Order adjustment strategy for highly perishable products at the perishable supply chain of SPAR

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Award date:
2012

Waalwijk, August 2012

Order adjustment strategy for highly perishable products at the perishable supply chain of SPAR

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BSc Industrial Engineering and Management Science — TU/e 2010

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In partial fulfilment of the requirements for the degree of

Master of Science

in Operations Management and Logistics

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TUE. School of Industrial Engineering.
Series Master Theses Operations Management and Logistics

Subject headings: supply chain management, retail trade, inventory control.

Abstract

This report tries to achieve one of the most desirable situations in inventory management, which is selling the entire available perishable inventory before the end of the day. However, when the selling horizon has not ended yet, this can result into another undesired effect: lost sales. The main focus of this research project is to improve the product availability of daily fresh product at SPAR stores, while minimizing the total relevant costs.

The research project starts with a thorough analysis of the supply chain of SPAR and a quantitative analysis of the current in-store on-hand inventory performances of perishable products. The performance of a stock point is the result of the forecast made for the order horizon, the control policy of the stock point, the parameter settings, and/or the supply chain structure replenishing the stock point. All these aspect were considered in improving the current in-store on-hand inventory performance. Resulting in the design of a new replenishment strategy for the stores, considering perishable products with a short product life. The new strategy incorporates the adjustment of the order quantity by store-owners during the cross-dock moment at the distribution centres of SPAR. Finally, a simulation study was performed to test the designed replenishment strategy.

Management summary

The SPAR format in the Netherlands positions itself as a local store for fresh-, daily-, and local products. SPAR stores are situated in small neighbourhoods and inner-cities. Thereby the format focusses on 'the neighbourhood-store' concept for everyday convenience. Previous research from Lammé (2010) and the annual reports of Gfk. indicated that product availability of daily perishable products is not as high as desired. Gfk. reports that product availability is one of the key points why consumers have a bad perception about the format SPAR. Lammé (2010) showed that circa 8.3% of the customers of SPAR face an out-of-stock situation.

Analyses

An out-of-stock situation can be the result of (a combination) several aspect(s); stock point control policy, the supply chain behind the stock point, and demand forecasting. These three points were analysed in the project. The supply chain of daily fresh products at SPAR was executed properly, the delivery performance was around 98.5%. Meaning that the replenishment processes and the supply chain performed as desired. However, the design of the supply chain resulted into lead-times of one day for perishable product orders. The order and delivery schedules applied resulted into long review periods between one and two days, depending on the moment of the week. The combination of the review-period and lead-time resulted into a long order forecast horizon of three days.

With the use of point-of-sales data, analyses of the demand characteristics of some daily fresh products in the A-segment of SPAR were performed. The average daily demand on Fridays (demand peak day) was around two products, ranging between less than one and extremes of almost seven products. Thereby concluding that most perishable products could be categorized as slow-movers. An analysis on the variation of the demand showed that the average coefficient of variation[1] was around 0.8, with a maximum of 1.0 and a minimum of 0.5. This implies that the variation was high and the demand can be categorized as erratic/lumpy.

The stock point in stores was controlled by the store owner. Order decisions were made by the store owner with his own tailored methods. Primarily the order-book method was used, whereby the current inventory position, sales, outdating, and order quantity is notated. The age-distribution was not included in the formal decisions of the order-book. With sales and order data, the relative outdating[2] was approximated between 6 and 11% for the selected perishable products. With the same data, the customer service level was measured in fill-rate[3]. The fill-rate was estimated to be around 92%. The low fill-rate was already detected by previous research at SPAR (Lammé, 2010), indicated by the low customer satisfaction results of Gfk. (2011), and by managers of SPAR.

From the different analyses, it was concluded that it was hard for store owners to make proper order decisions with currently used order methods. This resulted into high outdating and low customer service. Insufficient order decisions were primarily the result of the high unpredictability of the demand and the long order forecast horizon for perishable products.

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[1] The coefficient of variation is defined as the ratio of the standard deviation to the mean.
[2] Relative outdating is defined as the ratio of the outdated to the ordered products.
[3] Fill-rate is defined as the ratio of the demand to the satisfied demand.

Order adjustment strategy

The literature study on perishable inventory control showed that lead-time shortening benefits perishable inventory performance in both customer service level and outdating. This research project therefore investigated a replenishment strategy where the regular store-orders (that are cross-docked) could be adjusted upwards before the final delivery. Thereby the stock point is effectively controlled with a shorter lead-time, which results in lower safety stock levels at equal customer service levels. Combining the regular and adjustment orders before shipments to the stores does not increase the transportation costs, which was the main reason why an emergency shipment strategy (Lammé, 2010) was not applied. The adjustment could be realized by ordering products which have a much shorter lead-time than the regular products. This is achievable by ordering products that are on stock or by the delivery of semi-finished orders. Whereby, at the cross-docking facility the adjustment order can be finished and combined with the regular order.

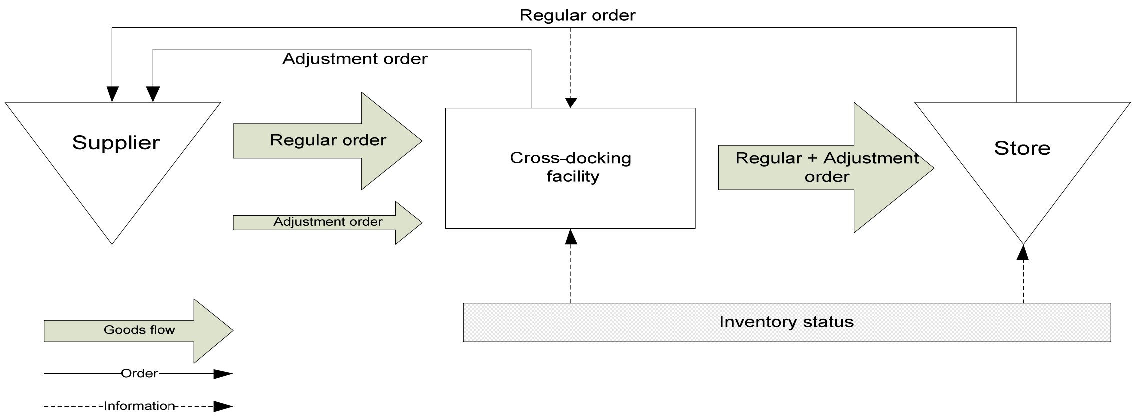

Figure A: Order adjustment supply chain model.

The order adjustment quantity is determined by SPAR, and based on the difference in actual change and expected change in inventory position. Unanticipated changes in the inventory, which lead to possible lower availability of inventory, could thereby be resolved with an adjustment of the regular order of the store owner. The refined main research questions of this research project was:

> ***"Is an order adjustment upwards and thereby implementing additional cross-dock operations, in order to reduce the out-of-stock rate at the stores beneficial for SPAR and the franchisee, when considering the total relevant cost of outdating and additional operations?"***

Model input

In order to answer the research question, a discrete event simulation was performed. In this simulation the order adjustment strategy was compared to a strategy without adjustment. In both strategies the regular order decisions were determined with the EWA-policy of Broekmeulen and Donselaar (2009). From the analyses of the POS-data, the input values of the product parameters were determined. The input of the mean daily demand was between one and six, thereby also including the week pattern of the demand. Demand for the simulation was modelled with a Poisson distribution. The shelf-life of a product was varied between four and eight days. Next, three different order and delivery schedules were considered. One that resembles the current desired situation of four deliveries per week, a schedule with three delivery moments, and a schedule with six delivery moments.

The performance of both strategies was measured by the achieved fill-rate and the total relevant costs, which were relative outdating and relative adjustment costs. Both outdating and fixed adjustment costs were made relative to the value of the ordered products. The relative adjustment costs were determined by the size of the adjustment assortment and the corresponding wholesale value. Different performance indicators were also measured, such as quality of the products sold, ratio of regular orders adjusted, and the size of the adjustment.

Results and conclusions

The simulation results showed that the designed order adjustment strategy was not beneficial for SPAR. The increase in costs and complexity, did not outweigh the higher fill-rates (around 2.85% fill-rate increase) achieved by the adjustment strategy. The benefits of the adjustment strategy were not big enough to overcome the extra costs, before the desired customer service levels were reached. The comparison between the EWA-policy with and without adjustment showed that an investment in outdating (higher relative outdating costs) is less than an investment in adjustment operations (higher relative adjustment costs) for improvement of the fill-rate in the case of the adjustment assortment of 58 SKU for 600 stores (see Table A). The relative adjustment costs were too high per product in comparison to the outdating costs. This was primarily the result of the size of the adjustment assortment. The assortment size was limited by the relative high frequency of the order adjustment quantity (42% of all regular order were adjusted). Also the already low relative outdating of the regular orders, made it almost impossible for the adjustment strategy to become beneficial. This is because, the strategy is only beneficial when the increase in costs of outdating is at least higher, than the adjustment costs, when considering higher fill-rates.

Table A: Business-case of SPAR for investment in fill-rate improvement from 92% to 95% and 97%.

Investment	for 95% fill-rate		for 97% fill-rate	
	NoAdjustment	Adjustment	NoAdjustment	Adjustment
Outdating	€ 291.667	€ 166.667	€ 666.667	€ 458.333
Adjustment	-	€ 250.000	-	€ 250.000
Total	€ 291.667	€ 416.667	€ 666.667	€ 708.333

The simulation results also revealed that the use of a more sophisticated and quantitative inventory policy resulted into a significant improvement of the current availability and outdating rates. The EWA-policy, used for the regular order decisions, making use of the age-distribution of the on-hand inventory. The simulation results showed that with this policy high fill-rates are achievable with low outdating rates for the selected perishable product assortment of SPAR.

Recommendation and future research

We recommend SPAR the investigation of a more sophisticated and quantitative based issuing and order policy for perishable products in-stores. The NoAdjustment-policy with the EWA-heuristic for the order decisions showed that customer service levels of around 95% was achievable with a limited amount of outdating.

For future research different designs of the adjustment strategy and different model inputs are recommended. The order adjustment quantity rule can be adjusted, such that the increase in outdating and adjustment costs is manageable, while fill-rates are significant improved. Next to this, a wider range of inputs and different assumptions needs to be investigated. Thereby the cost of an adjustment strategy can be better determined.

Preface

"All good things must come to an end" is a well-known statement that especially holds for my student life. This report is a partial fulfilment for the degree of Master of Science in Operations Management and Logistics at Eindhoven University of Technology. This research was facilitated by and in cooperation with SPAR Holding B.V. in Waalwijk, The Netherlands. After an extensive analysis at SPAR a solution direction for the low availability of perishable products in the stores was proposed. In a simulation study, an order adjustment policy for the perishable supply chain of SPAR was tested. This report describes the current problem context, our solution direction, findings, and implications.

In my preface, I want to thank a lot of people. First I would like to thank my direct colleagues, Pieter, Gert "Storm", Pieter, and Sandra for the pleasant and humorous working hours at SPAR. Also I want to thank my other colleagues for their time and willingness to help me during my project. Next, I would like to thank two important persons, my first supervisor Rob Broekmeulen and my company supervisor Nico Kuipers, who supported me with input, feedback, discussions, and made this project possible. Finally, I would like to thank my second supervisor for his feedback and discussions on the report and project.

Finally I would like to thank my family, friends, and especially my girlfriend for their support and patience during my study and graduation project.

Bart van Gessel

Waalwijk, August 2012

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1. Introduction

In this first chapter of the thesis, an introduction to the report is made. The introduction starts with a description of the company involved. The description will include the organization, retail strategy, market, and consumers' perception of the company. Next, the initial problem statement, which was formulated before the start of the project and updated during the first weeks of the project, is discussed. Finally, a report outline is given.

1.1 The company

The largest supermarket chain in the world under one name is SPAR. The format SPAR had in 2010 a yearly turnover of 29 billion euros worldwide with 12,136 stores in 33 countries. SPAR-International is the custodian of the brand-name SPAR and its headquarters are located in Amsterdam, the Netherlands. SPAR-International functions as a platform for the exchange of ideas and information between the independent SPAR organizations worldwide. The main mission of SPAR-International is to build and protect the global brand-name SPAR, which has three international formats; InterSpar, Spar and Spar City Store.

The SPAR organization in the Netherlands is SPAR Holding B.V. (from now on called SPAR). SPAR is a franchisor that facilitates franchisee of grocery stores. The organization SPAR Holding B.V. is owned by three different parties: Sperwer Holding (45%), Sligro Food Group (45%), and the last 10% is owned by the franchisers (see Figure 1.1). Around 120 people work at the head-office of SPAR and around 300 people work at the two distributions centres of SPAR. The format SPAR was founded in the Netherlands by Adriaan van Well in 1932. At that time it was a cooperative of sixteen outlets with the slogan: "Door Eendrachtig Samenwerken Profiteren Allen Regelmatig" (DESPAR).

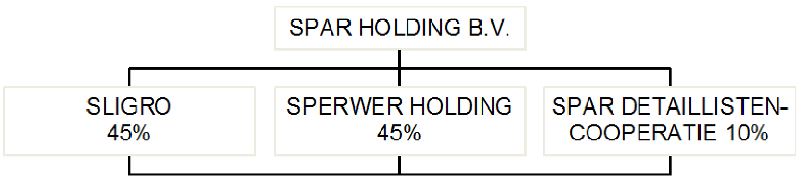

Figure 1.1: Shareholders of SPAR Holding B.V..

SPAR is responsible for the distribution and buying of products, but also provides category management, marketing, education and acquisition for the Attent- and SPAR-format. The SPAR organization in total delivers to more than 450 stores spread over the Netherlands and an additional few hundred neutral stores. These neutral stores make only use of logistics services (buying and distribution). SPAR participates in the purchasing organization Superunie. This organization represents thirteen independent retailing companies in the Netherlands, with a combined market share of more than 30%.

Strategy

In 2011, SPAR held two formats in the Netherlands, namely SPAR and Attent. SPAR stores are typically found in neighbourhoods with 2,500 up to 5,000 habitants. The newest type of stores are SPAR City stores, they are positioned in inner-city shopping locations. Attent stores are typical found in areas with between 1,000 and 2,000 habitants or at recreation-areas like, campsites and bungalow parks. The Attent and SPAR stores have an average selling floor area between 150 and 600 square meters, depending on the concept. All stores are privately owned by preferably local entrepreneurs; therefore all stores are independent although they have to follow the guidelines of the format chosen.

SPAR positions itself as a local store for fresh products and everyday convenience. The vision of SPAR is to provide a pleasant and lively environment, with local high-service stores. SPAR wants to be locally involved in the community and fulfils a social function in small neighbourhoods. Considering the retail mix; customer service, merchandise assortment, location, communication mix, pricing, store design and display (see Figure 1.2). SPAR wants to be a high-service retail company, with the keywords friendly and nearby. The assortment of SPAR is broad (large number of categories), but not deep (few items in each category). A SPAR store has primarily local-, fresh-, and daily products in the assortment. The location of a SPAR store is typically in small neighbourhoods. Therefore the format communication is also locally focussed. SPAR tries to promote itself in the local news and advertises locally. The format wants to have the best price/quality rate, with primarily high quality products for realistic prices. The overall mission-statement of SPAR is therefore: "Being the best store for the neighbourhood".

Figure 1.2: Retail strategy SPAR.

Market

In 2010, SPAR Holding B.V. had a wholesale turnover of about 500 million euro, meaning that SPAR is one of the smallest retail companies in the Netherlands. When looking at the number of stores, SPAR is one of the largest retailers in the Netherlands with over 600 stores. The number of neutral locations in 2010 was still high, but in the future the number of neutral locations will be reduced and more neutral locations will become Attent or SPAR stores. This is because SPAR wants to change from a partly wholesaler to a full retailer.

In the past years, great changes have been seen in the grocery market. Many companies have merged or have been taken over, leading to bigger retail companies with primarily large supermarkets. SPAR is profiting from this fact, because its focuses on the niche markets for their local and small stores. Compared with other Dutch supermarkets, SPAR wants to be a full service supermarket. In this segment of the market, Plus, Coop, and some local formats are the main competitors of SPAR. Taking the retail strategy of SPAR into account, then there are no real nationwide competitors of SPAR. This is because SPAR focusses on small neighbourhoods and communities. While no other national supermarket format has this focus.

Consumers about SPAR

For a supermarket organization it is important to know what your customers think about you. Gfk Panel Services and Foodmagazine conducts each summer and Christmas a research on the consumers' perception about the different supermarket formats in the Netherlands. Gfk and Foodmagazine monitor the consumers' responses on a lot of different aspects, like: neatness of stores, quality of products, pricing, friendliness of personnel, out-of-stock rate, and freshness of the assortment. This research showed that SPAR stores have a high customer service level, by being the friendliest of all supermarket formats (Gfk, 2011).

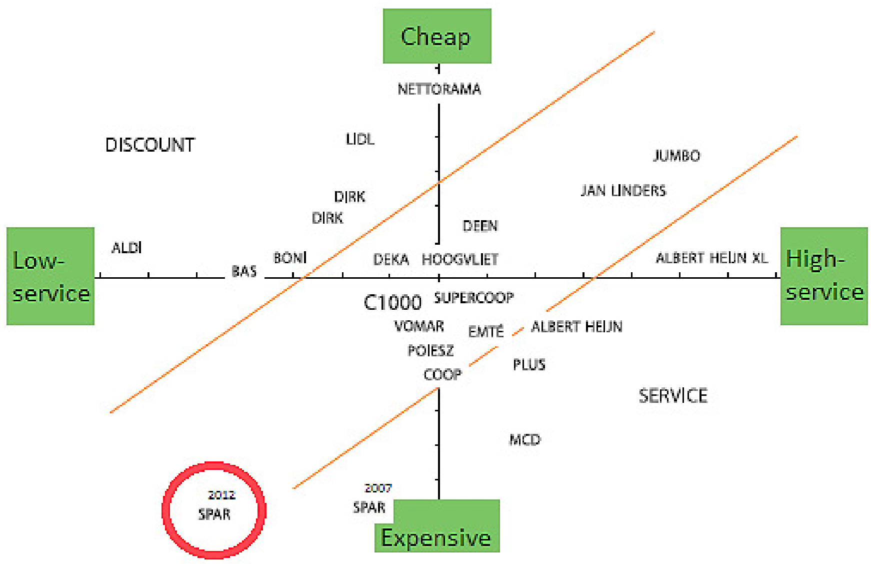

Figure 1.3: Positioning matrix Dutch supermarkets 2012 ('Kerstrapport 2011', Gfk.).

Also the SPAR stores are neat and waiting times at the checkouts are minimal. Looking at the overall scores of the formats, SPAR was second last of all formats in 2011. Only the format 'Super de Boer' was worse, but this format disappears in 2012. Consumers see SPAR as a very expensive supermarket, with no real price deals. SPAR stores primarily perform worse on out-of-stock ratios of products, fresh assortment, and quality. Despite the fact that SPAR is a neighbourhood store ('buurtsuper') and therefore hard to compare to the bigger supermarkets, the grocery consumers were not very satisfied with the format SPAR in 2011.

1.2 Initial problem analysis

As discussed in the paragraph ‘consumers about SPAR’, the format SPAR was not judged as well as compared to other supermarket formats. The consumers of SPAR were especially not happy with the fresh products, despite that these products were one of the key strategy points of the SPAR format. Due to high fixed cost in the retail industry, a high sales volume is crucial in order to survive. A bad consumer perception can lead to lower sales, therefore it is important to have a good format perception. Based on the Gfk (2011) reports, a previous project at SPAR (Lammé, 2010) and discussions with the SPAR supervisor and TU/e mentor, a global causes and effect diagram was made for the bad perception (see Figure 1.4).

The Gfk report (2011) mentioned four main causes why consumers had a bad perception of the SPAR format. These four causes were: Price, quality, assortment, and out-of-stock. First, quality issues can be caused by less fresher products in the stores. When supply chain speed is too low, consumers can face less fresh products. Also, the on-shelf quality of the perishable products can be poor, due to bad store management of fresh products, by for example not adequately checking the shelves for outdated products. Second, a high experienced price can be the result of bad promotions or the fact that SPAR consumers do not experience real price-deals. Both bad quality and price perception were a real problem for SPAR, because having a good price/quality ratio was one of the retail strategies of the SPAR format. Third, a small assortment is part of the retail strategy, therefore not an essential problem. Last, being out-of-stock is always an essential problem for a retailer, because an out-of-stock situation leads directly to a lower store performance. In the short run this leads to lost sales, in the long run the format can be damaged and potential consumers can be lost. An out-of-stock situation can be caused by problems in stock point control (including the supply chain behind the stock point), demand forecasting, and/or order decisions.

Good matching of supply and demand reduces the out-of-stock rate of a stock point. A good demand forecast is therefore crucial, because supply needs to be planned at least costs. With a long order forecast horizon it becomes more difficult to accurately predict the demand, especially in combination with demand characteristics such as a high demand variation and/or non-stationary demand. A long order forecast horizon is caused by the fresh production of perishables at the perishable product supplier, from which the store orders are delivered via cross-docking at the SPAR distribution centres.

Supplying the right products, at the right place and on the right time is also crucial. The replenishment process and stock point control policies are therefore important. A good execution of the replenishment processes leads to high delivery performances and low uncertainty. The right control policy of the stock point can ensure that inventory is available when needed.

Lastly, the ordering process of store owners is important. Store management is responsible for ordering on time and in the right quantity. The order quantity of fresh products is determined by balancing the costs of outdating and the cost of a lost sale. Determining the right value of each parameter can be a tricky and difficult task. Next to that many store owners can act irrational, by for example being outdating averse, thereby the order quantity is on the safe-side for outdating.

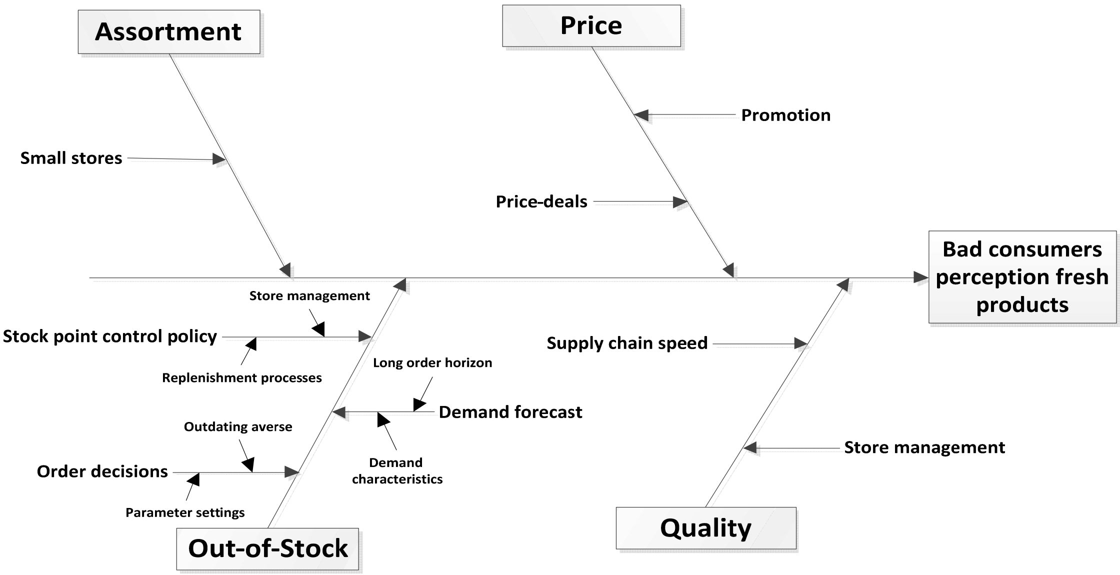

Figure 1.4: Cause and effect diagram (fish-structure).

The focus of this project will be on the out-of-stock cause, and initially on the control policy and ordering decisions of SPAR stores. The focus will not be on quality and pricing, because this is not an expertise of the student and the other parties involved in the project. Supervisors of SPAR pointed out that the current processes are executed as desired. Therefore, it is necessary to redesign the current processes to solve the problems. From this initial problem statement the initial research question is stated;

"Can a redesign of the current replenishment and/or ordering processes reduce the out-of-stock rate at the SPAR stores, while maintaining high quality products and minimizing total relevant cost?"

1.3 Report outline

The report started with an introduction chapter on the company involved and the initial problem statement. The second chapter will deepen the perishable supply chain of SPAR, thereby looking at the assortment, supply chain network, replenishment process, ordering process, and financial flow considering highly perishable products. The third chapter will deepen on the research assignment, thereby looking at literature on possible solution directions, the research methodology and data collection methods. After the deepening into literature and the problem context, chapter four will provide a thorough analysis on the current problem and validating the initial problem statement. In chapter 5 then the proposed solution direction, an order adjustment strategy, is discussed and tailored for SPAR. Chapters 6 and 7 describe the input and results of the simulation experiment conducted for this solution direction. Ending with chapters eight and nine, where the implementation for SPAR and conclusions of the research project are described and discussed.

2. The perishable supply chain of SPAR

This second chapter will provide more insights in the current problem context. In this chapter, the perishable assortment, supply chain network, replenishment process, in-store order process, and financial flow of perishable products are discussed. With the insights in the problem context, a possible research direction can be more thoroughly chosen.

2.1 Perishable assortment

A perishable product at SPAR is a food product with a certain lifetime (known or uncertain), this means that the product can become unacceptable for consumption or obsolete. Perishable products can be divided into two subcategories (Donselaar et al., 2006): Daily-fresh and weekly-fresh. Daily-fresh products are perishable products with a life-time less than 10 days after production. Weekly fresh products have a life-time of less than 30 days. This research project focuses on daily-fresh products with a fixed life-time. In the case of fixed life-time product, the manufacturer or supplier determines the expiring date, by setting a sell-by-date or best-before-date on the perishable products.

The total assortment of SPAR is around 7500 products. From these 7500 products there were around 977 daily-fresh products. Around 65% of these daily-fresh products belongs to the so-called ‘A’ segment. This assortment-category is present in all SPAR stores. This indicates that daily-fresh products are important strategic products for the SPAR format and high in-store availability is required.

2.2 Perishable supply chain network

Since the new distribution centre of SPAR in Waalwijk is in operation, all products that enter the SPAR stores flow through the distribution centres of SPAR (South DC and North DC). Due to consolidation of goods flow and control, there are no longer direct shipments to the stores. SPAR has two distribution centres to supply all stores in the Netherlands. The south DC is located in Waalwijk and the north DC is in Alkmaar. Each SPAR store has its own dedicated distribution centre, from which it receives all deliveries. The distribution centres function separately from each other, except for non-perishable slow-moving items. These products are only stored and order-picked at the south DC. When considering only the perishable items, both distribution centres had the following functions: storing, picking, cross-docking, and distributing of products.

