benefits. It can reduce the inbound logistical costs and expedite the time of truck arrival at WD. Also, it is likely that larger order quantities will improve the efficiency of the order picking process and reduce the wage expenses in the warehouse, as less hours are worked after 19:00 hours. Therefore, the recommendation is to order quantities respective to their RP for a week or so and start an hour earlier in the warehouse. If there are no big hiccups in this process, like a large amount of products going obsolete, it can be considered to always adapt order quantities to their respective RP.

7.5. Future research

Section 7.2 describes why the model cannot be implemented currently. Although many criteria are already taken into account with the model, there are several factors that could affect the sales and therefore, can be researched further. An example of this could be by implementing an extra criterion that is based on the weather. Temperature is a factor that can strongly affect the demand, and therefore, implementing an extra input value that can adjust the estimated demand in these scenarios would be worthful.

Lastly, the critical ratio is a factor that currently is calculated only for the upcoming period with the purchase and selling price. However, prices are dynamic and price deviations can largely affect the profitability of a product during (a) period(s). For that reason, the critical ratio should not only be calculated on the current buy and sell prices but also on historical data. If a product is almost out of inventory and the prices are exceptionally high, it is irrational to order the product for the whole RP. The order quantity should than be based on the upcoming period or not happen at all. This also works the other way around. If a price of a product is exceptionally low, it may be profitable to purchase despite the fact that the inventory is high. Therefore, it could be beneficial to base the critical value also on historical prices.

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Appendix

A. Data choosing forecasting method

Table 12. Moving average vs. exponential smoothing results for five variables respective to the tomato demand for every Monday in 2022

Moving average period	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
Length = **3 days**	112	193	for **α=0.10**	112	195
Length = **4 days**	99	189	for **α=0.15**	109	191
Length = **5 days**	106	195	for **α=0.20**	107	188
Length = **6 days**	111	205	for **α=0.25**	104	185
Length = **7 days**	113	208	for **α=0.30**	102	181

Table 13. Moving average vs. exponential smoothing results for five variables respective to the tomato demand for every Tuesday in 2022

Moving average period	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
Length = **3 days**	141	205	for **α=0.10**	121	183
Length = **4 days**	141	216	for **α=0.15**	117	182
Length = **5 days**	155	220	for **α=0.20**	116	182
Length = **6 days**	150	224	for **α=0.25**	114	182
Length = **7 days**	148	225	for **α=0.30**	113	182

Table 14. Moving average vs. exponential smoothing results for five variables respective to the tomato demand for every Wednesday in 2022

Moving average period	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
Length = **3 days**	144	199	for **α=0.10**	162	221
Length = **4 days**	144	205	for **α=0.15**	158	218
Length = **5 days**	165	217	for **α=0.20**	153	214
Length = **6 days**	175	223	for **α=0.25**	149	210
Length = **7 days**	153	224	for **α=0.30**	145	206

Table 15. Moving average vs. exponential smoothing results for five variables respective to the tomato demand for every Thursday in 2022

Moving average period	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
Length = **3 days**	174	222	for **α=0.10**	144	194
Length = **4 days**	170	235	for **α=0.15**	141	195
Length = **5 days**	183	243	for **α=0.20**	139	196
Length = **6 days**	177	253	for **α=0.25**	137	196

Length = **7 days**	172	246	for **α=0.30**	136	196

Table 16. Moving average vs. exponential smoothing results for five variables respective to the tomato demand for every Friday in 2022

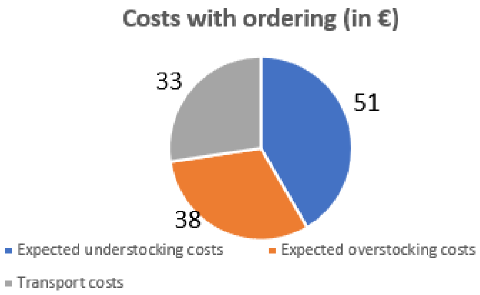
Moving average period	MSE/AD of moving average	MAD of moving average	Exponential smoothing input	MSE/AD of exponential smoothing	MAD of exponential smoothing
Length = **3 days**	179	229	for **α=0.10**	183	244
Length = **4 days**	144	217	for **α=0.15**	177	241
Length = **5 days**	157	232	for **α=0.20**	172	238
Length = **6 days**	159	240	for **α=0.25**	167	235
Length = **7 days**	168	245	for **α=0.30**	162	231

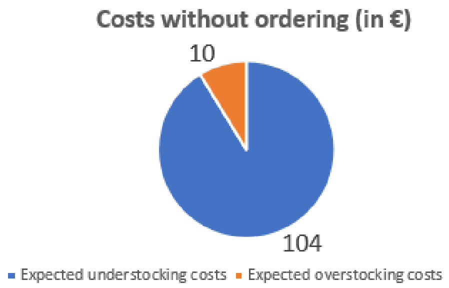
B. Dashboard

Inputs	
Product number *(#i)*	1
Period number *(#t)*	36
Purchase price (in €)	1
Selling price (in €)	1,3
Residual price (in €)	0,5
Transport costs (in €)	33,33
Inventory level (#)	650
Inspection period of product *i* (in *t*)	3