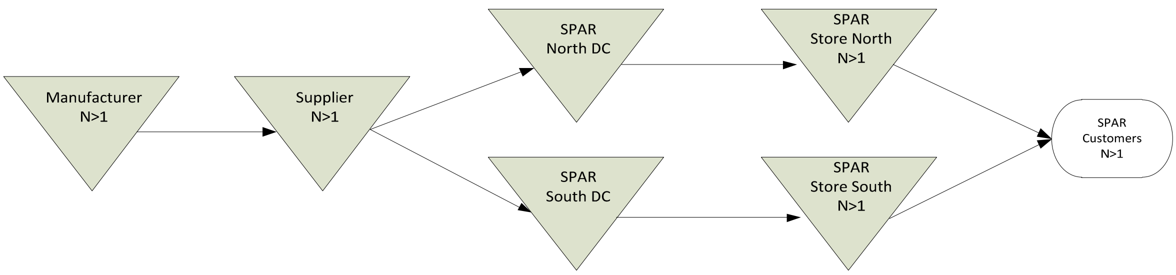

Figure 2.1: Perishable supply chain of SPAR.

From the perspective of SPAR, the supply chain starts with many manufactures who deliver their (raw) goods to the suppliers of SPAR (see Figure 2.2). The suppliers of SPAR fabricate the products in order to be able to sell at grocery stores. The operations of the supplier are for example: Order-collecting, packaging, cleaning, and cutting of (raw) perishable products. Then, the finished perishable products are sent towards both distribution centres. At a distribution centre the products are stored and order picked, or directly cross-docked towards the stores when ordered. Each store has its own dedicated distribution centre where it can place orders. Hereby, stores are labelled as Store-North, which receive products from the North-DC, and labelled Store-South, which receive products from the South-DC.

2.3 Replenishment daily-fresh products

The ordering and delivering processes of daily-fresh perishable products are discussed in this paragraph. Daily-fresh products are cross-docked at the distribution centres of SPAR, meaning that the store-ordered daily-fresh products arrive at the distribution centre on store-specific roll-containers. At the distribution centre the roll-containers are then allocated to doors, to be shipped towards the stores.

Order and delivery schedule

The delivery schedules are adapted to the demand week pattern in stores. Higher demands are on Fridays and Saturdays, therefore there are more deliveries at the end of the week. This results into two possible delivery schedules (see Table 2.1) for stores. SPAR stores are equally divided over these two schedules. Thereby it was noticed that more than half of the stores did not use the fourth delivery moment at the end of the week. The primary reason for this is that store owners do not have a clear picture of their inventory position at the moment of ordering. This was the result of the fact that the ordering process was partly overlapped by the replenishment process of the shelves.

Table 2.1: Different delivery schedules SPAR stores, between brackets the moments that are not always used by store owners.

Weekday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Schedule 1	X		X	(X)	X	
Schedule 2		X		X	(X)	X

Replenishment process

Next to the delivery schedules, there are also two different delivery moments on a day. Approximately 60% of the stores are so-called 'morning stores', these stores get delivered between 8:00 and 11:00. The other 40% of the stores are so-called 'afternoon stores', these stores get delivered between 12:00 and 17:00. The morning stores have to order their products before 13:30 the previous day and the afternoon stores have to order before 17:00. The order-information of the stores is received at the distribution centre and directly forwarded to the suppliers of daily-fresh products. Within a certain lead-time, the supplier prepares the store-specific orders and sends the orders on store-specific roll-containers to the distribution centres of SPAR. At the distribution centre the orders are cross-docked and made ready for shipment to the stores. The complete timeline and activities for the morning and afternoon stores are summarized in Figure 2.2.

When taking the two delivery schedules and the two types of stores into account, the number of stores that are delivered in each replenishment cycle is different. For Monday, Tuesday, Wednesday, and Saturday the number of stores per replenishment cycle is approximately 120 (morning-stores) and 80 (afternoon-stores). For Thursday and Friday this amount is around 240 (morning-stores) and 160 (afternoon-stores).

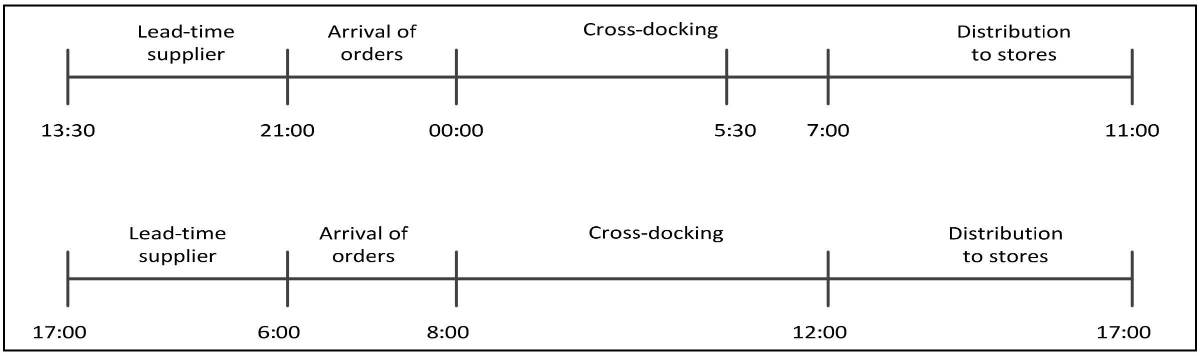

Figure 2.2: Time table cross-docking process at distribution centre (above Morning stores, beneath Afternoon stores).

Lead-time perishable products

An average SPAR store has openings hours from 8:00 until 19:00 hours. Also the stores have time windows for arriving orders, so stores assume that they have their ordered products at the end of the 'distribution to stores' process (see Figure 2.2). Therefore the total lead-time for a store is approximately one day. The review period is maximal two days and minimal one day, depending on the day of the week (see Table 2.1). This results in an order horizon of maximal three days and minimal two days.

Performance

The delivery performance of the cross-docking replenishment process was around 98.5%. The delivery performance was measured by the comparison of actual delivery quantities and ordered order quantities of the store owners. Meaning that in only 1.5% of the cases the ordered order had a deviation from the actual delivery. Concluding that the current replenishment process was executed as desired.

2.4 Ordering process of stores

The actual ordering process depends on the person involved, therefore store owners base their order quantity on different methods. Some store owners work systematic, by for example using historical sales data and current inventory statuses. Other store owners make more qualitative ordering decisions, by for example ordering what they have ordered previously and adjusting this amount only slightly, based on their observations on spoilages and out-of-stock situations. In general, order quantities are based on gut feelings and the experience of the store owner.

		wk	maandag				dinsdag				woensdag				donderdag				vrijdag				zaterdag			
	panklaar	nr	BV	B	D	V	BV	B	D	V	BV	B	D	V	BV	B	D	V	BV	B	D	V	BV	B	D	V
art.nr	***baby leaf 100 gram***	39																								
		40																								
726001		41																								
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art.nr	***slamelange 200 gr***	39																								
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72605		41																								
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Figure 2.3: Order-book method advised for highly perishable products.

SPAR and the store advisors advise store owners to make use of an order-book method for ordering highly perishable products. In the order book the following is registrated; the current inventory level (at the beginning of the forecast horizon) called 'BV', the outdating of the previous period 'D', the sales of the previous period ‘V’, and the order quantity ‘B’. Based on the previous outdating and sales, an estimation of the upcoming sales was made. Combined with the starting inventory, an order decision is made by the store owner. An example of the order-book for two products is depicted in Figure 2.3 and a detailed explanation of the method is given in Appendix H. The used order-book method did not incorporate the age distribution of the on-hand inventory. Therefore the order decisions for daily fresh products are only based on the inventory position and not on the inventory status. The store advisors estimated that more than 90% of the stores use this method to order perishable products. The performance of the current order method is further discussed in the fourth chapter. There the current inventory performance was measured for the store owners that used this order-book method.

3. Research assignment

After exploring the problem context, the third chapter will first provide some academic insights on different aspects related to the problem statement and context. Followed by the research direction and research methodology of the solution direction for the business problem. This chapter ends with a short discussion on the different data collection methods that were used for the analyses and the simulation experiment design.

3.1 Literature review

Perishable product availability

Out-of-stock (OOS) situations are the leading annoyances of Dutch supermarket customers in 2010 (CBL, 2010). Increasing product availability (service level) is one way of improving the satisfaction of Dutch supermarket customers. In the Netherlands the OOS rate was estimated around 7%, varying between 5-10%, depending on the product category (Sloot, 2006). In order to measure the effects of OOS situations it is important to understand the customer behaviour when such an event occurs. Corsten & Gruen (2003) investigated the reactions of customers and showed that buying the item at another store was the most common reaction (31%), followed by buying a substitute of a different brand (16%) (see Figure 3.1). These responses result in direct and/or indirect losses to both the retailer and supply chain (manufacturers). However the responses varied considerably by category, type of product, type of consumer and the immediacy of need. Highly perishable products, like bread, were more frequently substituted by another product (Van Woensel et al., 2007).

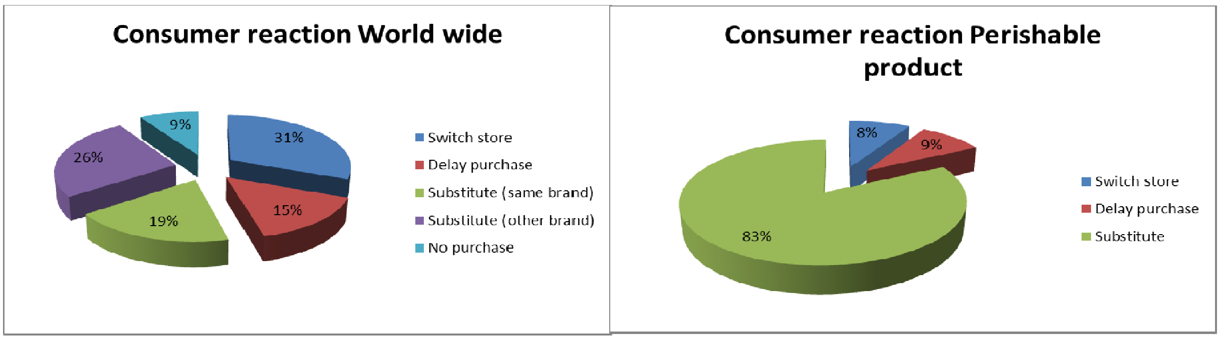

Figure 3.1: Overview of customer responses on OOS.

The customers of SPAR had a slightly different reaction to an out-of-stock situation. Lammé (2010) showed, in a sample of 984 customers, that 8.3 % of the customers faced an out-of-stock situation. In a situation of out-of-stock, 50 % of the SPAR consumers indicated to buy the non-available product at a different store. This percentage is higher than in the research of Gruen et al. (2002), a reason for that could be the fact that 76 % of the customers also indicated that they visit another store for their weekly and daily shopping trips (Lammé, 2010). Another 35 % of the SPAR customers delay their purchase when they faced an out-of-stock situation. This is probably due to the high shopping frequency of the SPAR customers. Substitution rates were very low, but this can be the results of the small assortment of the SPAR format.

Inventory control policies for perishables

Cost-effective control of inventories can cut costs significantly, and at the same time contribute to the efficient flow of goods and services (Nahmias, 2011). An effective control of inventories can also boost the service levels of stock points. Inventory theory tries to answer a specific question, namely: When should an order be placed, and how much should be ordered? Optimal ordering policies are for perishable products age-dependent, instead of stock-level dependent. This extra information makes the models more complex and harder to analyse.

When looking for inventory control models/policies, you have to take the following aspects into account. First, a lost sales environment, meaning that when on-shelf inventory is zero, demand will be lost. This fact is also confirmed by Lammé (2010) and very common in the FMCG industry. Therefore the perishable inventory models that consider backordered demand are not relevant. Second, inventory in stores and on shelves were not continuously monitored. Therefore continuous inventory models cannot be applied. Last, the inventory control policies have to consider the perishability of the products. This product characteristic implies that inventory can be depleted due to a demand and an obsolete product. Specifically, a product becomes obsolete after a fixed predetermined lifetime, resulting in a maximum available shelf-lifetime. A good inventory control policy for perishables takes these different aspects into account.

Newsvendor models

With periodic review, the state of the system (on hand inventory) is known only at discrete points in time. Demand in successive discrete points in time is not known, but is often assumed to be a random variable with known probability distribution. When taking only one period into consideration, the traditional newsboy inventory model can be adjusted for perishability. The penalty costs thereby included a penalty for future outdating. In order to determine the optimal order quantity each period, the expected number of future outdated products has to be determined. This is the number of products left at the end of lifetime of the order. For one period this model is relatively simple and easy to use for finding optimal order quantities. For multiple periods a transfer function needs to be formulated and the withdrawal behaviour needs to be specified, which makes the problem more dynamic and complex (Nahmias, 2011).

An easier alternative is sequential newsvendor for a multiple single-period horizon. The optimal order quantity in a newsvendor model is traditionally determined by a known theoretical demand distribution (see Silver et al., 1998). With this method the demand is assumed to be stationary. However this is very uncommon with perishable products in the FMCG industry. Bertsimas and Thiele (2005) developed a data-driven approach to this problem, they made a model that only considers the previous observed demand. With a one-side trimming factor for observed demand, and a mark-up factor and a discount factor, the order quantity can be determined before each order horizon.

In 2011, Beutel and Minner extended this model with external predictive factors. With their approach they are trying to explain larger portions of demand variability, because the forecast does not only depend on the historical demand observations. Therefore, the safety stock level can be reduced even further with explanatory variables, like price and weather. In this way the demand distribution does not need to be determined upfront, but the inventory level is determined by an integrated approach. The inventory level is a linear function of the explanatory variables. The weights of each variable can be determined by linear programming or with the ordinary least square method (Beutel and Minner, 2011).

Perishable ordering policies

The complexity of the optimal ordering solution depends on the maximal age levels (*m*) of a perishable product. With more than 2 different shelf lives the optimal solution becomes very complex, therefore a good approximate policy can be of great interest. Zyl (1964) for m=2 and Cohen (1976) for m>2, considered an optimal critical number policy. Zyl (1964) showed that there is a stationary distribution of the system state, but this policy is known to be suboptimal. Cohen (1976) was not able to find a stationary distribution of the system state. Also the practical computability is low for large values of *m*. Therefore Nahmias (1976) developed a different method that is independent of *m*. This method tries to find approximations for the expected outdating and the one-period transfer function, for a one-period model.

Most single stage perishable inventory models assumed that the issuing of inventory is FIFO. Broekmeulen and Donselaar (2009) have recognized that this is not always the case in real-life. Especially perishable products in supermarkets are rather issued LIFO or at random. Broekmeulen and Donselaar (2009) developed a heuristic based on a (R,s,nQ)-policy, called the Estimated-Withdrawal-and-Ageing (EWA) policy. In the EWA-policy the inventory position in each period is first adjusted for the expected outdating of the inventory on-hand during the review period and order lead-time. In this way the control policy takes into account that inventory is also depleted by outdated products. The expected outdating depends on the way the inventory on-hand is issued (FIFO, LIFO, or random). Further their model is based on practical issues, like batch-sizing, positive lead-times, and time-varying demand. For a single stage model, this heuristic is one of the first that takes the practical setting as a starting point in modelling inventory systems.

Minner and Transchel (2011) acknowledge the fact that models with stock-out penalty costs are hard to implement in practise. Therefore, they designed a periodic-review inventory-control for perishable products under service-level constraints model. The model provides a dynamic method for determining replenishment quantities, which depends on the current age of the stock and the outstanding orders. The model assumes non-zero lead-times, lost sales, and is capable of satisfying multiple service-level constraints during the day with non-stationary demand (Minner and Transchel, 2011). The model outperforms the base-stock policy and constant order policy in many cases on waste and average inventory level. Another advantage is that this method provides a lower order quantity size variance than the base-stock policy, which makes other supply chain operations easier to plan. However, this model does not include situations where the review period is longer than the lead-time.

Improving availability and freshness of perishable products

For perishable products a common method for increasing supply-chain speed is cross-docking. At the distribution centre of the retailer, the incoming goods are not stored, but directly shipped forward to the local stores. Thereby the incoming products need to be already on store-specific roll-containers. The available shelf-life-time of a perishable product on the shelf is so maximized, because the total time of a product in the upstream supply chain is minimal. However, the order lead-time is longer, because a store's order is placed at the manufacturer where the perishable product is produced-to-order. The lead-time is thereby longer, because the perishable product supplier has to prepare and ship the store's orders to the distribution centres. In a stochastic setting, a longer lead-time means that safety stock levels need to be set higher in order to achieve certain end-customer service levels. But higher safety stocks lead also to higher outdating rates of perishable products. A way to reduce the order lead-time could be direct-shipments to the stores, but this is too costly, because of high transportation cost and low utilization of trucks at SPAR. Therefore also emergency shipments between the delivery moments, as researched by Lammé (2010) and Lardinois (2010), are not beneficial for SPAR. Next to this, the retail stores face operational difficulties, when their backdoor is visited too often by different suppliers.

In order to manage daily-fresh inventory, it is essential to maximize available shelf-life-time and reduce the forecasting horizon. Reducing lead-time and/or review period is one of the options that Donselaar et al. in 2006 identified in order to reduce waste, while maintaining the right service levels. In this way, supply and demand of the right product is met on time at the right place. Moreover total supply chain costs are reduced (outdating and holding costs) and service is increased (less out-of-stock situations and fresher products).

A possible solution in order to reduce the safety stock and keep customer service levels high, is to update the order quantities of the stores at a later moment, for example during the cross-dock operations at the final distribution centre. This is the last moment in the chain before the products are allocated and send towards the stores. With this update the safety stock can be reduced, because the uncertainty of the forecast horizon is reduced. The order adjustment can be based on an information update of the inventory position of the products in the stores, between the moment of ordering and final shipment towards the stores. This idea is further explained and tailored for SPAR in the next section.

3.2 Research direction

The perishable supply chain of SPAR results into an order forecast horizon of three days at the beginning of the week, and two days at the end of the week (forecast horizon is lead-time plus review period). During the lead-time of an order (approximately one day), the order quantity cannot be changed. A lead-time reduction is not possible, due to make-to-order operations of fresh products. A hybrid structure, where the orders quantity can be changed slightly during the lead-time, can result into a better supply and demand fit. This idea can be beneficial in circumstances where the forecast of the order horizon is difficult and demand can suddenly change. The value of the opportunity to change the order can be very high is these cases, because safety stock levels can be lowered, while maintaining high service levels.

The idea at SPAR is to use the in-store inventory status information at the moment of cross-docking for determining the final replenishment quantity. The final replenishment quantity will be an order adjustment upwards, by having sufficient goods with a shorter lead-time available at the cross-docking facility. The in-store inventory status information can come from the cash-registration system of the store, which could be monitored by SPAR. The change in inventory status, between ordering and cross-docking, could be sufficient in order to take profitable order adjustment actions.

The refined main research question is:

“Is an order adjustment upwards and thereby implementing additional cross-dock operations, in order to reduce the out-of-stock rate at the stores beneficial for SPAR and the franchisee, when considering the total relevant cost of outdating and additional operations?”

In order to correctly answer the main research question, sub- and additional questions have to be answered:

1. ***What are the demand characteristics of the highly perishable products?***
2. ***How do the current store practises perform in ordering perishable products?***
3. ***How will SPAR arrange the order adjustment process and how will the order adjustment quantity be determined?***
4. ***What are important performance indicators for deciding to implement the adjustment strategy?***

Low product availability can be the result of the demand forecast, the stock point control policies used, and the settings of the stock point control parameters. The first two questions answer whether the demand for perishables can be easily forecasted, and whether the current ordering practises can be improved in order to solve the business problem sufficiently. These questions need to be answered, before different and additional control policies and supply chain designs are suggested to solve the business problem.

When applying the idea of order adjustment, you must determine when and how much products need to be ordered extra. There are different perishable inventory policies that can be used, the right rules and settings need to be specified for applying the idea at SPAR. Also important key performance indicators need to be investigated, in order to judge the feasibility of the idea.

3.3 Research methodology

This report describes a model-based quantitative research. In order to perform good academic research some phases need to be taken into consideration (Bertrand and Fransoo, 2002). Based on Mitroff et al. (1974) research model, four phases can be determined:

1. Conceptualization
2. Modelling
3. Model solving
4. Implementation

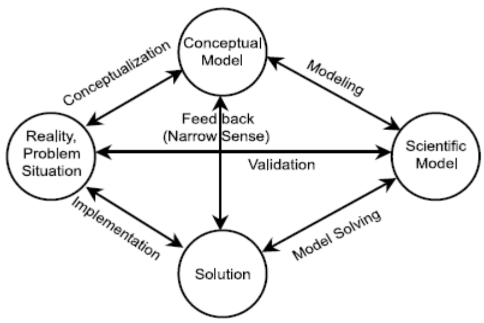

Figure 3.2: Research model by Mitroff et al. (1974).

This research model of Mitroff et al. (1974) will be used in order to correctly answer the research questions as stated in the previous paragraph. Thereby, making sure that all aspects for doing proper model-based quantitative research are performed and reported. The conceptualization phase is performed by studying the perishable supply chain (Chapter 2) and by analysing the aspects of the problem (Chapter 4). The first feedback on the proposed solution direction is determined in chapter 3, with a literature review, and in chapter 4, with a thorough analysis of the current situation. The modelling phase starts in chapter 5, where the scientific model is presented and adjustment strategy is discussed for SPAR. The model solving steps are discussed in chapter 6. Finally the feedback on the proposed solution is presented in chapter 7, where the simulation results are presented.

3.4 Data collection methods

For the analysis of demand and current inventory performances, data was collected at various sources. In order to make the scope of the data manageable, first a product and store selection was performed (case selection). This is described in the first part, in the second part the various data sources are explained. The data will also be used for the simulation study design.

Product selection

The management of SPAR pointed out that ready to cook vegetables are strategic products with high out-of-stock rates. The data availability and accuracy of these products were good at the moment this research was performed. Also these products were cross-docked at the distribution centres of SPAR during this research period. To keep the range of products manageable it was decided to only include products of the A-segment (assortment) and the products from one supplier. A-segment products are labelled as traffic drivers for the stores, therefore strategic important products for SPAR. A specific list of the selected products can be found in Appendix A.

Store selection

To keep the analysis manageable, not all SPAR stores are considered in this project. The management of SPAR selected eight representative SPAR stores. These stores form an accurate image of SPAR stores in general. Because the availability problem of strategic products is a common problem at SPAR stores, there was no need to specify store selection criteria. The average retail floor space (RFS) of SPAR stores in the Netherlands is around 400 square meters. The smallest store has a sales area of approximately 150 m2 and the biggest store is around 650 m2. An overview of the selected store characteristics is shown in Appendix A.

Point-of-Sales and Store-order data

Next, daily sales data from the cash-registration system were collected (Point-of-Sales data). For the store ordering performance, this was done for a period of nearly 5 months, namely 1-8-2011 until 17-12-2011. This period was maximal available at the supplier of SPAR, therefore this period was used to investigate the ordering performance. Because the products are perishable, a short period was sufficient to perform an allocation analysis. For the customer demand characteristics analysis, also point-of-sales data was used, but with a longer period namely from 1-1-2011 until 17-12-2011. For the determination of a week pattern all days were considered, but for the demand characteristics only Friday sales were considered. Data from only Fridays was considered, because this was the most reliable day in whether there were sales or not and if the sales were correctly registrated by the cash registration system. For the investigation of other inventory control policies the same daily demand data were used, but also weekly demand data of the period 2010 and 2011. Next to this, all demand data used was corrected for outliers by Winsorising at a percentile of 95% (Hasings et al., 1947). The technique Winsorising replace the outliers by its boundary values, this technique preserves the already limited amount of data points in the analyses. The percentile of 95% means that from all data 5% of the lower and higher extremes are seen as outliers.

4. Analysis

An analysis of the current situation is described in this chapter. Product characteristics and the issuing of inventory in the stores are discussed first. Demand was analysed in order to determine the predictability of the sales in the order horizon. With the sales and order data, the current inventory performance was analysed. These first analyses will provide an answer to the first research questions. After that some perishable inventory policies were tested, for the demand of SPAR, in order to see which policy can be used best in the new replenishment strategy.

This chapter starts with a discussion on the product characteristics, the issuing of on-hand inventory, and the demand characteristics of the selected products of SPAR. After that the 'current' inventory performances are discussed, by analysing the sales and order data. Lastly, other perishable control policies are discussed for the demand data. Ending with a conclusion, whether the proposed research assignment can be a proper solution for the business problem and how the new replenishment strategy can/must be designed.

4.1 Product

For analysing the demand and current inventory performance, and the design of the new replenishment strategy, it is important to know some key product characteristics. One important characteristic is the shelf-life of a product at the moment of replenishment. SPAR agreed with their perishable product supplier that the minimum lifetime of the products was 5, 6 or 7 days, at arrival at the distribution centres of SPAR (see Appendix A). The average agreed lifetime of the selected products was 6.4 days, a few products with a shelf-life of 5 days and the rest (and common) was 6 or 7 days. The maximum available shelf-lifetime was lower, due to the lead-times between distribution centre and stores, and replenishment moment of the shelves. This resulted in a maximum available shelf-lifetime of 4, 5, or 6 days for the selected perishable products. However it was noticed in stores and reported by store owners that the available shelf-lifetime was mostly higher, due to the delivery of fresher products. The maximal available shelf-lifetime that the supplier can deliver was 8 days, because this is the lifetime at the moment of production minus the minimal supply chain delay.

Another important characteristic is the case-pack size of the products, which was for the selected perishable products one customer unit. Next to that there are no total order-size restrictions. However, it is known that the supplier produces partly based on forecasts and will not be able to proper react on large order quantity deviations from SPAR (Jong, 2011).

4.2 Issuing on-hand perishable inventory

When the shelves are replenished by the store owners, the products were presented in order from least fresh to most fresh. This is necessary, because the replenishment frequency was higher than the shelf-life of products. This means that a shelf can have different product batches. Because orders were fresh produced and arrive in ordered sequence, this results into a FIFO presentation of the products on the shelves.

Whether inventory on shelves is issued in FIFO manner depends on the grabbing behaviour of the customers. Grabbing behaviour is the picking of the freshest product available instead of the upfront presented product, thereby customers search the on-hand inventory for the longest shelf-life products. For SPAR, grabbing behaviour was very limited, due to the following combination of facts; low delivery frequency of stores (3/4 times per week), short maximum available shelf-life of products, and a low inventory level (on average 2.9 the daily demand). The combination of these factors ensures that the possibility of grabbing a fresher product was very minimal, due to the fact that the number of different batches (with better best-before-dates) on the shelves is very limited just before arrival of a new batch. Next to this, FIFO issuing was stimulated by giving price discounts on the products that almost perish (one day before the best-before-date).

Making a trace of the inventory level of all 144 product-store combinations, based on daily POS and order data between 1-8-2011 and 17-12-2011, revealed that inventory was indeed issued in a large extend in FIFO manner. Because making the on-hand inventory level trace with the assumption of LIFO depletion, resulted into sales at 20% of time when no inventory was on-hand. Therefore was concluded and further assumed that perishable inventory is depleted in FIFO manner in the stores of SPAR.

4.3 Demand characteristics

From the Point-of-Sales (POS) data the demand characteristics of the selected products were determined. Notice that this source of data does not always represent the full demand in stores. Demand that not is satisfied will stay unobserved by the cash-registration system (source of POS). When the customer service levels are sufficiently high enough this effect on the POS data will be limited. It was assumed that the POS was not truncated too much by lost sales for the demand analysis.

For the analysis POS data of one year was used. The POS data was first filtered for promotion data, extremely slow-movers (less than an average demand of one per day), and seasonal/trend products. Seasonal and trend products were indicated by applying a visual inspection and in dialogue with the Category Manager. Hereby, all the known variation was removed from the dataset. The demand characteristics per product were based on the averages of the selected stores (store Store_Sc was excluded, due to insufficient demand and products). After filtering the data, 144 store-product combinations were left for the customer demand analysis.

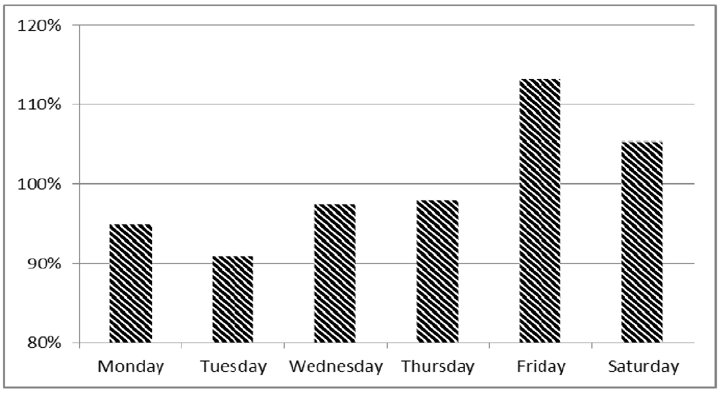

Figure 4.1: Week pattern demand perishable products.

Week pattern at SPAR stores

It is known that grocery stores face a week pattern in sales. The demand pattern over the week for SPAR stores can be seen in Figure 4.1. Sunday was excluded in this analysis, because only one SPAR store was open on this day for a very short period. The SPAR stores clearly had a week pattern for the selected perishable products. The week pattern showed that demand is low at the beginning of the week and somewhat higher at the end of the week. Fridays were peak days and Tuesdays were low demand days. The variation between stores and between products in the week pattern was very low (see Appendix B for more details), meaning that all the SPAR stores and products face to a large extend the same week pattern.

Demand characteristics

The demand characteristics were analysed with the time series of Friday sales. The time series of Friday sales was chosen, because this day was a peak day for SPAR stores and therefore an important selling moment in the week. Also the variation due to the week pattern was thereby excluded from this analysis. Friday demand was on average 2.3 products for the selected perishable store-product combinations. More than 77 % of the store-product combinations had an average demand of less or equal to three (see Figure 4.2). Thereby concluding that most perishable products could be categorized as slow-movers.

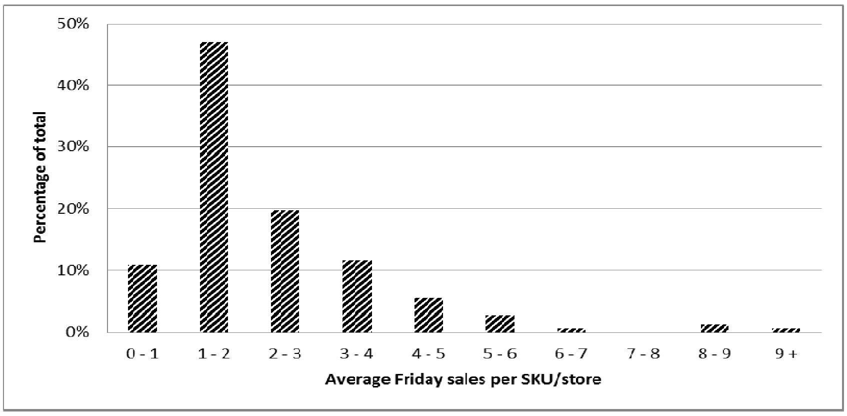

Figure 4.2: Average sales on Friday in SPAR stores.

For effective decision making in inventory management, one needs good predictions of future demand (Silver et al., 1998). For determining the predictability of the demand, the variation of the demand series was analysed. Thereby, the coefficient of variation (CV) of the Friday demand was calculated. The average CV was 0.8, with a maximum of 1.0 and a minimum of 0.5 (see Figure 4.3). This implies that the variation of the demand series was high and the demand pattern can be categorized as erratic/lumpy (Syntetos et al., 2005). It must be noted that the CV can be misleading with low average demands. Therefore some additional variation measures were calculated. Next, the kurtosis and the skewness of the demand series were determined. The average kurtosis was zero and the average skewness was 0.6. This implied a moderate peak (comparable with a normal distribution) and a skewness to the right in the demand distribution. This shows a moderate level of variation in the demand series. Finally, a five-number summary boxplot was performed for each product (see Appendix B). The five-number summary gives the mean, the boundary of the 1ste and 3rd quartile, and the minimal and maximum value of a series of numbers. The five-number summary confirmed the moderate till high variation of demand, and showed that the customer demand had a wide range (see Figure 4.3). The first conclusion was therefore, that the predictability of perishable product demand was very difficult for store owners.

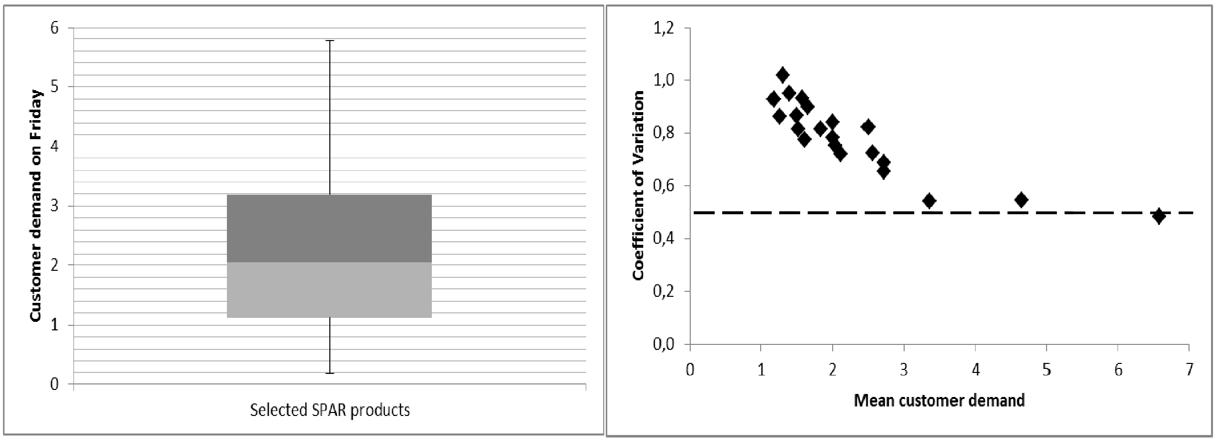

Figure 4.3: Boxplot of the average customer demand on Friday and Coefficient of variation analysis (dashed line is cut-off value for erratic demand (Syntetos et al., 2005)).

Concluding, the perishable products of SPAR had a volatile demand pattern and therefore are hard to predict by the store owners. The products have a very low daily demand, even with often no demand at all. The demand of the products also had a high coefficient of variation with a wide spread. Based on these findings, it was concluded that making a forecast was very difficult for store owners.

Fitting a discrete demand distribution

For further analyses and the simulation design, it was determined how demand can be best modelled. Adan et al. (1995) presented a method in order to fit a discrete distribution on the first two moments of a non-negative random variable. Four classes of distributions can be fitted, namely; Poisson, mixtures of binomial, mixtures of negative-binomial and mixtures of geometric distributions. Most of the product Friday demands can be fitted best with a Poisson distribution (see Appendix D). This is the result of a combination of low demand and a relatively high variation. When looking at the demand distribution of the review period plus lead-time, the Poisson distribution is even a better fit (see Appendix D).

The method of Adan et al. (1995) suggests that the demand can be best modelled with a Poisson distribution. A one-sample Kolmogorov-Smirnov test did not reject this for almost all store-product combinations, with a significance level of .05. The null hypothesis; Distribution is Poisson, could not be rejected for the store-product combinations, and therefore had to be retained. However, this test is not designed for testing discrete distributions, therefore additionally a Chi-square test was performed. The null hypothesis; Distribution is Poisson, was not reject in 90.5% of the cases (significance level of .05). Therefore concluding that the demand of a large part of the perishable products can be modelled with a Poisson distribution. For detailed results of both tests see Appendix D.

4.4 'Current' inventory performance

In the current situation store owners make order decisions for perishable products, with the use of some tools. With sales and order data from the same period some analyses were performed, in order to investigate the inventory performance on customer service and outdating.

For the comparison of POS data with the order data, the data-set for the period between 1-8-2011 and 17-12-2011 was filtered on season/trend products. This was necessary, because the end and begin inventory situation needs to be assumable equal. Also the data-set was filtered on store-product combinations with a very low demand, because with a high average demand the margin of error due to non-systematic effects will be reduced. Due to the same reason, fast-movers give a better indication of the outdating level that store owners tried to achieve in their ordering decisions. This filter resulted into the same 144 store-product combinations that were used in the demand analysis.

Outdating

The outdating of inventory was measured by making the number of outdated products relative to the number of ordered products. Therefore relative outdating was defined as the total number of outdated products divided by the total number of ordered products. Different methods were used in order to approximate the current relative outdating levels for the selected stores and products at SPAR.

First, in fixed time period the incoming flow of products plus the begin inventory must be equal to the outgoing flow of products plus the ending inventory. When assuming that begin- and end-inventory are equal, then the outgoing flow must be equal to the incoming flow. The common incoming flows of products are the ordered products and the common outgoing flows are the sales plus spoilage. Spoilage can be outdated products (systematic), but also faulty products or theft of products (non-systematic). When taking a longer horizon, the margin of error due to non-systematic factors reduces. For this analysis 20 weeks of data was used (from 1-8-2011 until 17-12-2011). With this first method, the average relative outdating of SPAR stores was 10.4 % for the selected perishable products and the average outdating was 1.1 products per week per product (see Appendix C).

The second method to approximate the relative outdating level was making a trace of the on-hand inventory level under the assumptions that the inventory is issued in FIFO manner by customers and that the shelf-lifetime is the minimal agreed lifetime of the supplier. The trace method revealed that some products were sold at moments when there was no inventory on-hand. Possible reasons for these events can be a wrong supply, or stores received fresher products than assumed. The results of these faulty product traces were excluded. The average relative outdating with this last method was 10.9 % (see Appendix C for more detailed information). This relative outdating is slightly different than the relative outdating of the first and second method. Reasons for this could be that the assumption in the first method is not completely valid, the inventory quantity and quality at the beginning and the end of the period could be different from each other. For example the actual begin inventory can be higher and fresher than the end inventory, this would lead to a lower measured relative outdating. The assumption in the second method can also be invalid, safety stock settings could have changed during the period. Lastly, the assumptions about completely FIFO and fixed shelf-lifetime could result into a slightly different measured relative outdating.

Combining the different methods resulted into an average relative outdating of 10.6% overall. In Table 4.1 the average outdating level per store can be seen, this shows that outdating was very different per store. The outdating rate was rather high compared to the findings of Lammé (2010). Therefore also the exact figures were collected one store. Because the actual outdate numbers are registrated manually by store owners and are very labour intensive to gather, the outdating levels are generated by estimation. For two stores the actual numbers where checked and compared to the estimated numbers (see Appendix C). This showed that our estimated numbers are somewhat on the high side. The registrated outdated products for the same periods resulted into an outdating level of 6.4% for Store_Ma (compared to 11.7% estimated). This difference can be explained by non-registrated sales, insufficient outdating registration and/or wrong supply of products. Both store owners acknowledge the fact that some sales are not registrated by the cash-registration systems, for example sales for neighbourhood parties and the home-delivery service. Also cashiers can make mistakes by not scanning each individual item, but using the multiply button for different products with the same price. Therefore our final conclusion about outdating is that the current level of actual outdating lies between 6.4% and 10.6%.

Table 4.1: Summary of the average inventory performances.

Store	Estimated outdating	Trace ready rate	
		Lowerbound	Upperbound
Store_An	8,8%	85,3%	96,9%
Store_Ha	6,8%	87,1%	98,1%
Store_Ma	11,7%	86,6%	96,9%
Store_Ze	14,4%	90,2%	98,5%
Store_Wa	8,3%	87,1%	94,7%
Store_Sp	10,8%	90,0%	97,9%
Store_Ho	13,7%	89,7%	97,1%
Average	10,6%	88,0%	97,2%

Customer service level

With the trace method, as discussed above, also the ready rates per store-product combination was calculated. The ready rate is the fraction of time during which the on-hand inventory is positive, in case of Poisson demand this is equivalent to the fill-rate (Silver et al., 1998). Order and POS data was on daily bases. Therefore the on-hand inventory can only be determined at the beginning and/or the end of the day. However stores got replenished during the day, therefore the ready rate just before replenishment cannot be exactly determined. The lower bound assumes that all demand is fulfilled before the replenishment and the upper bound assumes that all demand is fulfilled after the replenishment. Most of the selected stores are delivered in the morning (except for Store_Ma), therefore the real ready rate will be more towards the upper bound, when sales are equally spread over the day. Lammé (2010) showed by field-research that sales are indeed equally spread over the day, except on Saturdays. Therefore a good approximation for the ready rate was the average of the upper and lower bound, which is 92.6 %. This was also approximately what Lammé (2010) found for fresh-cut vegetables in his pilot study for several stores. The ready rate figures per store-product combination can be found in the Appendix C.

4.5 Inventory control policies

With the daily POS data (between 1-8-11 and 17-12-11) of 144 store-product combinations, perishable inventory control policies were tested to see if reliable and improved fill-rates and outdating figures can be generated for the demands of SPAR stores and products. This was done in order to determine which perishable inventory control policy can be best used for determining the intrinsic value of an adjustment strategy. Supply chain settings and demand series are used that hold for the time period between 1-8-2011 and 17-12-2011, for details on supply chain settings see Chapter two.

Three inventory policies were tested: Estimated Withdrawal and Ageing (Broekmeulen & Donselaar, 2009), Dynamic replenishment policy (Minner & Transchel, 2010), and Constant order (Beutel & Minner, 2011 and Bertsimas & Thiele, 2005). The first policy assumes a stationary demand process with constant safety stock levels, thereby adjusting the order for estimated outdating during the lead-time and review period. The second policy assumes a non-stationary demand process. This policy optimizes in the short run inventory decision, based on defined service targets for several intra-day points. The last policy is based on sequential newsvendor policies, where products perish at the end of the order horizon and demand can be non-stationary. For details on implementation of the used policies see Appendix E.

EWA-policy

Broekmeulen and Donselaar (2009) have developed an inventory control policy for short life perishable products, called the Estimated Withdrawal and Ageing (EWA) policy. The EWA-policy is based on a (R,s,nQ)-policy. The inventory position at period t (IP_t) just before ordering is first adjusted for the expected outdating ($\hat{O}$) of the inventory on-hand, during the review period and order lead-time (see Formula 4.3). The expected outdating depends on the way the on-hand inventory is issued (FIFO, LIFO, or random) and the age distribution of the on-hand inventory. In this case it was assumed that the withdrawal behaviour was FIFO (see paragraph 4.2 for motivation). Products can be ordered on Monday, Wednesday, Friday, and Saturday and have a lead-time of one day. Replenishment and order decisions take place at the end of the day. The order-quantity is determined as follows:

$$q_t = S_t - IP_t + \sum_{i=t+1}^{t+L+R-1} \hat{O}_i \quad (4.1)$$

The order-up-to level (S) was determined by setting the fill-rate at 98%, and using simple exponential smoothing to forecast the demand (*EWA path*) or use a fixed level after the warm-up period (*EWA level*). For more details about the EWA-model and implementation, I refer to the article of Broekmeulen and Donselaar (2009) and Appendix E.

The use of an EWA-policy can improve the current store owner ordering performances, by ordering more products when outdating will be expected. This correction leads to a higher fill-rate, while the level of outdating stays approximately equal. Figure 4.4 shows the results of the applied EWA-policy, on achieved fill-rate and relative outdating. The 144 store-product outcomes of the EWA-level method are mostly around the set 98% fill-rate, while the EWA-path method has no stable outcomes around the 98%. The fill-rate results of the path method lie only in 22% of the store-product outcomes in the interval 97-99%, for the level method this percentage is much higher (around 85%). The unstable performance of the path method can be due to a lot of noise in the demand pattern, than historical demand information is not relevant for the forecast and leads to wrong forecast decisions. Concluding, the EWA-level perishable inventory control policy shows to be reliable with respect to set and achieved outcomes for fill-rates when applied to the SPAR demand data.

Dynamic replenishment policy

In the perishable inventory policy of Minner and Transchel (2010) the order quantity is determined such that service level constraints are met at predetermined moments during the order horizon. The order quantity is therefore based on the expected inventory level at a predetermined moment for which service level constraints are set (and must be met). The current inventory decomposition, outstanding orders, and assumed demand distribution determine the order quantity. This results in a dynamic replenishment policy of the perishable stock point. With a service level requirement just before delivery and a lead-time of one period (one day), the inventory level is a function of current inventory detailed by age, the previous order, and demand realization until replenishment:

(4.2)

By setting the required fill-rate level at 98%, and taking the same order and delivery schedule as for the EWA-policy into consideration, the method of Minner and Transchel was applied with the level method (same as applied with the EWA-policy). This method (*MT-level*) performed not as desired (see Figure 4.4). The set fill-rate of 98% was not achieved in any store-product combination and the results were not stable/reliable. By setting the desired fill-rate at 98% the method achieved fill-rates between 77% and maximally 95%. This was probably because the model of Minner & Transchel (2010) was not designed for long review periods. Therefore the method was also tested for daily ordering (MT path daily) and with the path method (MT-path). Again both methods did not show stable and desired fill-rate outcomes (see Appendix E). Concluding that the dynamic replenishment policy of Minner & Transchel (2010) is not suitable for determining the intrinsic value of the adjustment strategy.

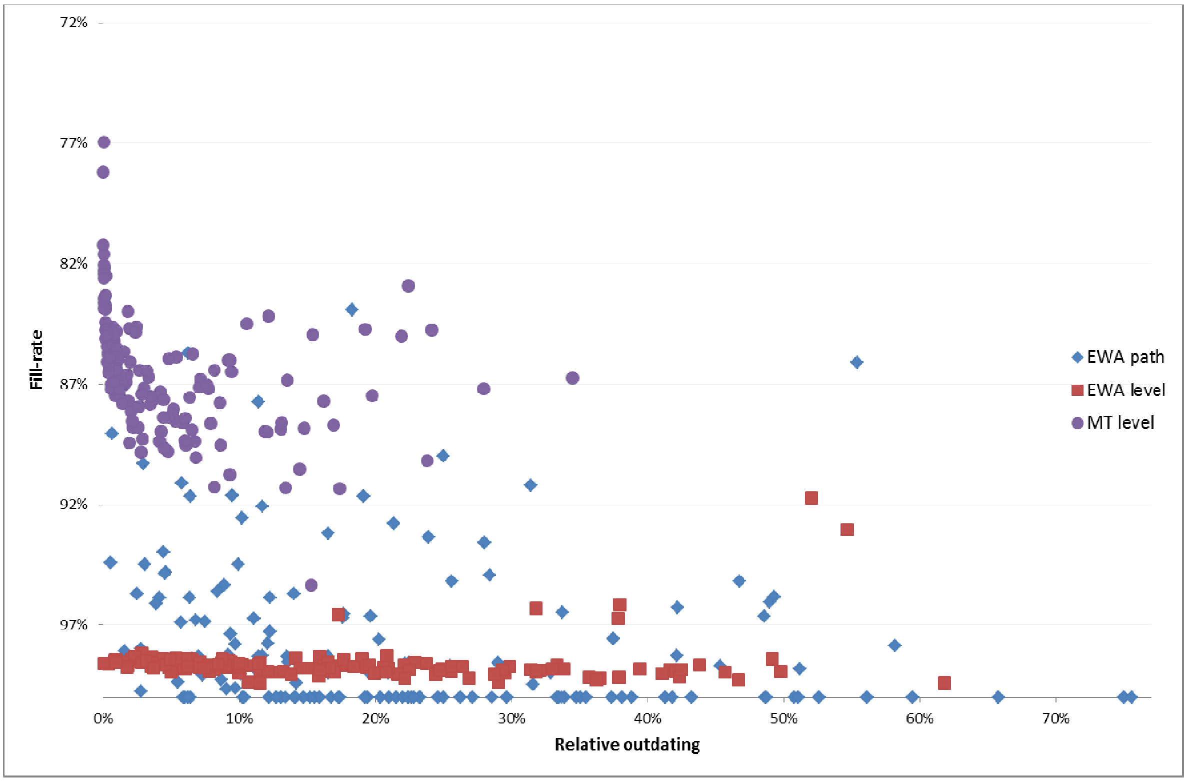

Figure 4.4: EWA-policy and MT-policy test results.

Sequential newsvendor Policy

When demand is not stationary, a dynamic inventory model can be a good policy. Bertsimas and Thiele (2005), and Beutel and Minner (2011) have developed a sequential newsvendor model for non-stationary demand situations. In their methods the optimal order quantity is determined with information from previous demand observations and explanatory variables. In the method of Bertsimas and Thiele (2005) the order quantity was selected from previously observed demand. With a trimming factor and the ratio between the mark-up factor and the discount factor, the order quantity is selected from the observed demand realizations. The order quantity was selected by taking the j-th demand observation in an ascending order of the total number of demand observations. The exact application of this method as a replenishment strategy and formulation is described in Appendix E.

The method of Bertsimas & Thiele (2005), called 'Seq. Newsvendor BT' showed no reliable results, the set service levels were achieved (see Appendix E). Next to this the achieved fill-rates resulted into high outdating. The model of Bertsimas and Thiele (2005) is cost based, where the order quantity is chosen from historical demand realizations. The order depends solely on the ranking of the historical demand realizations, which can result in a bad performance when the actual demand distribution is highly skewed. For this reason also the data-driven linear programming service model of Beutel and Minner (2011) is considered. The method of Beutel and Minner (2011), called 'Seq. Newsvendor BM', tries to find the target inventory function parameters such that inventory costs are minimized subjected to the fill-rate constraint. The required inventory level is a linear function of explanatory variables, in this case only based on historical demand observations. For the exact formulation and applied method see Appendix E. Under different fill-rate constraints the method was applied, the fill-rate outcomes are more reliable than of the method of Bertsimas and Thiele (2005) (see Appendix E). However the method results into high outdating figures. Therefore sequential newsvendor policies are not suitable for analysing the adjustment strategy.

4.6 Summary

After the different analyses the following concluding statements are made:

- Products had a short maximum available shelf-life of approximately 6 or 7 days.
- Perishable inventory on the shelves was issued in FIFO manner by customers.
- With historical sales data (POS) we could determine the product demand characteristics at SPAR.
- SPAR stores faced a clear and common week pattern.
- The selected products were primarily slow-movers, with a moderate till high demand variation.
- Customer demand could be modelled with a Poisson-distribution.
- Stores had a high relative outdating and moderate on-shelf availability, when store owners make the order decisions. Concluding, that store owners have trouble in correctly forecasting the upcoming demand and need to set safety stock levels high in order to achieve high service levels.
- Dynamic order quantity policy (sequential newsvendor) and a dynamic replenishment policy are not suited for determining the intrinsic value of the adjustment strategy.
- The EWA-policy shows to be reliable with respect to set and achieved outcomes for fill-rates when applied to the SPAR demand data and therefore is suitable for determining the intrinsic value of the adjustment strategy.

5. Order adjustment strategy

This chapter will discuss several aspects of the research assignment. First the concept of the research assignment will be explained in general. Then the concept is fully designed and discussed for SPAR, followed by the order adjustment mathematical model for SPAR.

5.1 Replenishment strategy

The order adjustment model is a special case of an emergency shipment model, whereby the emergency shipment takes place within the lead-time of the regular order and whereby the emergency shipment and regular shipment arrive together. Meaning that somewhere along the route the orders can be combined such that the regular shipment can be updated (order adjustment upwards) before it arrives at the stock point. Lammé (2010) already investigated an emergency shipment model for SPAR, however not this specific form.

The idea that will be modelled is a replenishment strategy where the regular store-orders can be adjusted before final delivery. The adjustment will be upwards and based on information gain during the regular review moment and the adjustment review moment. Information can for example come from the cash registration system. The inventory status at the adjustment review moment can determine whether the store-order needs an upward adjustment. The adjustment can be realized by ordering products which have a much shorter lead-time than the regular products. This is done by ordering products that are for example kept on stock or semi-finished.