Output	
Order quantity	0
Extra expected profit	€ 0,00

Run





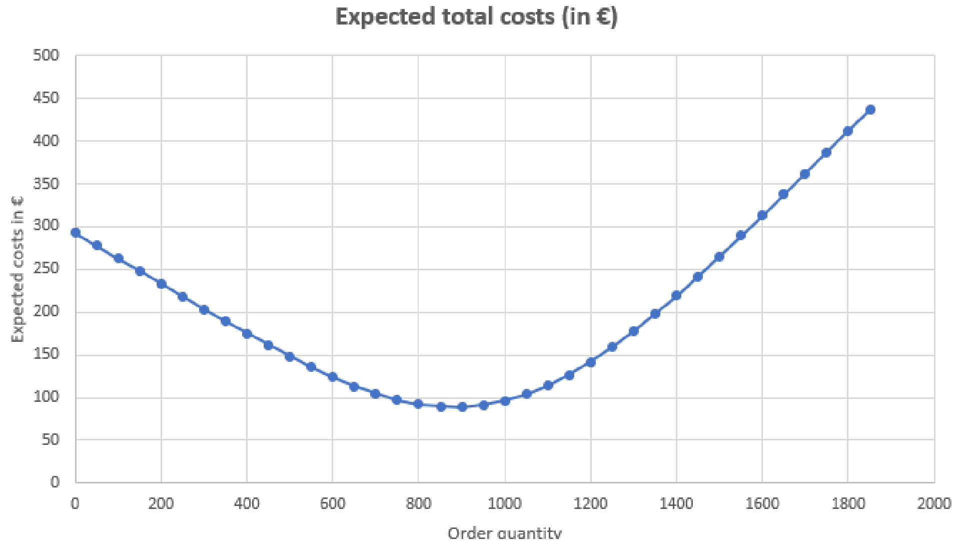
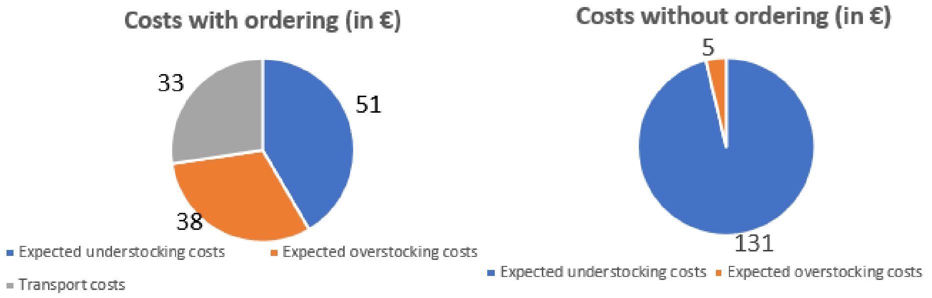


Figure 19. Dashboard with output section showing the order quantity is zero. Explanation of the graphs is given in Section 5.7.

Inputs	
Product number (*#i*)	1
Period number (*#t*)	36
Purchase price (in €)	1
Selling price (in €)	1,3
Residual price (in €)	0,5
Transport costs (in €)	33,33
Inventory level (#)	550
Inspection period of product *i* (in *t*)	3

Output	
Order quantity	333
Extra expected profit	€ 13,45

Run



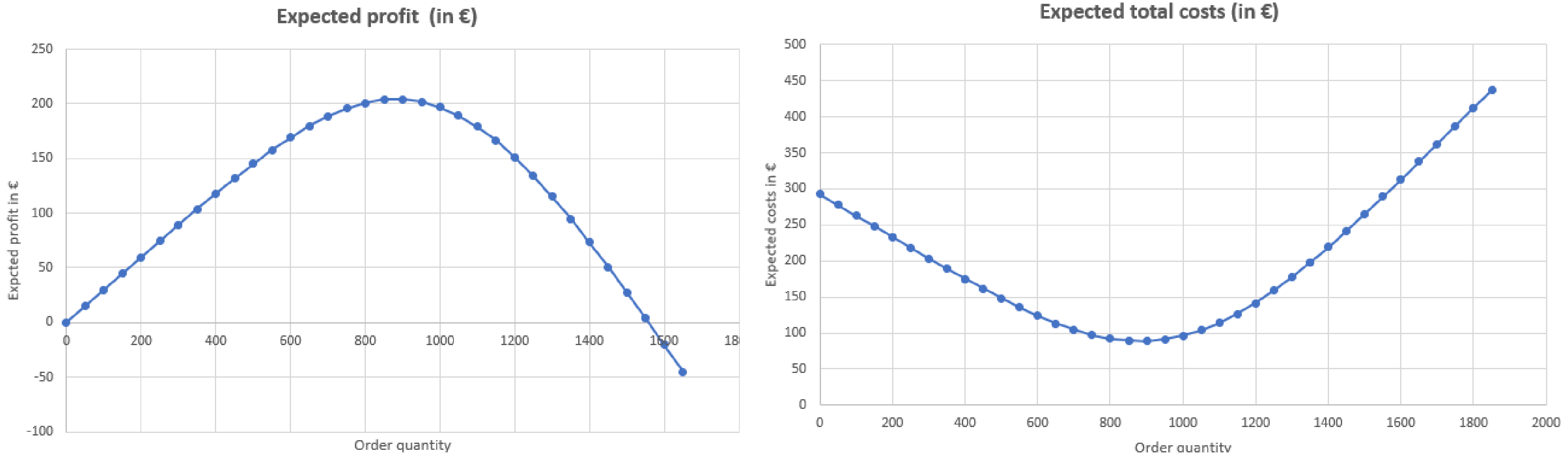


Figure 19. Dashboard with output section showing that the order quantity is larger than zero, 333. Explanation of the graphs is given in Section 5.7