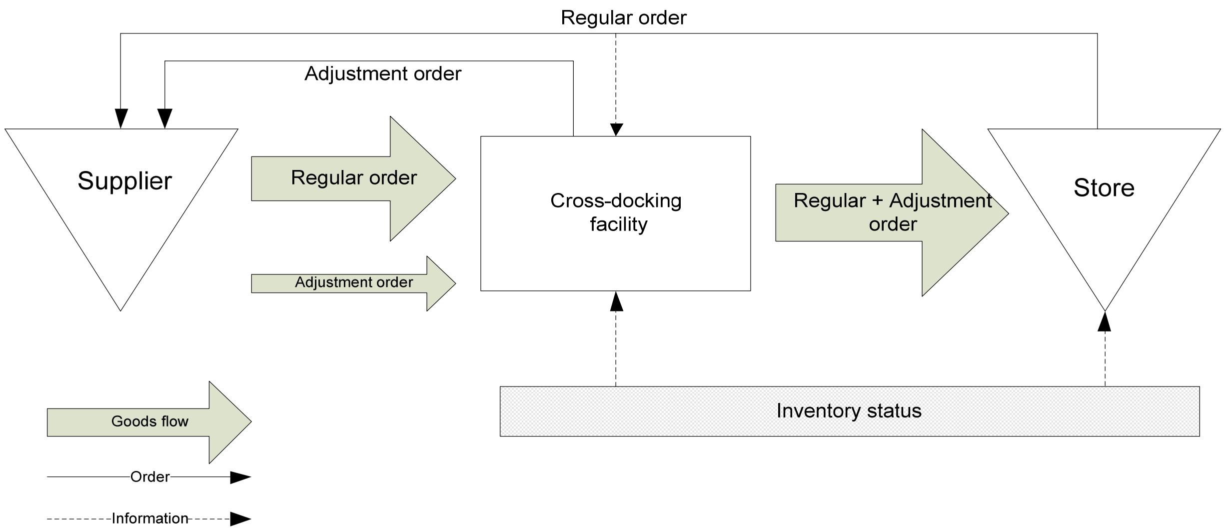

Figure 5.1: Order adjustment model.

It will be assumed that both the regular order and the adjustment order can be shipped together to the cross-docking facility, where the regular orders are cross-docked. The adjustment order products will be combined with the regular ordered products, by performing additional cross-dock activities (see Figure 5.1). After adjusting the regular orders, all the products are send towards the stores. It will be assumed that the lead-time between the stores and the cross-dock facility is not lengthened, due to the extra operations, because for example the activities take place during the closing times of the stores.

An upward adjustment can be beneficial, when a demand realization occurs above the expectation or an incorrect order is placed by the store owner. If the above expected demand or incorrect order is not due to a random cause, but structural and/or for all stores, then the concept of an adjustment order will not be suitable, since the adjustment order quantity will then be too much in order for the supplier to deliver within a short lead-time. Also the extra cross-docking activities will take too long in order to keep the lead-time between the cross-docking facility and the stores short.

Timeline

The proposed replenishment strategy in events, ranked on time, is described below and depicted in Figure 5.2:

1. Store places regular order at the perishable good supplier (via the cross-dock facility) at the first review moment (R_R). The order is based on the, at that moment, inventory status, safety stock and forecast of the regular order horizon ($R_R + L_R$).
2. After a specified time the cross-dock facility places an adjustment order at the perishable good supplier, this is at the adjustment review moment (R_A). The adjustment order is based on the information known at the cross-dock facility.
3. The regular order and adjustment order, both arrive at the cross-dock facility.
4. The regular order and adjustment order are combined and cross-docked towards the store.
5. L_R and L_A time after the review moments, the regular order and the adjustment order (combined into one shipment) arrive at the store and the perishable product shelves are replenished.
6. At the next review moment the process starts over (go to Step 1).

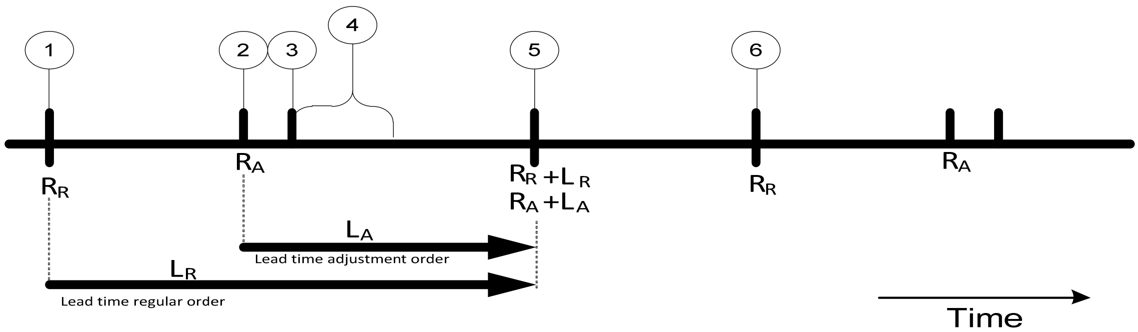

Figure 5.2: Time-line events.

Advantages and disadvantages

Reducing the lead-time of a stock point (by using an additional review moment) results in better inventory performance, due to a lower required safety stock setting, especially for perishable products (Donselaar et al., 2006). For perishable products this results into lower outdating at higher customer service levels. The safety stock level is lower, because no safety stock is needed for the uncertainty of above expected demand, for the time between the regular and adjustment review moment.

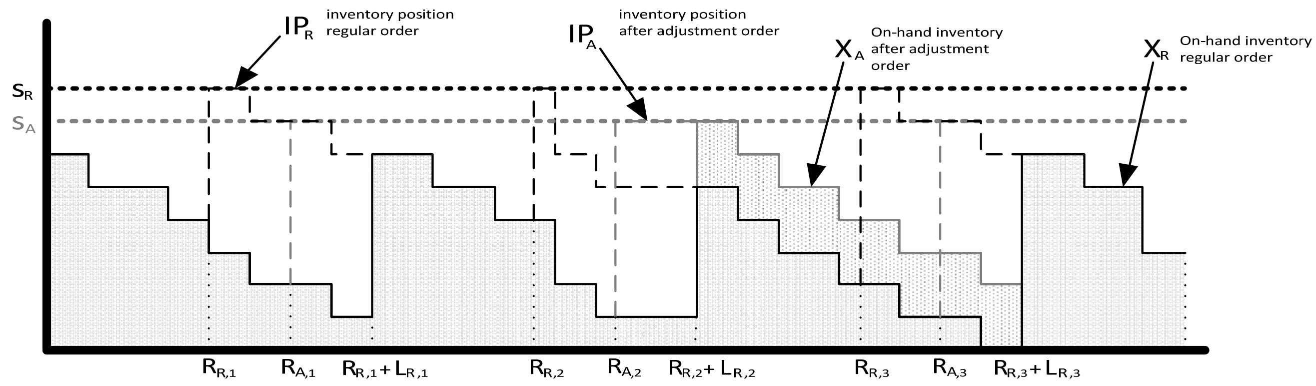

Figure 5.3: Inventory status with and without the order adjustment.

The benefits and differences in inventory status between a 'No adjustment' strategy and the 'Adjustment' strategy are depicted in Figure 5.3. Here you see that an above expected demand realization (between $R_{R,2}$ and $R_{A,2}$) or incorrect order can lead to an on-hand inventory of zero. But with the use of an adjustment review moment this situation can be avoided, by having an adjustment order at $R_{A,2}$.

The disadvantage of the proposed replenishment strategy is primarily the higher handling costs of the cross-dock facility. During the cross-docking process, extra activities have to take place. These activities are receiving, collecting, order-picking, and distribution of adjustment products over the regular orders. Next to that, the replenishment system becomes more complex. An adjustment review moment requires additional actions and decision making rules. Lastly, the determination of above expected demand requires that assumptions need to be made about the demand characteristics.

Suitable context

A replenishment strategy with order upwards adjustments based on an inventory status update, will not be recommendable for every situation. Making extra costs in order to have the possibility to adjust the regular order will not always be efficient. Therefore a list of some aspects and situations in which this particular replenishment strategy can be beneficial to implement was made:

- Lumpy demand patterns, low mean and high variation, are hard to predict. With a long forecast horizon a good forecast is very difficult to make and can result into high safety stock settings or low service levels. An adjustment opportunity will reduce the uncertainty in the order forecast horizon and improve service levels and/or safety stock levels.
- Products with a short shelf-lifetime require a good match between supply and demand. Excess supply directly leads to higher costs, due to rapid outdating. A strategic product needs to have a high availability, therefore supply needs to be sufficient at all times. A shorter lead-time will be beneficial for strategic perishable products, because supply can better react on demand changes of these products, thereby keeping costs manageable.

- In situations with high over-stock and under-stock costs, like lost sales and outdating, the extra costs for reducing the lead-time can become beneficial. When the shorter forecast horizon and better reaction on demand changes leads to better inventory performances.
- Supply chains were for example high transportation cost have led to long review periods, and were cross-docking has led to longer lead-times, the proposed replenishment strategy can result into a better control of the end-stock point.

When looking at the retail strategy (chapter 1), perishable supply chain (chapter 2), and demand characteristics of SPAR products (chapter 4), the proposed replenishment strategy could be a way to resolve the current business problem sufficiently.

5.2 SPAR order adjustment strategy

The proposed replenishment strategy could be a good new replenishment strategy for the strategic and highly perishable assortment of SPAR. The upcoming paragraphs will discuss some design choices for the order adjustment strategy at SPAR.

Inventory policy stores

At the review moments, regular and adjustment order decisions are made. In the current situation, the perishable stock point in the store is reviewed periodically by store owners. At the review moment an order is placed based on the forecast and safety stock settings of the store owner. In combination with the current inventory status, the store owner makes his own order decision. In order to forecast and set the safety stock level, store owners work with an order-book for highly perishable products. In this order-book the store owner registrates outdating, sales, ordered products and inventory levels per day (see Appendix H). As seen in the analysis chapter this way of working leads not to an efficient inventory control, resulting in a moderate outdating with lower customer service level as desired.

From the tested perishable inventory policies, the EWA-policy of Broekmeulen and Donselaar (2009) performed reliable for the demand series of perishable products at SPAR. Next, the EWA-policy can improve the current inventory performance of store owners and is indicated by SPAR managers as the principles that ideally should be applied by store owners. Therefore in determining the intrinsic value of the proposed order adjustment strategy the regular order is made with the EWA-policy. It will be assumed that regular order decisions of the store owners are made such that the highest fill-rate is achieved under maximum acceptable costs for outdating and/or adjustment. Also store owners are indifference with respect to associated costs of the adjustment strategy. This indifference behaviour for costs of the store owner will be assumed and called rational behaviour.

Some additional reasons for this choice are that the EWA-policy logic is easily explainable to store owners when considering to implement the adjustment strategy. The correction for expected outdating is good explainable to store owners, and the current order-book method that is used by the store owners can be slightly adjusted for the EWA-heuristic mind-setting.

Order adjustment quantity

At the adjustment review moment, SPAR has to make the order adjustment decision. Ideally, this should be done with the same policy and information-sources that store owners have. Then the adjustment quantity would be based on the exact information gain, between the regular and adjustment review moment. However, SPAR does not have access to the same information as the store owners do.

SPAR has only insights in the daily sales and outdating of the perishable inventory in the stores. These facts are recorded by the cash registration system and the management system of store owners. Both systems can remotely be accessed by SPAR. The exact inventory position and age-distribution of the inventory are not known by SPAR and a solution to get to known these facts will be very time consuming and/or costly. Also the possible mistakes between a system's inventory level and the actual inventory level can lead to wrong decisions. Therefore it is assumed that SPAR can only determine the order adjustment quantity by using sales and outdating between the two review moments.

The order adjustment quantity will be based on the difference between the actual change in inventory position and expected change in inventory position. The actual change in inventory position can be measured by the cash-registration system and the outdating registration of store owners, which both can be remotely read by SPAR. The expected change in inventory position will be the expected demand forecast of SPAR, between the two review moments.

Because the demand at SPAR stores for perishable products can be described with a Poisson distribution, the inter-arrival times of demands are exponentially distributed. This means that demands are independent and have the property of being memory less. Therefore the upcoming demand after the adjustment review moment does not depend on the 'early' sales before the adjustment review moment. The order adjustment quantity can therefore be justifiable based on the change in inventory position between the regular and adjustment review moment. The change comes only from sales, because no replenishment takes place between the regular and adjustment review moment and no outdating takes place in half a day. The order adjustment quantity will be the difference between the expected sales, determined by SPAR, and the actual sales.

Two critical notes have to be made when choosing this method for determining the order adjustment quantity. First, the expected change in inventory position is based on the forecast of SPAR, and not on the forecast of the store owner. A difference in forecast between SPAR and the store owner has a major effect on the adjustment strategy execution. For example when the SPAR forecast is much higher than the store owner's forecast, the adjustment will not take place. Due to the fact that SPAR thinks that demand is lacking and therefore no adjustment take place. When the forecast of SPAR is much lower than the store owner's forecast, the adjustment order will be incorrectly high. Because SPAR thinks a higher than expected demand is realized. Therefore store owners have to indicate whether their order is based on 'normal' demand expectations or 'higher' demand expectations. In the last case, the adjustment is not applied on the store owner's order. Second, the change in expected outdating for which the store owner corrects his order (EWA-heuristic) is not included in the order adjustment method. This can lead to a situation where an adjustment is not necessary, this is when above expected demand realization is resolved by the extra ordered products for the expected outdating. The store owner already corrected his order, for products that would leave the system for outdating, and now instead leave the system by an higher demand as expected. This issue cannot easily be dealt with in practise. Therefore the consequences of this effect will be measured in the simulation study. This is done by not letting the store owners correct their orders for expected outdating, meaning that the EWA-heuristic is not applied.

Order adjustment process

When both orders arrive at the distribution centres of SPAR, the adjustment order has to be added to the regular order. The regular order is already on a store-allocated roll-container. The adjustment orders arrive in bulk, this can be on a pallet or in crates. However, it will be assumed that the products of the supplier are already sorted by product. Then an order-picking lane can be arranged, where the store-allocated roll-containers can be complemented with the order adjustment quantities, by performing order picking operations. Therefore a requirement for adjusting an order, is the placement of a regular order by the store owner. Otherwise there will be no roll-container to place the adjustment order on.

Adjustment costs

The implementation of an order adjustment strategy leads to extra costs for the logistics at the distribution centres of SPAR (from now on called ‘adjustment’ costs). The start-up costs are assumed to be negligible small, because all requirements can be arranged with the current staff and facilities of SPAR. The costs for performing the adjustment process at the distribution centres of SPAR are assumed to be fixed.

These adjustment costs are assumed to be forwarded to the store owners by a raise on the current ‘Distributiebijdrage’. The ‘Distributiebijdrage’ is a percentage that determines store’s payment for logistic costs. The payment is a percentage of the average total purchase value (wholesale turnover) of the store per year. The current logistic costs that are forwarded to the stores are around 17 million euro’s per year (Note: These are not the total logistic costs of SPAR, but only the forwarded costs to the store owners). The total extra costs are estimated at 250.000 euro per year, this number represents 4 FTE working day and night shifts. These costs are fully forwarded to the stores, because they can also fully benefit (higher customer service with lower safety stock) from the adjustment activities. The increase of 250.000 euro leads to an increase of 0.05 % of the ‘Distributiebijdrage’. Because the ‘Distributiebijdrage’ is relative to the wholesale turnover (purchase value products for stores), there will be assumed that total turnover stays equal with the new replenishment strategy. In real-life a higher customer service can lead to more sales, resulting in a lower increase of the ‘Distributiebijdrage’.

Lead-time adjustment-order

The lead-time of the adjustment order must be shorter than the lead-time of the regular order. Otherwise the regular order cannot be changed at the distribution centre during the cross-docking process. For morning-stores (70% of all stores) the regular orders are placed at the supplier at 13:30 hour. These orders arrive at the SPAR distribution centres between 21:00 and 00:00 hours. The adjustment order review moment must be set before the arrival of the regular order at the distribution centre of SPAR and after the regular order review moment. The stores of SPAR close at 19:00 hour, therefore the adjustment order review moment could be set ideally at 19:00 hours. The time between 19:00 and 21:00 hour can be used by the supplier to arrange the adjustment order. This short lead-time is possible, because the products are not yet order-picked and/or are kept on-stock at the supplier. However when products are kept at stock, the agreed shelf-life-time can be lower for the adjustment order products.

Stock point lead-times are only accounted when the stores are open and the stock point is accessible. The opening hours of a SPAR store are between 8:00 and 19:00 hours. Therefore 11 hours lead-time corresponds to one day lead-time. The time between ordering the regular order and receiving the goods at the DC of SPAR is half a day. The supplier lead-time of the extra order is zero days, because all activities take place during closing times of the store. The lead-time between the DC of SPAR and the store is approximately half a day. This is the duration of the distribution to the stores and the fully replenishment of the shelves in stores. The morning stores are delivered before mid-day, after that the shelves can be replenished. Replenishment of the shelves is done directly after receipt, because it is mostly done by the store owner himself and permanent employees. Resulting in a total lead-time of the regular order of one day ($\mathrm{L_R}$), and a total lead-time of the adjustment order of half a day ($\mathrm{L_A}$).

5.3 Mathematical model

In this paragraph the order adjustment strategy is mathematically modelled for the SPAR situation. The mathematical model will be used in the simulation experiment. A simulation was conducted, because a precise mathematical analysis will be very difficult and time-consuming to make. Also the situation is not suitable for a precise mathematical treatment. The simulation of the stock point will be performed with a discrete event simulation.

Discrete event simulation

A discrete event simulation (DES) is a simulation method where a sequence of discrete defined events is simulated in a chronological order. Each event changes the state of the system. For the simulation the exact time moments were different than described in the design. This was done, because the building of the simulation was then much easier and it will have no consequence for the main outcomes. In order to perform a DES, the events need to be clearly specified and set in chorological order:

1. Inventory is depleted during the opening hours of the store, due to customer demand.
2. At the end of the day (after closing time), outdated products are removed from the system and outstanding orders arrive and are replenished.
3. After that, check if regular order is necessary, when necessary place regular order.
4. At the middle of the next day, check if adjustment order is necessary, if necessary, place adjustment order.
5. Regular and adjustment order are (combined) replenished at the end of the day (after closing time).

Next to the chronological order of events, the following assumptions are made for the simulation. These assumptions are based on the findings in the analysis chapter and design choices for the SPAR order adjustment strategy:

- Customer demand is stationary and Poisson distributed with mean λ. Demand (D_t) is independent and identically distributed between the periods t.
- The week pattern is included, by modifying the mean period demand parameter of the Poisson distribution for each weekday with the factor f_{day}. The period mean parameter for the Poisson distribution will be adjusted as follows: $\lambda_{day} = f_{day} \times \lambda$. The week pattern is assumed to be consistent for all product and store combinations.
- Stores are open every day from 8:00 until 19:00 hours, except on Sundays. But products can still perish on Sundays, therefore this weekday is included in the simulation.

- Perishable products have a lifetime of *n* days, after delivery to the stores. Outdated products are removed from the inventory at the end of a day.
- When on-hand inventory is insufficient to satisfy demand, then excess demand will be lost.
- Inventory in-stores is controlled with the EWA-policy of Broekmeulen and Donselaar (2009).
- Store owners are assumed to act rationally when ordering, thereby regular order decisions of the store owners are made such that the highest fill-rate is achieved under a maximum acceptable costs for outdating and/or adjustment.
- On-hand inventory is withdrawn from the shelves in FIFO manner.
- Regular orders arrive after a fixed and known lead-time L_R and adjustment orders arrive after a fixed and known lead-time L_A (planned lead-time concept). Both orders are delivered at the same time moment.
- The periods between the review moments (*R)* are fixed and known, thereby a fixed order and delivery schedule is assumed.
- Order/replenishment quantity (*q*) is lot-for-lot in consumer units, with no maximum and minimum quantity. But an adjustment order can only be placed, when there already exist a regular order for a perishable product.
- Adjustment and outdating costs are the only costs parameters included.

Order adjustment model

For the regular order decisions the stock point is controlled with a modified EWA-policy from Broekmeulen and Donselaar (2009). The correction for outdating, due to withdrawal and ageing, is applied to an (R,S-1,S)-policy (instead of a (R,s,nQ)-policy). Therefore the formulas in the paper of Broekmeulen and Donselaar (2009) are slightly different. The regular order quantity ($\mathrm{q_R}$) is determined by the order-up-to level (*S*), safety stock setting (SS), the inventory position (*IP*), and the expected outdating ($\widehat{\mathrm{O}}$). The regular order quantity is determined as follows:

$$q_{R,t} = S_t - IP_t + \sum_{j=t+1}^{t+L_R+R_R-1} \hat{O}_j \tag{5.1}$$

Where the order-up-to level is determined as follows;

$$\mathrm{S_t} = \sum_{\mathrm{i=t}}^{\mathrm{L_R+R_R}} \lambda_{\mathrm{i}} + \mathrm{SS} \tag{5.2}$$

The safety stock level depends on the targeted fill-rate. The value of the expected outdating depends on the assumed withdrawal behaviour and the age distribution of the stock point. The procedure with recursive equations, for determining the value of the expected outdating, is called the EWA heuristic. Because the EWA heuristic is very specific, the used formulas and exact procedure is copied from the article of Broekmeulen and Donselaar (2009) and depicted below:

In the case of FIFO withdrawal of the shelves with a perishable product with fixed lifetime of *n* days, we have the following recursive expressions at the end of each period *t*:

$$W_{t,r} = Min\left(B_{t,r}, D_t - \sum_{i=1}^{r-1} W_{t,i}\right) for\ r = 1, \dots, n \qquad (a)$$

The withdrawal quantity (*W*) of the on-hand inventory is the minimum of the remaining batch size (*B*) with remaining shelf life *r* and the unsatisfied demand from older batches on the shelf.

At the end of each review period, an order decision is made which determines $B_{t+L_R+1,n}$. After each day, the batches are updated for ageing, withdrawal and outdating:

$$B_{t+1,r-1} = B_{t,r} - W_{t,r}\ for\ r = 2, \dots, n \qquad (b)$$

$$O_t = B_{t,1} - W_{t,1} \qquad (c)$$

The recursive equations above are needed to estimate the outdating quantities (*O*). These are estimated by calculating for consecutive periods i (ranging from $i = t + 1$ to $i = t + L_R + R_R - 1$) the withdrawal, the remaining batches and the outdating in period i using (a)-(c) under the assumption that in period i demand is equal to the expected demand for that period. This implies the following procedure, starting with $i = t + 1$:

1. Determine the estimated withdrawal in period i using (a) and by assuming demand in period i was equal to the expected demand.
2. Determine the estimated remaining batches available for the next period and the estimated outdating in period i using (b) and (c) and by assuming the withdrawal in period i is equal to the estimated withdrawal as determined in Step 1.
3. While $i < t + L_R + R_R - 1$ do i: $= i + 1$ and continue with Step 1, otherwise stop.

The order quantity of the adjustment review moment (q_A) is determined by the above expected demand realization between the regular review moment and the adjustment review moment. Because the model only assumes an order upwards adjustment, the adjustment order quantity cannot be negative and is determined as follows:

$$q_{A,t} = Max\ (0, D_{t-1} - E[D_{t-1}]\ ) \qquad (5.3)$$

6. Model solving

In this chapter the chosen model inputs that are used in the simulation experiments are explained. First, the model inputs are discussed, like product and supply chain characteristics. The model inputs will determine if the proposed adjustment strategy can be beneficial for the selected products and stores of SPAR. Therefore secondly, a full factorial experimental is designed and ending with a discussion on key performance indicators for the adjustment strategy.

6.1 Model input

Products

Based on the suitable context points, SPAR products were selected that are suitable for this order adjustment strategy. Important points mentioned are very short lifetime, low mean demand, and high variation. A combination of these factors will lead to high outdating and/or low service levels (Donselaar & Broekmeulen, 2011). Daily demand of our selected products was between one and seven consumer units, with a mean of 2.3 products (see Appendix B). The products with a low demand had also a high variation. These products also performed moderate under the current inventory control policy. Therefore the products with a mean daily demand between one and six, and that could be modelled with a Poisson distribution were selected. Thereby including 95% of the selected products of our analysis. The sales of SPAR stores also clearly had a week pattern. Therefore the demand parameter is corrected with the daily factor for including the week pattern (see Table 6.1).

Table 6.1: Daily demand factor for the week pattern of SPAR stores.

Weekday	Factor (f_{day})
Monday	1.11
Tuesday	1.06
Wednesday	1.13
Thursday	1.14
Friday	1.32
Saturday	1.24
Sunday	0

The supplier agreed with SPAR that the products have at least a lifetime of 5, 6, and 7 days when delivered at the distribution centre. We have noticed that a store mostly receives products that are fresher than the agreed lifetime. However with the order adjustment strategy, products can be less fresh due to fact that the supplier keeps more products on stock for the adjustment order. We therefore set the lifetime parameters between four and eight days. Next to this the products can be ordered lot-for-lot, meaning that the orders can be any non-negative integer value.

Table 6.2: Product input parameters

Product parameters	Values
Mean daily Poisson demand (λ)	{ 1, 2, 3, 4, 6}
Shelf-life *n* in days	{4, 5, 6, 7, 8}
Wholesale price ($P_{wholesale}$)	{1, 2, 4}

Order and delivery schedule selection

The design of the perishable supply chain of SPAR results into a lead-time of one day for the regular orders. With a review period of two days at the beginning of the week and one day at the end of the week. The extra moment is always half a day after the regular order moment, and has a lead-time of half a day. Such that the regular and adjustment order can be combined at the distribution centre and delivered together at the store. Therefore the review period of the regular and adjustment orders are one and two days, with a lead-time of one day for the regular order and half a day for the adjustment order. We call this the ‘ Schedule I ’, this schedule represents the current desired order and delivery schedule of SPAR. Because we noticed that some stores still use the ‘old’ order and delivery schedule (order every other day), we will also use this in our simulation. This schedule also saves SPAR around one million euro’s on transportation costs yearly. Therefore it is interesting to evaluated this scenario, called ‘Schedule II ‘. Lastly a schedule is simulated whereby stores can order each day of the week, thereby the forecast horizon becomes shorter and the order adjustment strategy can become less useful. To investigate in what extend the strategy becomes less beneficial, we also simulated this schedule, called ‘Schedule III ‘. All schedules and the values for review period and lead-time are summarized in Table 6.3. In this table also the order schedule code is included, the first digit in the code stands for number of order moments per week, the following digits represent weekdays (Monday, Tuesday, etc..), a one stands for order moment that day and zero stands for no order moment that day.

Table 6.3: Different order and delivery schedule scenarios for the experiment.

Order and delivery parameters	Schedule I	Schedule II	Schedule III
Review period regular order in days (R_R)	{ 1 or 2}	{ 2}	{ 1}
Lead-time regular order in days (L_R)	{ 1.5}	{ 1.5}	{ 1.5}
Lead-time adjustment order in days (L_A)	{ 1}	{ 1}	{ 1}
Order schedule (code)	4101110	3101010	6111111

Adjustment costs

When applying the order adjustment strategy, the current ‘Distributiebijdrage’ will raise with 0.05%. This increase in ‘Distributiebijdrage’ corresponds with increase of distribution costs, due to the fixed adjustment costs of 250.000 euro relative to the total wholesale turnover of SPAR. In order to compare the adjustment costs with other costs of a product, we will make the adjustment costs relative to the wholesale turnover of the product that makes use of the adjustment strategy. Therefore we have to know how many of the selected SPAR products can be adjusted and what the corresponding total wholesale turnover of these selected products is.

First, the maximum number of products that can make use of the adjustment strategy must be determined. The average order picking speed of one FTE was 182 order-lines per hour (source: Logistics SPAR). Therefore four FTE can handle 3640 order-lines (store-product combinations) in approximately five hours. Five hours is the average time between orders arrival at DC and the loading and final planning of trucks. Depending on the average number of regular-orders adjusted (*NrRegularAdjusted)*, which is determined in the simulation, we can determine the average of store-product combinations that can be handled. The maximum number of products is then determined by the amount of stores in the replenishment cycle (*NrStoresCycle*). This is for the 31010100-schedule on average 100 stores (average of morning and evening stores), for the 41011100-schedule this is at the end of the week around 200 and in the beginning of the week around 100, for the 61111110-schedule this is around 200 stores. The adjustment assortment number is determined as follows:

$$\#A = 3640/(NrRegularAdjusted * NrStoresCycle) \tag{6.1}$$

Second, the wholesale turnover for the adjustment assortment depends on the maximum number of products in the adjustment assortment, the weighted wholesale price ($P_{Wholesale}$) of the adjustment assortment, and the total supply in a year to all stores of the adjustment assortment (*TotSupply*). The average supply per day is determined in the simulation run, from which the weighted total yearly supply can be calculated to all 600 stores. The total wholesale turnover for the adjustment products is determined as follows:

$$TotWholesale = \#A * P_{Wholesale} * TotSupply \tag{6.2}$$

And the relative adjustment costs are then determined as follows:

$$RelAdjustment = 250.000/TotWholesale \tag{6.3}$$

6.2 Experiment design

With the different product characteristics (mean demand and shelf-life) and order & delivery schedule inputs, a full factorial simulation resulted into $5 * 5 * 3 = 75$ experiment settings. Each run (experiment with targeted fill-rate) was replicated at least 10 times, until a fill-rate was achieved with a precision level of 0.002 (Law & Kelton, 2000). Thereby, three scenarios were used, namely; Adjustment, No-adjustment, and Adjustment with (R,s,nQ).

Adjustment versus No-Adjustment

In order to determine whether an adjustment strategy (called 'Adjustment') is beneficial above a strategy without (called 'NoAdjustment'), we propose the following comparison method:

We compare both strategies on customer service level versus total relevant costs (such as seen in Figure 6.1). Customer service level will be measured in fill-rates, and total relevant costs are measured in outdating and adjustment costs. In order to make both costs comparable, we have to make both costs relative to the same factor. Therefore we determined that the outdating cost of a single product is only the wholesale price. This ensures that the relative outdating and relative adjustment costs are both relative to the wholesale price of the product.

In order to decide whether the order adjustment strategy was beneficial above a strategy without, we should compare the fill-rate of both policies by equal total acceptable relevant costs. Total relevant costs are for the NoAdjustment-policy the relative outdating, and are for the Adjustment-policy the relative outdating plus the relative adjustment costs. We expect the following function between the fill-rate and the total relevant costs for both policies:

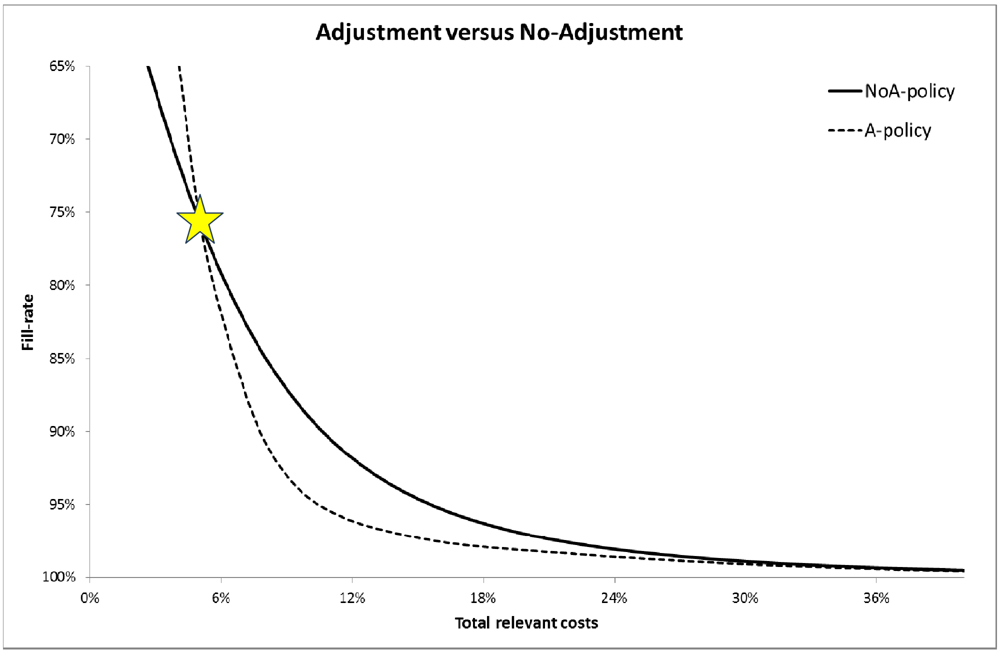

Figure 6.1: Example of comparison method, whereby Adjustment-policy outperforms the NoAdjustment-policy at high targeted fill-rates.

The Adjustment-policy line has a fixed costs component (relative adjustment costs), therefore starting more to the right. But the Adjustment-policy will have a sharper pitch, due to a director control of the perishable stock point, leading to lower relative outdating at higher fill-rates. The main question is: Is the difference in pitch (between Adjustment policy and NoAdjustment-policy) big enough to overcome the extra costs before the desired fill-rate or before the acceptable total relevant costs are reached? Therefore we have to determine whether the Adjustment-policy line goes beneath the NoAdjustment-policy line, before the total acceptable relative costs of 6% are reached or the fill-rate achieves desired levels. The moment the Adjustment-policy becomes beneficial above the NoAdjustment-policy will be called the cut-off point (yellow star in Figure 6.1).

In order to compare the policies, we should compare the fill-rate at equal total acceptable relevant costs. The method of dead reckoning can therefore be used on the parameter safety stock. However, from an initial run we noticed that the steps in fill-rate and relative outdating are unpredictable when adjusting the safety stock levels. The method of dead reckoning will not easily result into comparable outcomes of both policies. We therefore decided to compare the both policies with equal safety stock levels. Thereby making a comparison based on the increase in service and the change in total relative costs. In order to come to a justifiable conclusion which policy performs better, we will run the simulation for a range of targeted fill-rates, between 80% and 95%. The different outcomes (fill-rate versus total relevant costs) can be interpolated and we can create the same graph as in Figure 6.1 for comparison of both policies.

Note: The method described does not compare both policies on their optimal outcomes. The full range of every parameter is not considered and no optimization technique is used. Therefore statements based on a limited range of safety stock levels and interpolation of the outcomes of each policy must be handled with caution. Thereby no strong conclusion can be formulated about the comparison of both policies. However, with the set of outcomes a Pareto frontier can be constructed. The Pareto frontier is a set of choices that are Pareto efficient, thereby isolating outcomes that are not strictly dominated on fill-rate and/or total relevant costs. The Pareto frontier allows for trade-offs between the different outcomes of the Adjustment- and NoAdjustment-policy for the given set of outcomes.

EWA versus No-EWA

As mentioned in the paragraph 5.2 about the SPAR order adjustment strategy, the use of the EWA-heuristic by the store owner is not desired in every situation. Especially in de situation where the shelves are withdrawn FIFO and the demand is very low. Therefore, we will also add the scenario (called AdjustmentNoEWA), whereby store owners order without the EWA-heuristic. Thereby the store's inventory policy will be an (R,s,nQ)-policy.

6.3 Key Performance Indicators

In order to judge the feasibility of the order adjustment strategy some performance indicators, besides the direct costs, need to be measured and compared with the current situation. These indicators are not primarily cost based, but will have an indirect influence on the costs. The implementation of this replenishment strategy will have an influence on four different parties, namely: The customers, the store owner, SPAR, and the supplier. In consultation with some parties and the managers of SPAR, certain performance indicators that determine the willingness and feasibility to implement the order adjustment replenishment strategy are chosen and desired levels were indicated. The performance indicators for the upstream party includes all performance indicators of the downstream parties (see Figure 6.2).

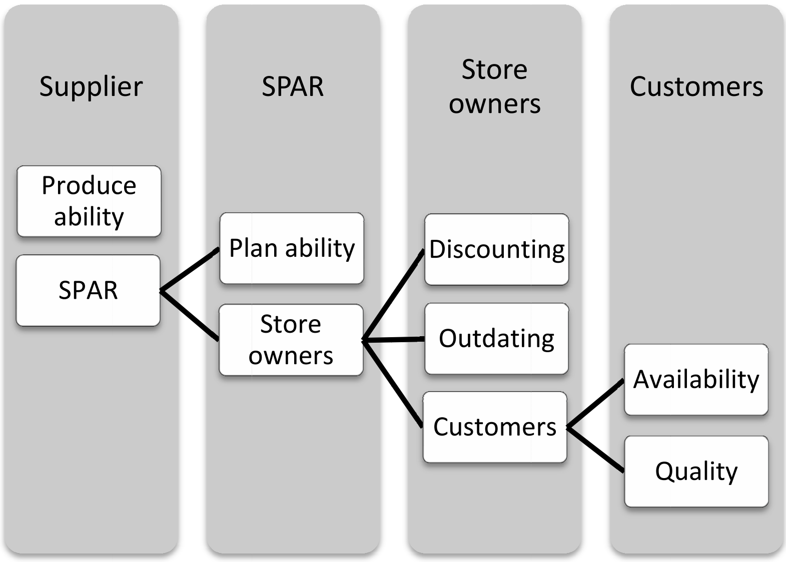

Figure 6.2: Relation between performance indicators and different parties.

The customers of SPAR expect that perishable products are of high quality (see paragraph 1.1). Meaning that, the products are really fresh and have a good life-time after the purchase moment. By measuring the average shelf-life of sold products, the quality of the sold products can be determined. Next, product availability is also very important. Therefore another performance indicator for the customers of SPAR is the fill-rate of on-hand inventory. Management indicated that the fill-rate should be at least 95% and the products are of high quality when the remaining lifetime of a product is at least 3 days.

Store owners have the same performance indicators as customers do, because satisfied customers are loyal customers. But store owners have some additional and different performance indicators for the adjustment strategy. A store owner is particularly concerned about his costs of inventory and especially the risk of products becoming obsolete (unsellable). Therefore the store owners indicated that the relative outdating rate must be minimal and ideally lower than 5%. Secondly, store owners have to discount products that have a low quality. Products with less than one day of life-time are discounted with 35%, yielding in a reduced margin for the store owner. Therefore the average remaining shelf-life of sold products needs to be maximized, because the change on large amount discounting is then reduced.

SPAR primarily wants to improve the image of the format. As seen in the report of Gfk. (2011) the strategy of SPAR is lacking in product availability and realistic pricing. It is important that customers can buy fresh and available products in the stores of SPAR. Therefore customers and store owners satisfaction are two important performance indicators. In order to manage the costs of the adjustment handling at the distribution centres of SPAR, the frequency of regular orders that have an adjustment order needs to be manageable. If not, the total costs and perfect execution of the adjustment handling operations can suffer sufficiently. Therefore the average ratio of regular orders that are adjusted needs to be minimized and management of SPAR indicated that this ratio is preferably lower than 15%.

The supplier of SPAR benefits from a better availability and quality of their products in the stores of SPAR, because this can lead to extra sales and more loyal customers of their brand. When outdating is also kept to a desired level, store owners will approve the adjusted orders from SPAR and the supplier. And when SPAR is able to manage the handling of the adjusted orders at the cross-docking facility, this also enables the supplier to manage the production of extra products. Additionally, the supplier has to make sure that the extra products are produceable within the agreed lead-time, meaning that the service level towards the stores can be kept at a high level. The agreed lead-time can be achieved for the production of the extra products, when the amount of extra products is minimal with respect to the regular order size. The average ratio between the amount of adjusted and regular products ordered is therefore a good performance indicator for the produce ability of the supplier. In consultation with some managers at SPAR this indicator was set to be smaller than 5%. A complete overview of all KPI's and their characteristics can be found in Table 6.4.

Table 6.4: Specified performance indicators for the adjustment strategy.

KPI	Measure	Objective	Desired level
Quality products	Average remaining shelf-life sold products	Maximize	≥3
Availability products	Fill-rate on-hand inventory	Maximize	>.95
Outdating level	Relative outdating	Minimize	<.05
Discounting products	Average remaining shelf-life sold products	Maximize	≥2
Manageable of adjustment handling	Average ratio adjusted/regular orders	Minimize	<.15
Produce ability	Average ratio adjusted/regular products	Minimize	<.05

7. Simulation outcomes

The results of the simulation experiment are shown and discussed in this chapter. Based on the model inputs and the experiment design, some analyses are performed. Because the model inputs are tailored to SPAR, no general results can be discussed for the Adjustment strategy.

Before discussing the results, we compared the Adjustment-policy with and without the EWA-heuristic on an (R,s,nQ), because the use of the EWA-policy could sometimes be undesired (explained in paragraph 5.2 – Order adjustment quantity). The comparison showed no significant undesired effects of the use of the EWA-policy for the adjustment strategy (see Appendix F). Therefore our further analyses will be based on the Adjustment-policy with the use of the EWA-heuristic for the regular orders.

7.1 Adjustment-policy versus NoAdjustment-policy

For the analyses of the Adjustment-policy, we take the 41011100 order-schedule and the target fill-rate of 85%, as the basis input. These facts most resembled the current and desired situation at SPAR. The most important measures of the simulation are the customer service level, measured in fill-rate, and the total relevant costs, which are measured in relative outdating and relative adjustment. The NoAdjustment-policy was taken as the basis for comparison with the Adjustment-policy, therefore an increase in fill-rate and decrease in relative costs are beneficial for the Adjustment-policy.

With the use of an adjustment strategy, the increase in the fill-rate is almost three per cent, while total relevant costs increases by almost one per cent. The fill-rate raises from 91.0% (NoAdjustment) to 93.9% (Adjustment), while total relative costs respectively raise from 2.6% to 3.7%. Most of the total relevant costs are due to an increase in relative outdating (see Table 7.1).

Table 7.1: Average increase Adjustment-policy in Fill-rate and Total relevant cost compared to the NoAdjustment-policy, for different product parameters.

Product parameter	Level	Fill-rate (Δ%)	Total relevant costs (Δ%)	Relative outdating (Δ%)	Relative adjustment (%)
Mean demand (λ)	1	2.73	3.37	1.87	1.50
	2	2.57	1.10	0.27	0.84
	3	3.65	0.79	0.23	0.56
	4	2.68	0.49	0.07	0.43
	6	2.62	0.32	0.04	0.28
Shelf-life (*n*)	4	2.74	1.78	1.11	0.66
	5	2.89	1.33	0.62	0.70
	6	2.90	1.10	0.37	0.73
	7	2.87	0.95	0.20	0.75
	8	2.87	0.92	0.17	0.75
Wholesale price ($P_{wholesale}$)	1	2.85	1.33	0.49	0.84
	2	2.85	0.91	0.49	0.42
	4	2.85	0.70	0.49	0.21
Total	all	2.85	1.22	0.49	0.72

The sensitivity of the different product parameters on the simulation results are now discussed;

Mean demand

The increase in fill-rate is higher for low mean demands, but the difference in total relevant costs are also higher with a low mean demand. When mean demand is very low, then the Adjustment-policy is less beneficial due a major increase in costs. The relative adjustment costs are also higher for smaller demands, this is the result of a smaller total supply to the stores. Therefore the relative adjustment costs increase, because the total value of the wholesale turnover is low compared to the relative costs made for the strategy. Concluding, products with a higher mean daily demand (λ>1) profit the most from the adjustment strategy, because the raise in total relevant costs is small compared to the increase in fill-rate. The proposed adjustment strategy is for very small demands not beneficial.

Shelf-life

The shelf-life of a product has no influence on the difference between the adjustment and no-adjustment strategy for the fill-rate and relative adjustment costs. The product parameter shelf-life only has influence on the difference in relative outdating costs. Relative outdating increases faster for the adjustment strategy, than for the no-adjustment strategy, when the product shelf-life becomes shorter. The increase in difference for relative outdating could come from the fact that the average inventory is higher, due to more supplies. Thereby the chance of outdating increases with a short shelf-life. Concluding, the adjustment strategy works better for products with a longer shelf-life time.

Wholesale price

The wholesale price only has an influence on the relative adjustment costs. With the fixed adjustment costs, the relative adjustment costs become lower, when the value of the products is higher. Concluding, products with a higher wholesale price can benefit better from the Adjustment-policy, because total relative costs are lower with equal benefits in fill-rate. With lower total relative costs, the adjustment strategy can become more quickly advantageous.

Verdict

Overall, the Adjustment-policy leads to a better fill-rate. Due to the adjustment operations and more supply to the stores, the adjustment costs and outdating costs also increase. In order to come to a justifiable conclusion, whether the Adjustment-policy is performing significantly better than the NoAdjustment-policy, we apply the comparison method described in the experiment design. With this method, we answer the question: Are the benefits of the Adjustment-policy big enough to overcome the extra costs, before the desired service levels are reached or within the range of total acceptable costs?

For several targeted fill-rates the simulation was performed with a weighted wholesale price and supply for the selected SPAR products. The result is shown in Figure 7.1, from which we should conclude that the Adjustment-policy does not perform better than the NoAdjustment-policy for the selected SPAR products in general. The extra costs of the Adjustment-policy cannot be compensated by the increase in fill-rate until already a reasonable service level of 95% was reached. Moreover, an investment in outdating (higher safety stock) is beneficial above an investment in adjustment operations, in order to reach desired fill-rates. Caution: this judgement is based on the interpolation of sub-optimal results for a limited range.

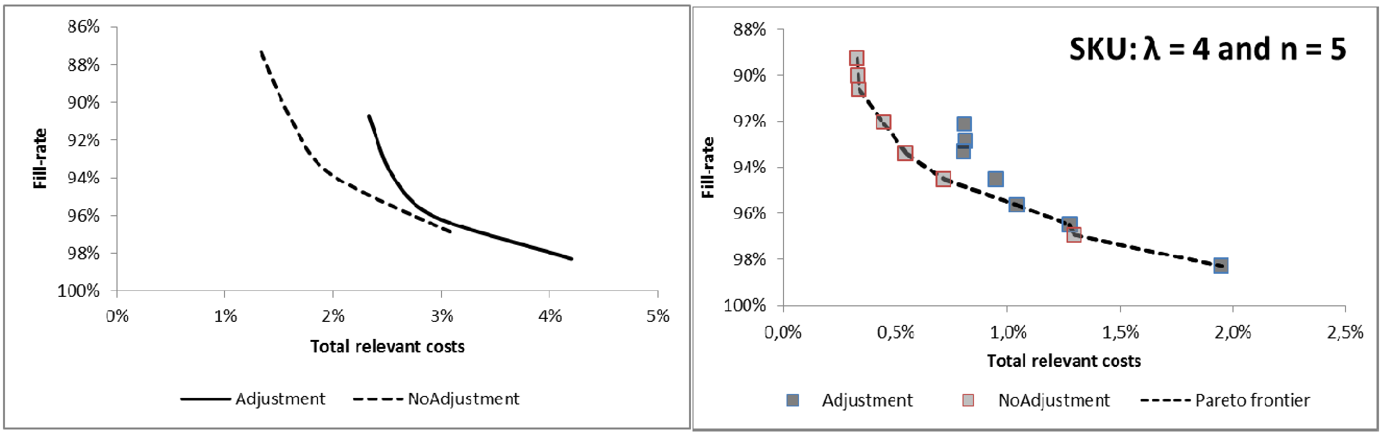

Figure 7.1: Overall performance (left-side) and outcomes for a specific SKU (right-side) of Adjustment and NoAdjustment strategy.

In order to underscore our initial conclusion, we looked at a specific product that performs well for the adjustment strategy (See Table 7.1). We choose the product (SKU) with mean daily demand of four and shelf-life of five days. For this SKU, the outcomes of both policies for seven different targeted fill-rates (safety stock levels) are plotted (See Figure 7.1). From this set of fourteen outcomes a Pareto frontier was constructed. All seven outcomes of the NoAdjustment-policy lie on the Pareto frontier, and only three of the Adjustment-strategy outcomes are Pareto efficient. Around the desired fill-rate of 95%, the NoAdjustment-policy outcomes are on the Pareto frontier, instead of the Adjustment-policy outcomes. Concluding that our initial verdict, the Adjustment-strategy is not beneficial can be confirmed by investigating a specific, best for the adjustment strategy, SPAR product.

7.2 Order and delivery-schedule insights

For the order and delivery-schedule insights, we take the average product parameters and 85% targeted fill-rate as the base inputs. The 61111101-schedule has the biggest increase in fill-rate, because this schedule has more order-moments per week and therefore more adjustments opportunities. Due to the same fact, the relative adjustment costs are also higher for the 61111101-schedule. When the number of stores per replenishment cycle increases, the size of the adjustment assortment also decreases. With the same fixed costs, but with a lower total wholesale turnover, this leads to a higher relative adjustment cost. The lowest costs are therefore for the 31010100-schedule, because the number of stores each replenishment cycle is lowest. Therefore, the 31010100-schedule performs best with the adjustment strategy, because the ratio between costs increase and fill-rate increase is best.

Table 7.2: Average increase between Adjustment-policy and NoAdjustment-policy for different order-schedules.

Order schedule	31010100 (Δ%)	41011100 (Δ%)	61111101 (Δ%)
Fill-rate	2.50	2.88	3.20
Total relevant costs	0.56	0.72	0.76
Relative outdating	0.33	0.34	0.25
Relative adjustment	0.23	0.38	0.52

An increase in delivery frequency is very expensive for SPAR, due to high transportation costs and low volumes. In the current (desired) situation, SPAR stores have four cross-dock deliveries per week. Reducing the delivery frequency can save a lot of money; therefore we compared the scenario of

NoAdjustment and current order schedule 41011100 with the Adjustment and 31010100-schedule. The NoAdjustment-policy with four delivery moments performs better than the Adjustment-strategy with three delivery moments. A service level of almost 97% can be reached with only 3% relative outdating, this is very good and outweighs the adjustment costs and operations for the 31010100-schedule (see Figure 6.2). Concluding, the implementation of the adjustment strategy cannot replace the fourth order-moment.

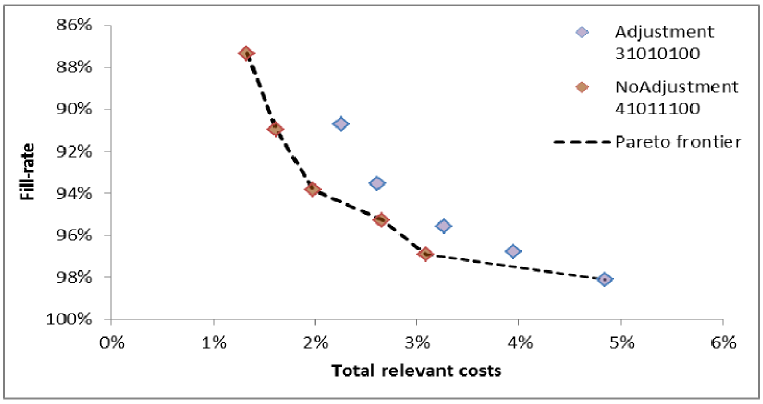

Figure 7.2: Adjustment-policy with 31010100-schedule compared to NoAdjustment-policy with 41011100-schedule.

7.3 KPIs for Adjustment-policy

In order to judge the feasibility of the proposed adjustment strategy, we indicated some performance measures. These key performance indicators were chosen for several parties involved in the strategy. We stated that the average shelf-life of a sold product must be at least 3 days for a customer and at least 2 days for the store owner. With the adjustment strategy these performance indicators are comfortable reached. The availability, which is measured in the fill-rate, is also reached when store owners set the targeted fill-rate at 90%. On average a fill-rate of 96.1% can be reached, with an average relative outdating of only 2.4% (see Table 7.3).

Table 7.3: KPIs for the 41011100-schedule with targeted service level of 90%.

Product parameters	Level	Shelf-life sold products (days)	Fill-rate (%)	Relative outdating (%)	Ratio Adjustment/Regular orders (#)	Ratio Adjustment/Regular products (#)
Mean demand (λ)	1	4.0	95.8%	9.0%	0.39	0.68
	2	4.4	96.6%	2.1%	0.32	0.46
	3	4.8	96.6%	0.6%	0.53	0.41
	4	5.1	95.6%	0.2%	0.42	0.30
	6	5.3	95.8%	0.0%	0.47	0.24
Shelf-life (*n*)	5	3.4	96.1%	5.2%	0.41	0.41
	6	4.2	96.1%	2.5%	0.43	0.42
	7	5.1	96.1%	1.2%	0.43	0.42
	8	6.1	96.1%	0.7%	0.43	0.42
Total	all	4.7	96.1%	2.4%	0.42	0.42

For SPAR and the supplier of the cross-dock products it is important that the adjustment strategy is manageable. For SPAR, handling of adjustment orders must be manageable, and for the supplier the production and forecasting of adjustment products must be doable. Two KPIs; average ratio between adjustment and regular orders and average ratio between adjustment and regular products were therefore chosen. The average number of regular orders that need an adjustment is on average 42%. The average size of an adjustment order is also 42% of the regular order size (1.7 SKU per regular order), resulting in a lot of small adjustment. These high ratios make the adjustment strategy not manageable when implemented and result into high relative adjustment costs. The relative costs are high, because the adjustment assortment is limited, due to high number of regular orders that have an adjustment order. Concluding, that based on the KPIs the adjustment strategy is not manageable and beneficial to implement at SPAR.

7.4 EWA-policy results

Besides the high relative adjustment costs, the good performance of the EWA-policy is another reason why the adjustment strategy is not beneficial. With a skewed demand distribution (Poisson distribution), the EWA-policy on average over-estimates the order quantity. This is because the adjustment for outdating is based on averages and rounding errors are made especially for low demands. The over-estimation of the order quantity is partly expressed by the positive difference in achieved fill-rate and targeted fill-rate in the simulation.

Table 7.4: Results NoAdjustment-policy for 41011100-schedule, for different product parameters.

Order-schedule		**31010100**			**41011100**		
Product parameters	**Level**	**Fill-rate (%)**	**Ready-rate (%)**	**Relative outdating (%)**	**Fill-rate (%)**	**Ready-rate (%)**	**Relative outdating (%)**
Mean demand (λ)	1	97.3	94.9	13.6	97.0	94.3	11.1
	2	97.3	94.2	4.0	97.2	93.5	3.0
	3	96.5	92.2	1.3	96.7	91.7	1.0
	4	96.7	91.9	0.5	96.9	91.5	0.4
	6	96.6	90.7	0.1	96.7	89.8	0.1
Shelf-life (*n*)	5	97.0	92.7	8.0	97.0	92.2	6.6
	6	96.9	92.9	4.1	96.9	92.1	3.1
	7	96.8	92.7	2.2	96.9	92.1	1.6
	8	96.8	92.8	1.3	96.9	92.1	1.1
Total	all	96.9	92.8	3.9	96.9	92.2	3.1

The use of the EWA-policy at the regular order moment results in high service levels with respectively low outdating. The current product availability in stores is around 92% and the current relative outdating is between 6% and 11%, when store owners using the current order-book method. With the use of the EWA-policy, store inventory performance can be significantly improved on both outdating and customer service. The achievable results for the 31010100-schedule and 41011100-schedule are shown in Table 7.4. On average a fill-rate of almost 97% is reachable with only 3 to 4 per cent relative outdating. This is a significant improvement on the current inventory performances with the store owners' method(s).

7.5 Conclusions and discussion

In this paragraph, the main findings about the simulation results are discussed in conjunction with a financial business case for SPAR. Followed, by a discussion on the performed simulation experiment with respect to the formulated research questions.

Conclusions

From the simulation analyses we learned that the adjustment policy is not beneficial for the selected products of SPAR and the franchisee, in order to improve the current customer service level. There are two main reasons why the adjustment strategy performs less than expected. First the EWA-policy used for the regular order performs very well. This means that the adjustment costs are not easy recouped by a slightly better performance of the Adjustment-policy. The comparison between the EWA-policy with and without adjustment showed that an investment in outdating (higher relative outdating costs) is less than an investment in adjustment operations (higher relative adjustment costs) for improvement of the fill-rate. For example improving the current 92% fill-rate (black star) to the desired 95% fill-rate, an investment in outdating ('O-star') is less than the investment in outdating plus adjustment operations ('A-star') (see Figure 7.3). In Table 7.5, the financial business case is calculated for the adjustment assortment of 58 SKU in 600 stores of SPAR. The financial calculations show that an investment in outdating is cheaper than an investment in the adjustment strategy for the improvement of the fill-rate for the selected products and stores of SPAR.

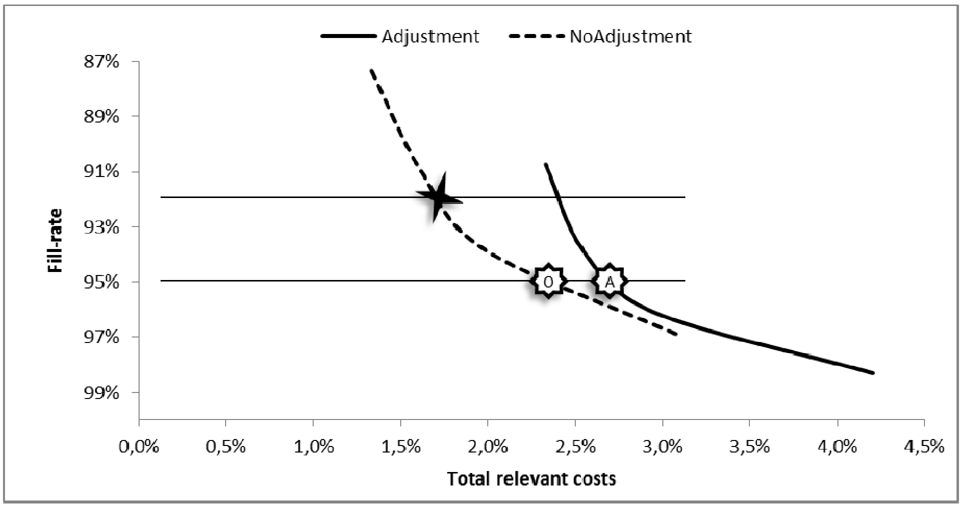

Figure 7.3: Investment options in outdating (moving along the NoAdjustment-line) and in adjustment operations (jumping to the Adjustment-line).

Second, the relative adjustment costs are high, due to the fact that a limited amount of products can be handled. The adjustment assortment is limited, due to a high average number of regular orders that need an adjustment (on average 42% of the regular orders has an adjustment order). Therefore four FTE can only handle a very limited amount of products per replenishment cycle.

The order and delivery schedule has only a minor influence on the Adjustment-policy performance. The adjustment strategy performs best when the number of orders per week is highest. This is primarily due to the fact that there are also more orders that can be adjusted during the week. The difference between a schedule with four and three order moments is very minor. Only costs differ, because with the 31010100-schedule the order moments are more spread over the week and no real peak moments exist. In the peak moment, double the stores need to be handled and thereby the number of different products that can use the adjustment strategy is halved. Going back to an order-schedule with three order moments with the adjustment strategy is not beneficial over a schedule with four order moments with no adjustment strategy. The benefits of the fourth order moment, during the high of the selling season, are bigger on relative outdating and fill-rate, than the application of the adjustment strategy.

Table 7.5: Business-case of SPAR for investment in fill-rate improvement from 92% to 95% and 97%.

Investment	for 95% fill-rate		for 97% fill-rate	
	NoAdjustment	Adjustment	NoAdjustment	Adjustment
Outdating	€ 291.667	€ 166.667	€ 666.667	€ 458.333
Adjustment	-	€ 250.000	-	€ 250.000
Total	€ 291.667	€ 416.667	€ 666.667	€ 708.333

The defined KPIs for the adjustment strategy of the stores and customers are well within the set boundaries. Availability, quality, and outdating levels show acceptable outcomes for the adjustment strategy. However the KPIs for SPAR and the supplier of perishable products are not within the pre-determined boundaries. The high number of adjustment orders will be hard to manage by SPAR. Also the size of the adjustment orders is high, meaning that the perishable product supplier of SPAR can have troubles in supplying the adjustment orders within the set adjustment order lead-time.

Concluding, the designed adjustment strategy does not provide a sufficient solution for the low availability of perishable products in the stores. However the used EWA-policy for the regular orders showed improved results with respect to product availability and outdating in stores. The current inventory performance could be significantly improved by applying a more sophisticated order-policy. A proper solution for the problem of SPAR is therefore the use of the EWA-policy by store owners, whereby the age-distribution of the on-hand inventory is taken into account when making an order decision.

Discussion

The simulation assumption that store owner orders are made with the EWA-policy is not accurately presenting the current reality at SPAR. The simulation experiment answers whether the designed adjustment strategy is beneficial on top of the use of the EWA-policy for regular orders. Due to the made design choices for a redesign of the current replenishment process, e.g. the EWA-policy for regular orders, the simulation experiment does not answer the question whether an adjustment is beneficial on top of the current used inventory policy. However, to make sound judgements about an adjustment strategy, the inventory control, forecast, and parameter settings need to be proper. The effects of the adjustment strategy on the current situation at SPAR cannot be exactly given. Investments in outdating can be more expensive for the current inventory policy than for the EWA-policy, in achieving higher service levels. Therefore the adjustment strategy could become beneficial. However the designed adjustment strategy is only based on the difference in forecasted and realized demand and does not consider the applied inventory control of the regular order. Therefore the increase in service level will not change much. Concluding, from the performed simulation and tested perishable inventory policies, we learned that applying the adjustment strategy is not a good first choice for improving the current inventory performances on outdating and customer service level.

7.6 Designed adjustment strategy

Despite the ideal setting for an adjustment strategy for a retailer (long review period with low demand and high variation), the cut-off point (from which the Adjustment-policy becomes beneficial above the NoAdjustment-policy) was not reached before already desired customer service levels were reached.

This does not necessarily mean that the designed adjustment strategy is always non-advantageous. Whether the cut-off point can be reached (and passed) before desired customer service levels and acceptable total costs are reached, will be discussed by looking at the effects of model inputs on both costs aspects.

The relative adjustment costs depend on the total value of the supplied product and the amount of products that make use of the adjustment strategy. First, the amount of products that makes use of the strategy depends primarily on the design of the order adjustment quantity rule. The design can be adjusted, such that the regular orders are adjusted less frequently. However different designs are part of future research, because this has major impact on all outcomes of the strategy. Second, the total value of the supplied products depends on the wholesale-price and the volume of the supplies. The wholesale-price directly affects the relative adjustment costs and has no effect on the relative outdating. Products with a high wholesale price have lower relative adjustment costs and higher outdating costs, therefore the cut-off point for the adjustment costs compared to the outdating costs can be reached sooner. The supply volume has effect on both relative outdating and relative adjustment costs. A higher supply volume leads to less outdating (and vice versa), because the change of outdating is reduced significant for higher average demands (see Table 7.4 and Appendix G). A higher supply leads also to lower relative adjustment costs (and vice versa), because the fixed costs are spread over more total supplies.

The adjustment strategy can become beneficial when the increase in costs of outdating (due to higher safety stock levels) is at least higher than the adjustment costs, when considering higher fill-rates. The relative adjustment costs are around .72% for the designed strategy (ranging between .26% and 1.75%). The total relative outdating have to at least transcend the relative adjustment costs, before adjustment costs can become even justifiable in terms of fill-rate improvements. With the EWA-policy for the regular orders this holds only for products with a very low shelf-life and/or low demand, or for very high desired fill-rates (see Appendix G). In these situations a relative high safety stock level is required in order to increase the fill-rate. A more suitable product, for which the adjustment strategy could be become beneficial, is a product with mean daily demand of three and a shelf-life of four. Because when you want to increase the fill-rate from 92.6% to 95.5%, the relative outdating increases significantly from 4.5% to 7.1%. The relative adjustment costs are probably less for the same size of increase in fill-rate, therefore the adjustment strategy could become beneficial. Next, costs of outdating is also much higher when demand variation is higher, a variance-to-mean ratio of two and higher results in high outdating costs for relatively high fill-rates (Donselaar & Broekmeulen, 2012). The occurrence of extreme demands is then higher and thereby the increase in fill-rate with the adjustment strategy could also be higher. Therefore the adjustment strategy can work better for these types of demands, settings, and products characteristics.

Concluding, the designed adjustment strategy will become more interesting for high value products. The strategy is also more interesting for products with a high desired fill-rate and low shelf-life, for which high relative outdating costs are necessary than were considered in this research project. Other factors have significant effects on both costs simultaneous, therefore the consequences cannot be clearly stated and should be input for future research on order adjustment strategies.

8. Conclusions and recommendations

In this final chapter, the conclusion is formulated about the research project. In the conclusion we summarize our findings and answer the main research question. The conclusion is followed by a SWOT-analysis of the research project. After that, we stated some recommendations for SPAR based on the findings of this project. Ending with some future research work for the academic literature and SPAR.

8.1 Conclusion

Highly perishable products are products with a shelf-life shorter than 10 days. These types of products belong to the strategic assortment of SPAR. A literature study and previous research at SPAR showed that the consumer reaction on out-of-stock of perishables almost always results in to lost sales. Therefore high in-store availability is crucial for the performance and customer perception of the format SPAR. However, other research at SPAR showed that the availability of highly perishable products is not always as high as desired by management. This was confirmed by this research on in-store availability and outdating of perishable products. We showed that the in-store availability was around 92% for highly perishable products, while a level of 95% and higher, is more desired.

The primary reason for the low availability was that the demand for highly perishable products was hard to predict. The selected perishable products had a low average daily demand with a high demand variation. From the selected products, three quarter had a mean daily demand of less than three and the average coefficient of variation was around .8. Combined this resulted into a lumpy demand pattern, that could be best modelled by a Poisson demand distribution. Next to the lumpy demand, the current supply chain structure of the highly perishable products resulted into review-periods of two days and lead-times of one day. This meant that forecast horizon of a perishable product order was long (approximately three days). A hard to predict demand, in combination with a long forecast order horizon, makes it very difficult for store management to make good order decisions. The order-book method used by store-owners was not able to ensure that the perishable inventory was efficiently managed. This all was confirmed by the fact that outdating was moderate high, between 6% and 11% of the supplies, while availability was lacking around 92% fill-rate.

In order to increase the availability, while managing outdating, we designed a new replenishment strategy. In this replenishment strategy store-orders could be adjusted during the order lead-time. The adjustment was upwards and based on sales information during the lead-time of the order. The store-order was upwards adjusted when the demand realization was higher than expected by SPAR. SPAR could make this decision, because it monitors the cash-registration systems in the stores. Thereby knowing the current sales and historical demand of the perishable products. In essence this strategy allowed that the in-store product availability could be improved with lower safety stock levels. The design also included that the store-order decisions were made with the EWA-policy of Donselaar & Broekmeulen (2009). An analysis of different inventory control policies for the perishable assortment of SPAR showed that the EWA-policy performed very well and better than the current methods used. Therefore, the use of the EWA-policy for the store-orders was included in the new replenishment strategy.

A simulation experiment was designed to compare the adjustment strategy with the no-adjustment strategy. The results showed that the adjustment strategy improved the fill-rate significantly, with a limited increase in costs. However, the adjustment strategy was still too expensive for the increase in customer service level to be justifiable. The main reasons were that the number of adjustment orders was too high per replenishment cycle, resulting into high relative adjustment costs. Second, the store-orders determined with the EWA-policy resulted into already very high fill-rates in combination with acceptable outdating. For an increase in fill-rate, an investment in outdating (higher safety stock levels) is more profitable than an investment in adjustment operations. Therefore the adjustment strategy is not beneficial for the selected products and stores of SPAR.

Concluding, the implementation of the order upwards adjustment method with additional cross-dock operations was not beneficial for SPAR and the franchisee in order to reduce the out-of-stock rate, when considering total relevant costs. However, the analyses and simulation showed that the availability and outdating could be significantly improved with the use of the EWA-policy for the store-orders.

8.2 SWOT analyses

Strengths

Several strong points of the project can be mentioned. First, due to a narrow focus of the project, thorough analyses could be performed and good conclusions could be stated about the business problem. Second point is a practical design and simulation of the adjustment strategy at SPAR. The designed adjustment strategy was tailored for SPAR and the solution could be implemented without high efforts and costs involved. Last, the quantitative approach of the project resulted into better insights and tangible results for the adjustment strategy at SPAR.

Weaknesses

The main weakness of the project was also the strength of the project. The tailored analyses and design provide little insights for academic literature. Only a selection of the SPAR assortment and stores were considered in this research project. Next to this, the set-up of the experiment did not result into the optimal outcomes of both policies for the model inputs. This meant that the comparison of both policies had to be performed with sub-optimal results and therefore no hard conclusion could be made.

Opportunities

More and more fresh products are cross-docked at retailers. Cross-docking allows retailers and supplier to provide fresher products in the stores. Next to this, corporate social responsibility is getting more and more important for companies. Therefore reducing spoilage of food products becomes an important aspect in retail companies. Therefore solutions needed to be designed to improve spoilage, while service levels are kept high levels for perishable products.

Threats

An important threat of the project was the upcoming implementation of an automated store ordering system at SPAR. The business problem could already been (partly) resolved by the implementation of a more advanced system for making ordering decisions.

8.3 Recommendation

The discussion about the simulation results concluded that an adjustment strategy is not beneficial for SPAR. However, the use of an EWA-policy for the regular orders (store orders) resulted into a significant improvement of the perishable inventory in fill-rate and outdating. Therefore we recommend the use of a more sophisticated and quantitative based issuing and ordering policy for perishable products in-stores.

8.4 Future research

The completion of this research project opens also some interesting future research topics for SPAR and for the academic literature. A few topics are discussed in this last paragraph.

First, the different designs of the adjustment strategy should be researched. Different order adjustment quantity rules should be investigated, that not result in to a lot of small adjustment, for example only adjusting when adjustment quantity is bigger than predetermined level. Next the upwards adjustment can be based on other criteria, for example also on the age-distribution of the stock-point. Besides an upwards adjustment, also a strategy whereby the store orders can be fully adjusted could be investigated. The fill-rate and outdating improvement could be better, when the regular orders are not only corrected upwards, but also downwards. This could lead to lower relative outdating while fill-rates stay equally, because over-stocking can prevented at one store and under-stocking at another store. A possible research direction for this is looking at pick-to-zero operations, were the complete order set is rearranged with the information gain during the lead-time. Second, different simulation inputs and assumptions can be analysed. These analyses can provide a more accurate insight why the adjustment strategy was not beneficial for SPAR. Also the implications for academic literature can thereby be extended. An important research issue is the combination of the EWA-policy and the adjustment strategy, the effect of this combination and possible other inventory control policies could be of high interest for future research. Also other assumptions like week pattern and different demand distributions need to be considered for the adjustment-policy. These facts could have significant effects on the outcomes of the strategy.

The implementation of an order decision system that includes the EWA mind-set should be investigated by SPAR. The strict use of the EWA-policy will not be possible for SPAR to implement. However, the current perishable order methods could be adjusted in order to take into account the principles of the EWA-policy. The exact form and performance needs further investigation, before it can be implemented in the stores.

More collaboration with the perishable product supplier should be investigated by SPAR. The goal of the collaboration must be a fresher product in the stores, because this significantly improves the inventory performance and customer satisfaction. A possible research direction could be vertical collaboration on forecasting and order decisions for stores. With the implementation of an automated store ordering system at SPAR, the benefits of information sharing in the supply chain could be also investigated for highly perishable products. Future research is necessary on these topics.

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ASO	Automated store ordering
COP	Constant order policy
CV	Coefficient of variation
DC	Distribution centre
DES	Discrete Event Simulation
DF	Daily-fresh
EWA	Estimated withdrawal and ageing
FIFO	First in, First out
FEFO	First expired, First out
FMCG	Fast moving consumer goods
FTE	Full Time Employee
KPI	Key Performance Indicator
LIFO	Last in, First out
MAE	Mean Average Error
MAPE	Mean Average Percentage Error
OOS	Out-of-Stock
POS	Point-of-Sales
RFS	Retail floor space
SKU	Stock keeping unit
UAP	Uniform article presentation

List of variables

β	Fill-rate service level (%)
λ	Poisson parameter (#)
μ	Average daily customer demand (#)
#A	Adjustment assortment quantity (#)
B	Batch (#)
D	Demand realization (#)
f	Weekday factor for demand
IP	Inventory position (#)
L	Lead-time replenishment (period)
n	Fixed lifetime of product (period)
O	Outdating (#)
$P_{Wholesale}$	Wholesale price of product for Store (Euro)
Q	Case pack size (#)
q	Order quantity (#)
R	Review (period)
S	Order-up-to level (#)
Sp	Spoilage (#)
SS	Safety stock (#)
W	Withdrawal quantity (#)
X	On-hand inventory (#)

Appendix A: Overview of selected stores and products

SPAR Holding B.V. exploit different store formats; SPAR and Attent (Super in de buurt and Super op vakantie). An overview of the locations in the Netherlands is presented (overview of 2009). The size of the spheres indicates the relative consumer turnover of the different stores. The eight stores (all SPAR format), that are used in this research are indicated with a white sphere.

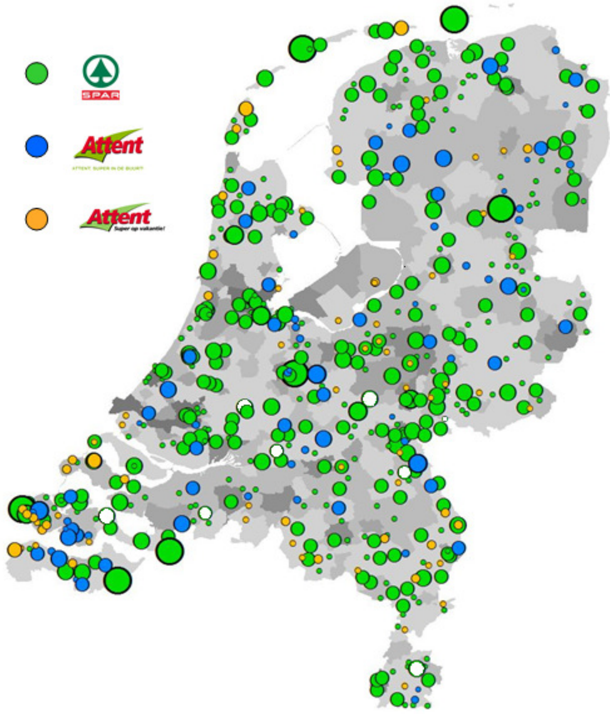

Figure A.1: Overview of stores under SPAR Holding B.V.

Detailed information about the stores that were selected in the analyses are shown in Table A.1 below.

Table A.0.1: Overview of selected SPAR stores for the analysis.

Store ID	RFS (m^2)	Weekly turnover (€)	Delivery frequency (#/week)	Morning/Afternoon store	Delivery window (time)
Store_An	700	36.259	3	Morning	7:00 – 10:15
Store_Ha	510	43.698	3	Morning	7:00 – 11:00
Store_Ma	421	55.620	3	Afternoon	12:00 – 17:00
Store_Ze	490	48.701	3	Morning	7:00 – 10:15
Store_Wa	506	45.506	3	Morning	7:00 – 12:00
Store_Sc	340	40.000	3	Morning	7:00 – 9:45
Store_Sp	655	36.412	3	Morning	6:30 – 10:30
Store_Ho	488	50.700	3	Morning	6:00 – 14:30

The assortment of the perishable supplier changes often during the year. This is an overview of the products in the assortment in week 6 of 2012. A selection of these products was used in the analysis. The 'best before'-label stands for the agreed minimum life-time of the product when shipped towards the distribution centres of SPAR. The 'order quantity' was the minimal order quantity that store owners can order at this supplier.

Table A.2: Overview of ready-to-cook vegetables.

PRODUCT	BEST BEFORE	ORDER QUANTITY	PRODUCT	BEST BEFORE	ORDER QUANTITY
SPAR champignon roerbakgr. 400 g	7	1	SPAR Zuurkool, bakje 500 g	7	1
SPAR slamelange, zakje 200 g	6	1	SPAR maca/spaghettigroenten 500 g	7	1
SPAR saladeschotel rauwkost, 350 g	7	1	SPAR bamipakket 450 g	7	1
SPAR bloemkoolroosjes, zakje 400 g	7	1	SPAR maca/spagh pakket 450 g	6	1
SPAR Andijvie minipack. zakje 250 g	5	1	SPAR nasipakket 450	7	1
SPAR Kleintje bami/nasi, zakje 250	7	1	SPAR tauge 150 g	7	1
SPAR Snijbonen, zakje 250 g	7	1	SPAR bakmix 200 g	6	1
SPAR miniworteltjes, zakje 350 gr.	7	1	SPAR maaltijdsalade geitenkaas	5	1
SPAR Prei, zakje 500 gr	7	1	SPAR lunchsalade gerookte kip 180 g	6	1
SPAR kleintje maca/spag., zakje 250	7	1	SPAR lunchsalade mozzarella 130 g	5	1
SPAR Spitskool, zakje 500 gr	7	1	SPAR maaltijdsalade Grieks 350 g	6	1
SPAR Bami/nasigroenten, zakje 500 g	7	1	SPAR hollandse roerbakgr 400 ZMK	6	1
SPAR Peultjes en worteltjes 300 gr	7	1	SPAR Oosterse roerbak 470	6	1
SPAR Prei minipack, zakje 200 g	7	1	SPAR rode biet met ui, 400 g	6	1
SPAR andijvie, zakje 400 g	6	1	SPAR maaltijdsalade kip/pasta 300 g	5	1
SPAR boerenkool 250 gram	6	1	SPAR saladeschotel spekjes 250 g	7	1
SPAR boerensoepgroenten, zakje 250g	6	1	SPAR rucola naturel, zakje 75 g	6	1
SPAR Baby leaf, zakje 100 gr	5	1	SPAR gourmetschotel 350 g	5	1
SPAR Veldsla, zakje 100 g	6	1	SPAR maaltijdsalade zalm 350 g	6	1
SPAR chinese roerbakgroenten, 400 g	6	1	SPAR savooiekool, zakje 350 g	7	1
SPAR fijne soepgroenten, zakje 200	7	1	SPAR soepgroenten, zakje 500 g	7	1
SPAR gemengde sla, zakje 200 g	7	1	SPAR mosselgroenten, zakje 350 g	6	1
SPAR geschrapte waspeen, zakje 500g	7	1	SPAR Zuurkool, bakje 250 g	7	1
SPAR hutspot, zakje 500 g	7	1	SPAR Hutspot, zakje 750 g	7	1
SPAR Spinazie, zakje 300 gr	5	1	SPAR Erwtensoepgroenten, zakje 450g	7	1
SPAR Uienringen, zakje 300 g	7	1	SPAR gepunte sperziebonen, 350 g	7	1
SPAR Uienblokjes, 250 gr	7	1	SPAR pittige rauwkost, zakje 250 g	7	1
SPAR Ijsbergsla, zakje 200 g	7	1	SPAR rauwkost naturel, zakje 150 g	7	1
SPAR IJsberg naturel, zakje 250 g	7	1	SPAR koolraap, zakje 500 g	7	1
SPAR italiaanse roerbakgroenten 400	6	1	SPAR wortelrauwkostmix, zakje 200 g	7	1
SPAR rucola slamix, zakje 100 g	5	1	SPAR tuinkruidensoep, zakje 250 g	7	1
SPAR saladeschotel ijsbergsla 300 g	7	1	SPAR ijsbergsla mini, zakje 100 g	7	1
SPAR mediterrane rauwkost, 250 g	6	1	SPAR, broccoli, zakje 300 g	7	1
SPAR Rode kool, zakje 350 g	6	1	SPAR bami/nasigroenten budget 500 g	6	1
SPAR Spruiten, zakje 350 g	6	1	FQ stoofperen 400 gr	6	1
SPAR Italiaanse roerbakgr. 250 gr	6	1	SPAR ananas, 560 g ReadyFr-label	5	1
SPAR Chinese roerbakgr. 200 gram	6	1	SPAR fruit 250 g ReadyFr-label	5	1
SPAR Witte kool, zakje 350 g	7	1	SPAR fruit 560 g ReadyFr-label	5	1

Appendix B: Demand analysis

In this appendix the detailed results of the demand analysis are shown in different figures and tables.

Table B.1: Week pattern analyses.

	Monday	Tuesday	Wednesda	Thursday	Friday	Saturday	Sunday
mean	111%	106%	113%	114%	132%	124%	0%
cv	0,2	0,2	0,2	0,2	0,2	0,2	0

The week pattern analyses show the relative factor for daily demand. The coefficient of variation (CV) shows the variation between products and stores on daily level. This shows that the week pattern is the same for different stores and product combinations.

A very common and simple forecast method, with a stationary time series, is the mean. This method was also often used by store owners of SPAR. Therefore a forecast was made on the POS data, by taking the mean. Two important goodness-of-fit measures that determine the variability of the time series when forecasting, are the mean absolute error (MAE) and the mean absolute percentage error (MAPE). The average MAE was 1.2 and MAPE was 58.6 % (see Table B.2), this implied a rather high variability of the demand series.

Table B.2: The demand characteristics from the 21 products on Fridays (after filtering the data).

SPAR_code	Product	Mean	CV	Kurtosis	Skewness	MAE	MAPE
7260	**SLA MELANGE**	1,66	0,90	0,55	0,87	1,10	66,5%
7270	**BOERENSOEPGROENTEN**	2,00	0,78	-0,37	0,54	1,11	55,3%
7390	**CHIN.ROERBAKGROENTEN**	1,57	0,93	0,50	0,89	1,09	69,4%
7400	**FIJNE SOEPGROENTEN**	6,58	0,48	-0,29	0,38	2,35	35,8%
7430	**GEMENGDE SLA**	4,65	0,54	-0,71	0,33	2,04	43,8%
7440	**GESCHRAPTE WASPEEN**	2,51	0,82	0,17	0,85	1,48	59,2%
7600	**GEMENGDE IJSBERGSLA EXTRA**	2,72	0,69	-0,25	0,61	1,48	54,5%
7610	**IJSBERGSLA NATUREL**	3,37	0,54	-0,74	0,20	1,47	43,8%
7650	**RUCOLA SLAMIX**	2,56	0,72	0,43	0,81	1,37	53,5%
72350	**GESCHR MINI WORTEL**	2,04	0,75	-0,41	0,52	1,06	51,7%
72420	**MACA/SPAG GROENTEN 250GR**	1,50	0,86	-0,39	0,57	1,01	67,4%
72440	**BAMI/NASI GROENTEN 500GR**	2,72	0,65	-0,27	0,47	1,42	52,0%
72570	**VELDSLA**	1,25	0,86	-0,18	0,60	0,86	68,6%
72600	**BABY LEAF**	1,83	0,81	-0,10	0,72	1,09	59,5%
99690	**RUCOLA NATUREL**	1,30	1,02	0,25	0,90	0,94	72,0%
99700	**BAMI/NASI GROENTEN 250GR**	1,52	0,81	-0,14	0,53	0,95	62,5%
515783	**BAMIPAKKET**	1,39	0,95	0,62	0,93	0,97	69,6%
515784	**NASIPAKKET**	1,18	0,93	-0,39	0,65	0,86	72,5%
515785	**MACA/SPAG GROENTEN 500GR**	2,12	0,72	-0,11	0,59	1,19	56,3%
515786	**MACA/SPAG PAKKET**	1,61	0,77	0,12	0,60	0,99	61,2%
515787	**TAUGE**	2,00	0,84	0,02	0,71	1,10	54,8%

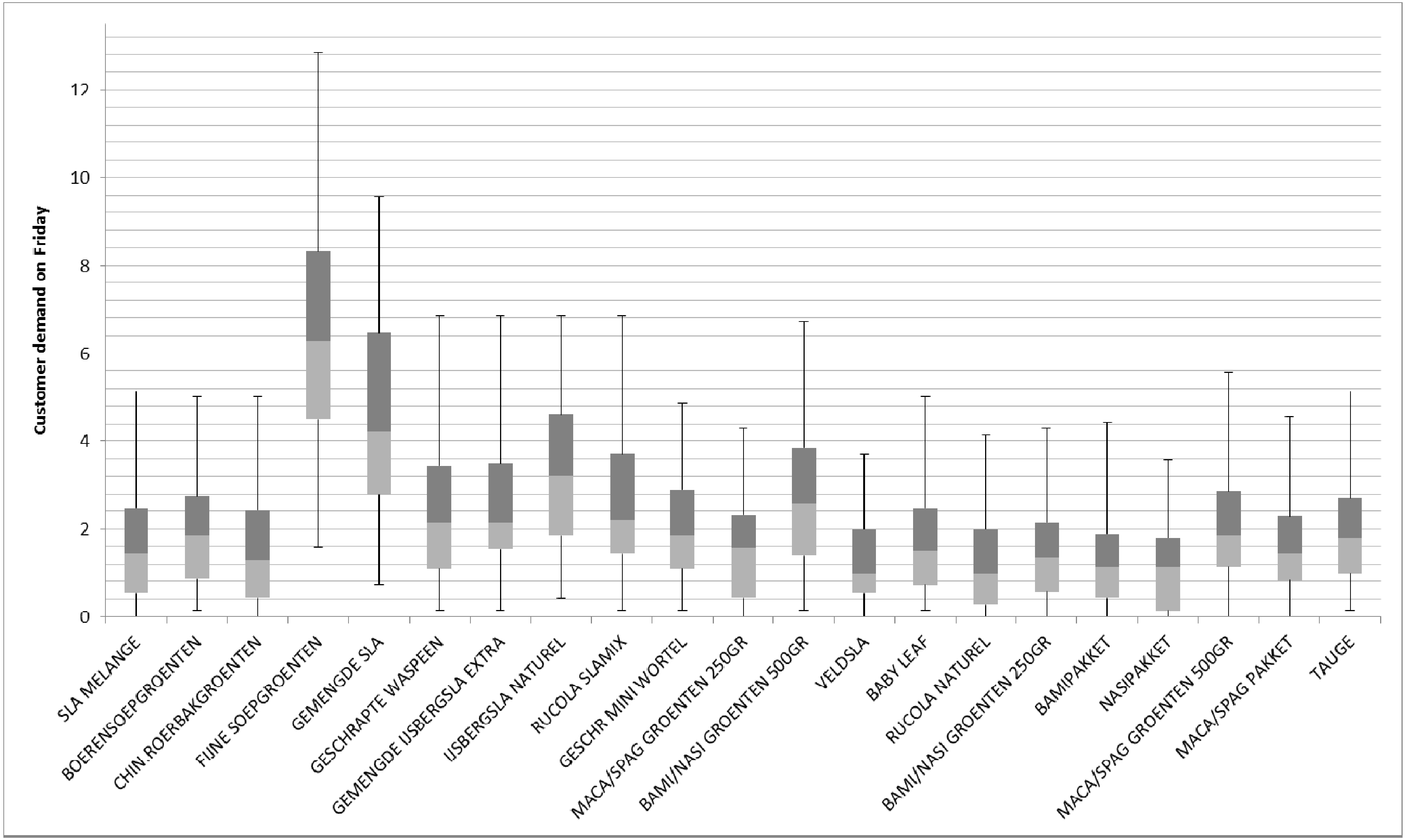

Figure B.1: Five-number summary boxplots.

Appendix C: Current store ordering performance

The data in this appendix was based on the ordering and sales data from 1-8-2011 until 20-12-2011. The outdating level and ready rate are calculated for all 147 store-product combinations.

Table C.1: Outdating level based on equal begin- and end inventory.

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	18,07%	4,72%	14,71%	20,80%	2,51%	5,45%	7,80%	10,58%
7270	BOERENSOEPGROENTEN	14,78%	3,63%	28,57%	40,63%	21,26%	3,68%	20,73%	19,04%
7390	CHIN.ROERBAKGROENTEN	7,59%	7,58%	24,02%	19,28%	12,59%	11,35%	28,30%	15,81%
7400	FIJNE SOEPGROENTEN	1,69%	0,00%	0,66%	4,20%	5,26%	1,11%	7,14%	2,87%
7430	GEMENGDE SLA	4,68%	9,87%	1,49%	16,44%	5,99%	0,30%	4,64%	6,20%
7440	GESCHRAPTE WASPEEN	1,78%	4,56%	23,89%	5,35%	0,81%	10,65%	16,04%	9,01%
7600	GEMENGDE IJSBERGSLA EXTRA	7,05%	5,25%	7,14%	10,45%	1,98%	1,23%	10,34%	6,21%
7610	IJSBERGSLA NATUREL	0,95%	1,79%	10,53%	2,89%	2,00%	1,04%	7,01%	3,74%
7650	RUCOLA SLAMIX	9,66%	9,96%	15,98%	21,14%	0,00%	8,74%	19,09%	12,08%
72350	GESCHR MINI WORTEL	1,47%	1,06%	4,55%	12,75%	0,28%	6,88%	15,11%	6,01%
72420	MACA/SPAG GROENTEN 250GR	7,11%	0,37%	4,33%	5,41%	5,81%	15,54%	15,82%	7,77%
72440	BAMI/NASI GROENTEN 500GR	3,37%	1,15%	1,22%	7,72%	1,16%	14,50%	1,98%	4,44%
72570	VELDSLA	6,12%	18,13%	28,99%	33,16%	8,50%	17,58%	34,27%	20,96%
72600	BABY LEAF	17,27%	11,74%	22,94%	25,12%	2,53%	22,13%	15,28%	16,72%
99690	RUCOLA NATUREL	5,00%	14,11%	12,57%	17,76%	5,20%	15,60%	23,08%	13,33%
99700	BAMI/NASI GROENTEN 250GR	9,62%	2,86%	8,91%	9,95%	18,22%	20,32%	22,44%	13,19%
515783	BAMIPAKKET	4,00%	10,78%	16,02%	24,49%	17,61%	25,00%	13,49%	15,91%
515784	NASIPAKKET	9,68%	26,90%	12,17%	13,74%	17,74%	18,52%	10,95%	15,67%
515785	MACA/SPAG GROENTEN 500GR	9,38%	0,00%	3,60%	10,55%	3,60%	7,46%	1,77%	5,19%
515786	MACA/SPAG PAKKET	3,97%	2,06%	10,36%	12,98%	13,98%	2,97%	4,12%	7,20%
515787	TAUGE	6,83%	3,15%	0,00%	0,00%	6,19%	23,08%	5,21%	6,35%
	Mean	7,15%	6,65%	12,03%	14,99%	7,30%	11,10%	13,55%	10,40%

Table C.2: Average outdated products per week based on equal begin- and end inventory.

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	0,75	0,50	1,00	2,35	0,25	0,45	0,55	0,84
7270	BOERENSOEPGROENTEN	0,85	0,45	2,70	3,25	1,35	0,55	2,00	1,59
7390	CHIN.ROERBAKGROENTEN	0,55	1,00	3,05	2,95	1,75	0,80	2,25	1,76
7400	FIJNE SOEPGROENTEN	0,45	0,00	0,15	0,90	1,00	0,35	1,60	0,64
7430	GEMENGDE SLA	0,65	3,15	0,25	3,60	1,85	0,05	1,40	1,56
7440	GESCHRAPTE WASPEEN	0,15	0,95	2,15	0,80	0,15	0,90	1,70	0,97
7600	GEMENGDE IJSBERGSLA EXTRA	0,85	0,85	1,00	2,10	0,45	0,20	1,20	0,95
7610	IJSBERGSLA NATUREL	0,10	0,35	1,40	0,60	0,40	0,15	1,70	0,67
7650	RUCOLA SLAMIX	1,00	1,40	1,75	2,60	0,00	0,90	2,30	1,42
72350	GESCHR MINI WORTEL	0,10	0,20	0,40	1,90	0,05	0,55	1,05	0,61
72420	MACA/SPAG GROENTEN 250GR	0,75	0,05	0,50	0,50	0,70	1,50	1,25	0,75
72440	BAMI/NASI GROENTEN 500GR	0,35	0,25	0,20	1,25	0,20	1,45	0,30	0,57
72570	VELDSLA	0,45	1,45	2,00	3,10	1,05	0,80	2,45	1,61
72600	BABY LEAF	0,95	1,65	2,50	2,70	0,45	2,70	1,75	1,81
99690	RUCOLA NATUREL	0,30	1,15	1,15	1,90	0,70	0,85	0,90	0,99
99700	BAMI/NASI GROENTEN 250GR	0,75	0,35	1,10	1,00	2,05	1,90	1,75	1,27
515783	BAMIPAKKET	0,30	0,90	2,05	2,40	1,25	2,15	1,45	1,50
515784	NASIPAKKET	0,60	2,30	1,15	0,90	1,10	1,50	0,75	1,19
515785	MACA/SPAG GROENTEN 500GR	0,60	0,00	0,50	1,45	0,45	0,75	0,25	0,57
515786	MACA/SPAG PAKKET	0,55	0,25	1,30	1,70	1,65	0,30	0,50	1,12
515787	TAUGE	0,55	0,40	0,00	0,00	0,95	2,10	0,55	1,12
	Mean	0,55	0,84	1,25	1,81	0,85	1,00	1,32	1,12

Table C.3: Relative outdating results TraceSPAR (* unreliable/insufficient trace/data).

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	22,9%	3,3%	15,4%	16,8%	2,5%	4,8%	8,5%	10,6%
7270	BOERENSOEPGROENTEN	11,3%	4,8%	26,5%	41,3%	23,6%	1,0%	18,7%	18,2%
7390	CHIN.ROERBAKGROENTEN	9,0%	7,6%	22,0%	17,6%	10,8%	8,5%	27,7%	14,7%
7400	FIJNE SOEPGROENTEN	*	0,0%	2,2%	2,8%	4,2%	0,0%	6,5%	2,6%
7430	GEMENGDE SLA	6,5%	9,1%	2,1%	16,4%	6,8%	0,0%	5,3%	6,6%
7440	GESCHRAPTE WASPEEN	5,9%	3,6%	22,8%	2,0%	2,2%	11,2%	*	8,0%
7600	GEMENGDE IJSBERGSLA EXTRA	7,1%	8,3%	7,1%	7,7%	3,1%	2,5%	7,8%	6,2%
7610	IJSBERGSLA NATUREL	2,9%	3,3%	*	2,2%	3,2%	1,0%	7,6%	3,4%
7650	RUCOLA SLAMIX	11,1%	9,3%	10,0%	17,1%	1,4%	9,2%	17,8%	10,8%
72350	GESCHR MINI WORTEL	3,7%	1,9%	*	12,1%	0,0%	8,8%	15,8%	7,0%
72420	MACA/SPAG GROENTEN 250GR	8,5%	2,2%	3,0%	5,9%	8,7%	16,6%	15,8%	8,7%
72440	BAMI/NASI GROENTEN 500GR	4,3%	2,3%	1,5%	9,0%	1,2%	14,5%	3,6%	5,2%
72570	VELDSLA	4,1%	18,8%	26,8%	32,6%	9,3%	16,5%	35,7%	20,5%
72600	BABY LEAF	16,4%	9,3%	21,6%	22,3%	2,8%	20,5%	15,3%	15,4%
99690	RUCOLA NATUREL	9,2%	14,1%	10,9%	15,4%	4,8%	14,7%	26,9%	13,7%
99700	BAMI/NASI GROENTEN 250GR	9,0%	4,9%	9,7%	12,4%	18,2%	18,7%	25,0%	14,0%
515783	BAMIPAKKET	6,0%	*	12,9%	23,0%	17,6%	22,1%	14,4%	16,0%
515784	NASIPAKKET	8,9%	26,3%	13,2%	11,5%	10,5%	19,8%	12,4%	14,6%
515785	MACA/SPAG GROENTEN 500GR	*	*	*	*	2,5%	*	*	*
515786	MACA/SPAG PAKKET	*	*	*	*	14,8%	*	*	*
515787	TAUGE	7,5%	2,4%	*	0,0%	5,2%	21,4%	5,7%	7,0%
	Mean	8,6%	7,3%	13,0%	14,1%	7,3%	11,1%	15,0%	10,9%

Table C.4: Average relative outdating.

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	21,7%	4,0%	15,1%	18,8%	3,3%	5,2%	8,2%	10,9%
7270	BOERENSOEPGROENTEN	13,5%	4,2%	27,5%	40,9%	23,2%	2,3%	19,7%	18,8%
7390	CHIN.ROERBAKGROENTEN	10,0%	7,6%	23,0%	18,5%	12,4%	9,9%	28,0%	15,6%
7400	FIJNE SOEPGROENTEN	2,6%	0,0%	1,4%	3,5%	5,4%	0,6%	6,8%	2,9%
7430	GEMENGDE SLA	5,6%	9,5%	1,8%	16,4%	7,6%	0,1%	5,0%	6,6%
7440	GESCHRAPTE WASPEEN	5,3%	4,1%	23,3%	3,7%	2,3%	10,9%	16,0%	9,4%
7600	GEMENGDE IJSBERGSLA EXTRA	7,3%	6,8%	7,1%	9,1%	3,6%	1,8%	9,1%	6,4%
7610	IJSBERGSLA NATUREL	2,9%	2,6%	10,5%	2,5%	4,0%	1,0%	7,3%	4,4%
7650	RUCOLA SLAMIX	15,5%	9,6%	13,0%	19,1%	2,3%	9,0%	18,5%	12,4%
72350	GESCHR MINI WORTEL	3,3%	1,5%	4,5%	12,4%	0,7%	7,8%	15,5%	6,5%
72420	MACA/SPAG GROENTEN 250GR	8,1%	1,3%	3,7%	5,7%	8,3%	16,1%	15,8%	8,4%
72440	BAMI/NASI GROENTEN 500GR	4,8%	1,7%	1,4%	8,3%	2,3%	14,5%	2,8%	5,1%
72570	VELDSLA	5,8%	18,4%	27,9%	32,9%	9,9%	17,0%	35,0%	21,0%
72600	BABY LEAF	17,7%	10,5%	22,2%	23,7%	3,5%	21,3%	15,3%	16,3%
99690	RUCOLA NATUREL	7,9%	14,1%	11,7%	16,6%	6,3%	15,1%	25,0%	13,8%
99700	BAMI/NASI GROENTEN 250GR	10,3%	3,9%	9,3%	11,2%	18,7%	19,5%	23,7%	13,8%
515783	BAMIPAKKET	5,7%	10,8%	14,5%	23,7%	18,3%	23,5%	14,0%	15,8%
515784	NASIPAKKET	9,7%	26,6%	12,7%	12,6%	14,9%	19,1%	11,7%	15,3%
515785	MACA/SPAG GROENTEN 500GR	12,5%	0,0%	3,6%	10,5%	4,5%	7,5%	1,8%	5,8%
515786	MACA/SPAG PAKKET	6,5%	2,1%	10,4%	13,0%	15,5%	3,0%	4,1%	7,8%
515787	TAUGE	8,1%	2,8%	0,0%	0,0%	7,0%	22,3%	5,5%	6,5%
	Mean	8,8%	6,8%	11,7%	14,4%	8,3%	10,8%	13,7%	10,6%

Table C.5: Upper bound ready rate.

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	92,86%	96,45%	93,62%	100,00%	100,00%	99,29%	98,58%	97,26%
7270	BOERENSOEPGROENTEN	94,29%	99,29%	92,91%	97,16%	91,43%	99,29%	98,58%	96,13%
7390	CHIN.ROERBAKGROENTEN	97,14%	97,16%	95,74%	99,29%	100,00%	96,45%	97,87%	97,67%
7400	FIJNE SOEPGROENTEN	98,57%	98,58%	97,16%	100,00%	99,29%	99,29%	97,87%	98,68%
7430	GEMENGDE SLA	98,57%	100,00%	99,29%	97,87%	100,00%	95,04%	99,29%	98,58%
7440	GESCHRAPTE WASPEEN	99,28%	99,29%	96,45%	97,16%	92,14%	97,87%	*	97,03%
7600	GEMENGDE IJSBERGSLA EXTRA	100,00%	99,29%	97,87%	99,29%	100,00%	98,58%	97,87%	98,99%
7610	IJSBERGSLA NATUREL	99,29%	98,58%	*	95,74%	100,00%	96,45%	99,29%	98,23%
7650	RUCOLA SLAMIX	97,86%	97,16%	96,45%	97,87%	80,00%	98,58%	99,29%	95,32%
72350	GESCHR MINI WORTEL	97,14%	97,16%	*	98,58%	86,43%	94,33%	97,87%	95,25%
72420	MACA/SPAG GROENTEN 250GR	95,71%	96,45%	99,29%	100,00%	88,57%	97,87%	96,45%	96,34%
72440	BAMI/NASI GROENTEN 500GR	98,57%	99,29%	98,58%	98,58%	95,00%	99,29%	99,29%	98,37%
72570	VELDSLA	98,57%	95,04%	97,16%	100,00%	95,71%	95,74%	97,16%	97,06%
72600	BABY LEAF	85,71%	100,00%	95,03%	97,16%	99,29%	99,29%	99,26%	96,53%
99690	RUCOLA NATUREL	95,00%	96,45%	96,45%	99,29%	*	97,87%	76,59%	93,61%
99700	BAMI/NASI GROENTEN 250GR	95,71%	98,58%	97,87%	98,58%	94,29%	99,29%	97,87%	97,46%
515783	BAMIPAKKET	97,14%	*	99,29%	97,16%	96,43%	99,29%	99,29%	98,10%
515784	NASIPAKKET	97,86%	98,58%	97,87%	98,58%	86,43%	98,58%	96,45%	96,34%
515785	MACA/SPAG GROENTEN 500GR	*	*	*	*	*	*	*	*
515786	MACA/SPAG PAKKET	*	*	*	*	*	*	*	*
515787	TAUGE	98,57%	98,58%	*	98,58%	100,00%	98,58%	99,29%	98,93%
	Mean	96,73%	98,11%	96,94%	98,47%	94,72%	97,95%	97,12%	97,15%

Table C.6: Lower bound ready rate.

SPAR_code	Product	Store_An	Store_Ha	Store_Ma	Store_Ze	Store_Wa	Store_Sp	Store_Ho	Mean
7260	SLA MELANGE	78,01%	87,23%	80,85%	91,49%	93,57%	97,16%	93,62%	88,85%
7270	BOERENSOEPGROENTEN	75,88%	89,36%	80,14%	90,78%	89,29%	90,07%	90,78%	86,61%
7390	CHIN.ROERBAKGROENTEN	85,10%	87,94%	82,98%	92,19%	98,57%	90,07%	93,62%	90,07%
7400	FIJNE SOEPGROENTEN	85,81%	81,56%	82,98%	91,49%	90,00%	92,91%	84,40%	87,02%
7430	GEMENGDE SLA	87,23%	96,45%	85,82%	88,65%	97,14%	81,56%	91,49%	89,76%
7440	GESCHRAPTE WASPEEN	90,78%	78,01%	88,65%	87,23%	80,71%	95,04%	*	86,74%
7600	GEMENGDE IJSBERGSLA EXTRA	91,48%	91,49%	87,23%	90,78%	97,14%	86,50%	92,20%	90,97%
7610	IJSBERGSLA NATUREL	90,07%	87,23%	*	80,85%	80,71%	88,65%	94,32%	86,97%
7650	RUCOLA SLAMIX	86,52%	84,40%	90,07%	90,07%	60,71%	90,70%	92,19%	84,95%
72350	GESCHR MINI WORTEL	82,27%	79,43%	*	85,11%	84,29%	79,43%	89,36%	83,31%
72420	MACA/SPAG GROENTEN 250GR	78,01%	82,27%	90,78%	93,62%	84,29%	89,36%	88,65%	86,71%
72440	BAMI/NASI GROENTEN 500GR	91,48%	87,94%	87,20%	89,36%	84,29%	88,65%	90,78%	88,53%
72570	VELDSLA	87,94%	82,97%	92,19%	96,45%	90,71%	86,52%	92,91%	89,96%
72600	BABY LEAF	71,63%	95,04%	86,52%	92,20%	87,86%	87,94%	90,07%	87,32%
99690	RUCOLA NATUREL	82,27%	88,65%	89,36%	92,20%	*	91,49%	65,24%	84,87%
99700	BAMI/NASI GROENTEN 250GR	84,39%	89,36%	84,39%	90,07%	82,14%	94,33%	92,19%	88,12%
515783	BAMIPAKKET	85,10%	*	87,94%	93,61%	90,00%	94,33%	90,78%	90,29%
515784	NASIPAKKET	87,23%	90,07%	87,94%	90,07%	85,00%	91,49%	87,23%	88,43%
515785	MACA/SPAG GROENTEN 500GR	*	*	*	*	*	*	*	*
515786	MACA/SPAG PAKKET	*	*	*	*	*	*	*	*
515787	TAUGE	92,90%	88,65%	*	87,23%	91,43%	93,62%	95,03%	91,48%
	Mean	84,95%	87,11%	86,56%	90,18%	87,10%	89,99%	89,71%	87,95%

Appendix D: Fitting discrete distribution

With the article of Adan et al. (1994) a discrete distribution was fitted to the demand data. This suggested that the most of the store-product combinations had a Poisson distribution for the daily demand and demand of the order horizon.

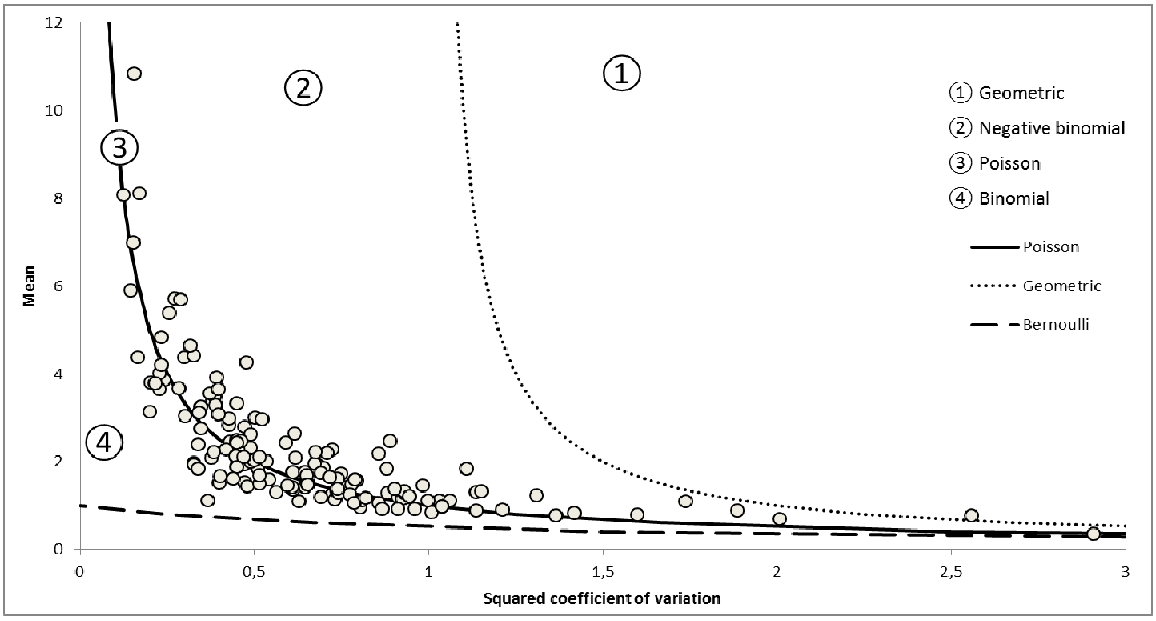

Figure D.1: Fitting discrete distribution on Friday demand data (Adan et al., 1994).

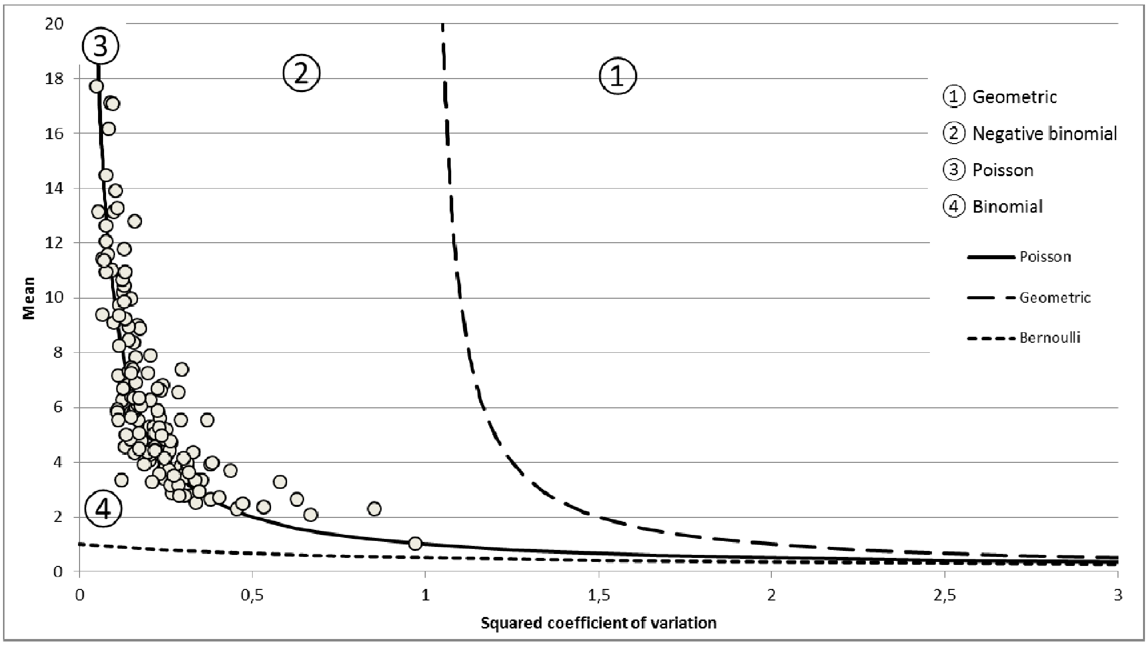

Figure E.2: Fitting discrete distribution on demand during review period plus lead-time (Adan et al., 1994).

A Kolmogorov-Smirnov test and a Chi-Square test were conducted to see whether the demand data differs from a Poisson distribution. The outputs of both tests are shown below. The *Asymp. Sig. (2-tailed)* value is also known as the p-value. When this value is above the specified α-value (in this case .05) then there is insufficient evidence to reject the hypothesis; the distribution is Poisson.

One-Sample Kolmogorov-Smirnov Test

	N	Poisson Parameter[a,b]	Most Extreme Differences			Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	Absolute	Positive	Negative		
S31496 P7260	52	1,25	,042	,038	-,042	,300	1,000
S31496 P7270	52	2,38	,035	,035	-,035	,254	1,000
S31496 P7390	52	1,29	,042	,042	-,035	,304	1,000
S31496 P7400	52	8,08	,094	,068	-,094	,678	,748
S31496 P7430	52	2,44	,072	,038	-,072	,518	,951
S31496 P7440	52	2,46	,147	,147	-,102	1,060	,211
S31496 P7600	52	1,54	,071	,071	-,045	,509	,958
S31496 P7610	52	2,10	,074	,062	-,074	,532	,940
S31496 P7650	52	3,00	,070	,070	-,063	,505	,960
S31496 P72350	52	1,42	,031	,031	-,029	,227	1,000
S31496 P72420	52	1,85	,045	,040	-,045	,326	1,000
S31496 P72440	52	2,27	,069	,069	-,046	,497	,966
S31496 P72570	52	1,12	,038	,038	-,031	,271	1,000
S31496 P72600	52	,79	,084	,084	-,063	,605	,857
S31496 P99690	52	1,25	,048	,038	-,048	,350	1,000
S31496 P99700	52	1,94	,037	,019	-,037	,268	1,000
S31496 P515783	52	1,52	,084	,068	-,084	,608	,854
S31496 P515784	52	,96	,036	,035	-,036	,261	1,000
S31496 P515785	52	1,58	,097	,063	-,097	,699	,712
S31496 P515786	52	2,31	,056	,036	-,056	,400	,997
S31496 P515787	52	1,98	,080	,051	-,080	,579	,891
S73016 P7260	52	2,42	,062	,062	-,046	,447	,988
S73016 P7270	52	3,81	,056	,045	-,056	,405	,997
S73016 P7390	52	1,85	,111	,111	-,076	,803	,539
S73016 P7400	52	10,85	,123	,123	-,088	,889	,408
S73016 P7430	52	5,90	,046	,039	-,046	,329	1,000
S73016 P7440	52	5,71	,117	,117	-,106	,842	,477
S73016 P7600	52	2,79	,080	,055	-,080	,579	,891
S73016 P7610	52	3,67	,058	,039	-,058	,417	,995
S73016 P7650	52	3,25	,077	,077	-,043	,552	,920
S73016 P72350	52	4,38	,049	,042	-,049	,356	1,000
S73016 P72420	52	1,94	,068	,068	-,049	,492	,969
S73016 P72440	52	3,40	,051	,046	-,051	,369	,999
S73016 P72570	52	1,37	,034	,031	-,034	,246	1,000
S73016 P72600	52	2,83	,062	,062	-,036	,447	,988
S73016 P99690	52	1,23	,112	,112	-,046	,806	,534
S73016 P99700	52	1,44	,077	,059	-,077	,558	,915
S73016 P515783	52	1,19	,035	,023	-,035	,252	1,000
S73016 P515784	52	1,42	,040	,028	-,040	,287	1,000
S73016 P515785	52	3,33	,075	,075	-,063	,544	,929
S73016 P515786	52	1,13	,072	,044	-,072	,516	,953
S73016 P515787	52	1,77	,043	,030	-,043	,308	1,000
S50512 P7260	52	,88	,164	,164	-,086	1,183	,122
S50512 P7270	52	1,94	,038	,017	-,038	,277	1,000
S50512 P7390	52	1,77	,047	,041	-,047	,336	1,000
S50512 P7400	52	8,12	,080	,080	-,046	,576	,894
S50512 P7430	52	5,69	,089	,081	-,089	,645	,799
S50512 P7440	52	1,48	,052	,051	-,052	,376	,999
S50512 P7600	52	3,48	,051	,041	-,051	,367	,999
S50512 P7610	52	2,62	,101	,101	-,098	,728	,664
S50512 P7650	52	2,19	,086	,086	-,056	,619	,838
S50512 P72350	52	1,52	,054	,031	-,054	,389	,998
S50512 P72420	52	2,27	,104	,104	-,074	,752	,624
S50512 P72440	52	3,87	,078	,033	-,078	,564	,908
S50512 P72570	52	1,15	,024	,013	-,024	,173	1,000
S50512 P72600	52	1,87	,056	,056	-,046	,405	,997
S50512 P99690	52	1,69	,081	,081	-,062	,586	,882
S50512 P99700	52	2,48	,032	,032	-,017	,229	1,000
S50512 P515783	52	2,46	,057	,030	-,057	,409	,996
S50512 P515784	52	1,96	,064	,064	-,042	,463	,983
S50512 P515785	52	3,29	,042	,042	-,038	,304	1,000
S50512 P515786	52	2,13	,025	,022	-,025	,180	1,000
S50512 P515787	52	4,83	,052	,052	-,038	,377	,999
S72605 P7260	52	1,85	,092	,092	-,046	,665	,769
S72605 P7270	52	1,12	,057	,057	-,032	,410	,996
S72605 P7390	52	2,10	,080	,080	-,057	,578	,892
S72605 P7400	52	4,42	,087	,087	-,043	,626	,828
S72605 P7430	52	4,27	,157	,157	-,107	1,132	,154
S72605 P7440	52	2,21	,064	,064	-,036	,458	,985
S72605 P7600	52	2,96	,126	,126	-,074	,907	,383
S72605 P7610	52	3,65	,081	,039	-,081	,582	,887
S72605 P7650	52	2,23	,078	,078	-,051	,561	,911
S72605 P72350	52	1,94	,076	,048	-,076	,546	,927
S72605 P72420	52	1,12	,027	,027	-,020	,194	1,000
S72605 P72440	52	2,63	,105	,105	-,075	,754	,620
S72605 P72570	52	1,37	,027	,024	-,027	,194	1,000
S72605 P72600	52	1,29	,035	,013	-,035	,251	1,000
S72605 P99690	52	1,31	,072	,068	-,072	,516	,953
S72605 P99700	52	1,29	,070	,070	-,035	,508	,959
S72605 P515783	52	1,10	,089	,089	-,052	,641	,805
S72605 P515784	52	,92	,015	,015	-,014	,105	1,000
S72605 P515785	52	1,60	,030	,023	-,030	,213	1,000
S72605 P515786	52	1,25	,048	,021	-,048	,350	1,000
S72605 P515787	52	2,00	,079	,038	-,079	,570	,901
S70084 P7260	52	2,04	,032	,024	-,032	,228	1,000
S70084 P7270	52	,88	,017	,013	-,017	,120	1,000
S70084 P7390	52	2,12	,066	,028	-,066	,479	,976
S70084 P7400	52	3,92	,076	,076	-,051	,546	,927
S70084 P7430	52	4,63	,103	,103	-,083	,743	,640
S70084 P7440	52	2,98	,086	,086	-,044	,623	,832
S70084 P7600	52	3,56	,065	,043	-,065	,467	,981
S70084 P7610	52	4,02	,052	,034	-,052	,373	,999
S70084 P7650	52	3,79	,070	,061	-,070	,504	,961
S70084 P72350	52	3,13	,084	,056	-,084	,604	,859
S70084 P72420	52	1,42	,103	,037	-,103	,744	,638
S70084 P72440	52	2,75	,058	,032	-,058	,421	,994
S70084 P72570	52	1,73	,074	,074	-,037	,533	,939
S70084 P72600	52	3,04	,048	,018	-,048	,345	1,000
S70084 P99690	52	2,23	,052	,052	-,040	,376	,999
S70084 P99700	52	1,48	,018	,018	-,014	,128	1,000
S70084 P515783	52	,77	,034	,026	-,034	,244	1,000
S70084 P515784	52	,85	,025	,016	-,025	,182	1,000
S70084 P515785	52	1,88	,054	,043	-,054	,386	,998
S70084 P515786	52	1,31	,087	,087	-,066	,627	,826
S70084 P515787	52	1,46	,052	,028	-,052	,372	,999
S31720 P7260	52	1,85	,081	,051	-,081	,584	,885
S31720 P7270	52	2,42	,046	,046	-,025	,331	1,000
S31720 P7390	52	1,19	,069	,033	-,069	,499	,964
S31720 P7400	52	7,00	,060	,058	-,060	,434	,992
S31720 P7430	52	4,21	,078	,061	-,078	,564	,908
S31720 P7440	52	1,33	,050	,042	-,050	,363	,999
S31720 P7600	52	3,08	,132	,132	-,062	,954	,323
S31720 P7610	52	3,12	,065	,048	-,065	,467	,981
S31720 P7650	52	1,75	,057	,057	-,053	,411	,996
S31720 P72350	52	1,06	,040	,023	-,040	,285	1,000
S31720 P72420	52	,92	,051	,044	-,051	,369	,999
S31720 P72440	52	2,02	,075	,041	-,075	,543	,930
S31720 P72570	52	1,12	,155	,103	-,155	1,116	,166
S31720 P72600	52	1,62	,083	,048	-,083	,602	,862
S31720 P99690	52	1,06	,023	,023	-,022	,164	1,000
S31720 P99700	52	1,10	,060	,060	-,047	,435	,991
S31720 P515783	52	1,12	,038	,038	-,020	,271	1,000

S31720 P515784	52	1,17	,039	,031	-,039	,282	1,000
S31720 P515785	52	1,48	,033	,018	-,033	,237	1,000
S31720 P515786	52	1,50	,039	,027	-,039	,278	1,000
S31720 P515787	52	1,21	,042	,034	-,042	,304	1,000
S48518 P7260	52	1,33	,046	,042	-,046	,333	1,000
S48518 P7270	52	1,46	,093	,064	-,093	,670	,760
S48518 P7390	52	,69	,038	,038	-,033	,274	1,000
S48518 P7400	52	3,65	,091	,091	-,063	,658	,779
S48518 P7430	52	5,38	,087	,067	-,087	,625	,830
S48518 P7440	52	1,38	,038	,038	-,025	,274	1,000
S48518 P7600	52	1,62	,033	,032	-,033	,239	1,000
S48518 P7610	52	4,38	,067	,066	-,067	,484	,973
S48518 P7650	52	1,69	,062	,062	-,049	,447	,988
S48518 P72350	52	,83	,045	,043	-,045	,323	1,000
S48518 P72420	52	,98	,031	,029	-,031	,226	1,000
S48518 P72440	52	2,12	,047	,047	-,028	,342	1,000
S48518 P72570	52	,92	,091	,067	-,091	,656	,783
S48518 P72600	52	1,38	,030	,019	-,030	,213	1,000
S48518 P99690	52	,35	,010	,005	-,010	,072	1,000
S48518 P99700	52	,90	,025	,017	-,025	,179	1,000
S48518 P515783	52	1,60	,070	,070	-,053	,505	,961
S48518 P515784	52	,98	,039	,018	-,039	,278	1,000
S48518 P515785	52	1,67	,072	,032	-,072	,521	,949
S48518 P515786	52	1,65	,050	,039	-,050	,362	,999
S48518 P515787	52	,77	,171	,171	-,092	1,235	,095

a. Test distribution is Poisson.
b. Calculated from data.

Table E.2: Results Chi-Square Goodness-of-fit test for Poisson distribution.

Store Product	Chi-Square of data	Number of classes (k)	Estimated parameters (p)	degr. of freedom (f)	Chi-Square of f	P-value
S31496 P7260	3,804	4	1	2	9,210	1,000
S31496 P7270	2,632	6	1	4	13,277	1,000
S31496 P7390	4,803	5	1	3	11,345	1,000
S31496 P7400	40,027	10	1	8	20,090	0,007
S31496 P7430	13,216	6	1	4	13,277	0,901
S31496 P7440	114,373	8	1	6	16,812	0,000
S31496 P7600	4,277	4	1	2	9,210	1,000
S31496 P7610	4,160	5	1	3	11,345	1,000
S31496 P7650	19,602	9	1	7	18,475	0,547
S31496 P72350	1,824	5	1	3	11,345	1,000
S31496 P72420	3,649	5	1	3	11,345	1,000
S31496 P72440	8,629	7	1	5	15,086	0,992
S31496 P72570	5,129	5	1	3	11,345	1,000
S31496 P72600	6,524	4	1	2	9,210	0,999
S31496 P99690	2,992	4	1	2	9,210	1,000
S31496 P99700	1,049	6	1	4	13,277	1,000
S31496 P515783	4,225	4	1	2	9,210	1,000
S31496 P515784	1,381	4	1	2	9,210	1,000
S31496 P515785	10,290	6	1	4	13,277	0,975
S31496 P515786	7,529	7	1	5	15,086	0,997
S31496 P515787	5,015	5	1	3	11,345	1,000
S73016 P7260	17,174	8	1	6	16,812	0,701
S73016 P7270	5,125	7	1	5	15,086	1,000
S73016 P7390	78,225	8	1	6	16,812	0,000
S73016 P7400	37,844	16	1	14	29,141	0,013
S73016 P7430	6,275	9	1	7	18,475	0,999
S73016 P7440	20,772	12	1	10	23,209	0,473
S73016 P7600	8,620	8	1	6	16,812	0,992
S73016 P7610	9,249	8	1	6	16,812	0,987
S73016 P7650	14,214	8	1	6	16,812	0,860
S73016 P72350	9,950	11	1	9	21,666	0,980
S73016 P72420	8,558	7	1	5	15,086	0,992
S73016 P72440	12,528	9	1	7	18,475	0,924
S73016 P72570	2,056	5	1	3	11,345	1,000
S73016 P72600	8,646	8	1	6	16,812	0,992
S73016 P99690	17,859	7	1	5	15,086	0,658
S73016 P99700	3,242	4	1	2	9,210	1,000
S73016 P515783	1,440	5	1	3	11,345	1,000
S73016 P515784	4,862	5	1	3	11,345	1,000
S73016 P515785	19,659	10	1	8	20,090	0,543
S73016 P515786	4,470	5	1	3	11,345	1,000
S73016 P515787	7,509	6	1	4	13,277	0,997
S50512 P7260	24,151	5	1	3	11,345	0,286
S50512 P7270	1,279	6	1	4	13,277	1,000
S50512 P7390	3,454	7	1	5	15,086	1,000
S50512 P7400	26,340	13	1	11	24,725	0,194
S50512 P7430	36,162	13	1	11	24,725	0,021
S50512 P7440	7,733	5	1	3	11,345	0,996
S50512 P7600	11,759	10	1	8	20,090	0,946
S50512 P7610	12,915	7	1	5	15,086	0,912
S50512 P7650	120,630	8	1	6	16,812	0,000
S50512 P72350	2,655	5	1	3	11,345	1,000
S50512 P72420	15,838	8	1	6	16,812	0,779
S50512 P72440	7,402	8	1	6	16,812	0,997
S50512 P72570	1,025	5	1	3	11,345	1,000
S50512 P72600	16,002	7	1	5	15,086	0,770
S50512 P99690	8,135	6	1	4	13,277	0,995
S50512 P99700	1,921	8	1	6	16,812	1,000
S50512 P515783	12,720	7	1	5	15,086	0,918
S50512 P515784	12,538	6	1	4	13,277	0,924
S50512 P515785	17,177	10	1	8	20,090	0,700
S50512 P515786	1,791	6	1	4	13,277	1,000
S50512 P515787	6,002	10	1	8	20,090	0,999
S72605 P7260	35,497	8	1	6	16,812	0,025
S72605 P7270	2,415	5	1	3	11,345	1,000
S72605 P7390	18,063	7	1	5	15,086	0,645
S72605 P7400	19,310	11	1	9	21,666	0,565
S72605 P7430	53,274	11	1	9	21,666	0,000
S72605 P7440	48,393	7	1	5	15,086	0,001
S72605 P7600	16,889	9	1	7	18,475	0,718
S72605 P7610	8,534	8	1	6	16,812	0,992
S72605 P7650	47,410	8	1	6	16,812	0,001
S72605 P72350	2,857	5	1	3	11,345	1,000
S72605 P72420	1,143	4	1	2	9,210	1,000

Store Product	Chi-Square of data	Number of classes (k)	Estimated parameters (p)	degr. of freedom (f)	Chi-Square of f	P-value
S72605 P72440	23,504	9	1	7	18,475	0,318
S72605 P72570	0,755	5	1	3	11,345	1,000
S72605 P72600	0,810	5	1	3	11,345	1,000
S72605 P99690	12,116	6	1	4	13,277	0,936
S72605 P99700	6,265	5	1	3	11,345	0,999
S72605 P515783	96,938	6	1	4	13,277	0,000
S72605 P515784	0,216	4	1	2	9,210	1,000
S72605 P515785	2,756	5	1	3	11,345	1,000
S72605 P515786	2,060	5	1	3	11,345	1,000
S72605 P515787	8,880	6	1	4	13,277	0,990
S70084 P7260	1,373	6	1	4	13,277	1,000
S70084 P7270	1,020	4	1	2	9,210	1,000
S70084 P7390	5,508	6	1	4	13,277	1,000
S70084 P7400	36,810	10	1	8	20,090	0,018
S70084 P7430	20,615	11	1	9	21,666	0,483
S70084 P7440	12,870	8	1	6	16,812	0,913
S70084 P7600	15,490	9	1	7	18,475	0,798
S70084 P7610	7,436	8	1	6	16,812	0,997
S70084 P7650	9,142	8	1	6	16,812	0,988
S70084 P72350	3,869	6	1	4	13,277	1,000
S70084 P72420	7,185	5	1	3	11,345	0,998
S70084 P72440	2,957	7	1	5	15,086	1,000
S70084 P72570	10,800	7	1	5	15,086	0,967
S70084 P72600	2,289	7	1	5	15,086	1,000
S70084 P99690	9,754	6	1	4	13,277	0,982
S70084 P99700	1,165	5	1	3	11,345	1,000
S70084 P515783	4,071	4	1	2	9,210	1,000
S70084 P515784	0,300	4	1	2	9,210	1,000
S70084 P515785	2,602	5	1	3	11,345	1,000
S70084 P515786	9,178	5	1	3	11,345	0,988
S70084 P515787	2,187	5	1	3	11,345	1,000
S31720 P7260	4,745	5	1	3	11,345	1,000
S31720 P7270	2,434	7	1	5	15,086	1,000
S31720 P7390	2,881	4	1	2	9,210	1,000
S31720 P7400	7,429	12	1	10	23,209	0,997
S31720 P7430	9,887	8	1	6	16,812	0,980
S31720 P7440	7,609	5	1	3	11,345	0,997
S31720 P7600	16,199	8	1	6	16,812	0,758
S31720 P7610	4,702	8	1	6	16,812	1,000
S31720 P7650	4,102	6	1	4	13,277	1,000
S31720 P72350	1,376	4	1	2	9,210	1,000
S31720 P72420	3,125	4	1	2	9,210	1,000
S31720 P72440	5,673	6	1	4	13,277	1,000
S31720 P72570	9,870	3	1	1	6,635	0,981
S31720 P72600	4,488	5	1	3	11,345	1,000
S31720 P99690	0,725	4	1	2	9,210	1,000
S31720 P99700	4,150	4	1	2	9,210	1,000
S31720 P515783	1,455	5	1	3	11,345	1,000
S31720 P515784	3,455	4	1	2	9,210	1,000
S31720 P515785	4,005	5	1	3	11,345	1,000
S31720 P515786	1,012	5	1	3	11,345	1,000
S31720 P515787	6,043	5	1	3	11,345	0,999
S48518 P7260	35,754	6	1	4	13,277	0,023
S48518 P7270	13,441	6	1	4	13,277	0,892
S48518 P7390	13,452	5	1	3	11,345	0,892
S48518 P7400	15,926	10	1	8	20,090	0,774
S48518 P7430	22,770	10	1	8	20,090	0,356
S48518 P7440	4,431	6	1	4	13,277	1,000
S48518 P7600	5,212	6	1	4	13,277	1,000
S48518 P7610	9,808	8	1	6	16,812	0,981
S48518 P7650	6,723	5	1	3	11,345	0,999
S48518 P72350	4,855	4	1	2	9,210	1,000
S48518 P72420	1,887	4	1	2	9,210	1,000
S48518 P72440	4,270	7	1	5	15,086	1,000
S48518 P72570	8,990	3	1	1	6,635	0,989
S48518 P72600	1,082	5	1	3	11,345	1,000
S48518 P99690	0,331	3	1	1	6,635	1,000
S48518 P99700	4,485	5	1	3	11,345	1,000
S48518 P515783	13,777	6	1	4	13,277	0,879
S48518 P515784	3,424	4	1	2	9,210	1,000
S48518 P515785	2,317	5	1	3	11,345	1,000
S48518 P515786	12,876	6	1	4	13,277	0,913
S48518 P515787	33,188	5	1	3	11,345	0,044

Appendix E: Tested perishable inventory policies

In these analyses three different inventory control policies were applied on the POS-data between 1-8-2011 and 17-12-2011. This appendix discusses the implementation of these policies and used parameter settings.

EWA-Policy

The EWA policy is a extend (R,s,nQ) policy, which corrects the order quantity for expected outdating during the order horizon. The correction for outdating, due to withdrawal and ageing, is applied to a (R,S-1,S)-policy (instead of a (R,s,nQ)-policy). Therefore the formulas in the paper of Broekmeulen and Donselaar (2009) are slightly different. The initial order quantity (q_i) is determined by the order-up-to level (*S*), the inventory position (*IP*), and the expected outdating ($\widehat{O}$). The initial order quantity is determined as follows:

$$q_{i,t} = S_i - IP_t + \sum_{j=t+1}^{t+L+R-1} \hat{O}_j \qquad \text{(E.1)}$$

The value of the expected outdating depends on the assumed withdrawal behaviour and the age distribution of the stock point. The procedure with recursive equations, for determining the value of the expected outdating, is called the EWA heuristic. Because the EWA heuristic is very specific, the used formulas and exact procedure is copied from the article of Broekmeulen and Donselaar (2009) and depicted below:

In the case of FIFO withdrawal of the shelves with a perishable product with fixed lifetime of *n* days, we have the following recursive expressions at the end of each period *t*:

$$W_{t,r} = Min\left(B_{t,r}, D_t - \sum_{i=1}^{r-1} W_{t,i}\right) for\ r = 1, \dots, n \qquad (a)$$

The withdrawal quantity (*W*) of the on-hand inventory is the minimum of the remaining batch size (*B*) with remaining shelf life *r* and the unsatisfied demand from older batches on the shelf.

At the end of each review period, an order decision is made which determines $B_{t+L_R+1,n}$. After each day, the batches are updated for ageing, withdrawal and outdating:

$$B_{t+1,r-1} = B_{t,r} - W_{t,r}\ for\ r = 2, \dots, n \qquad (b)$$

$$O_t = B_{t,1} - W_{t,1} \qquad (c)$$

The recursive equations above are needed to estimate the outdating quantities (*O*). These are estimated by calculating for consecutive periods i (ranging from $i = t + 1$ to $i = t + L_R + R_R - 1$) the withdrawal, the remaining batches and the outdating in period i using (a)-(c) under the assumption that in period i demand is equal to the expected demand for that period. This implies the following procedure, starting with $i = t + 1$:

1. Determine the estimated withdrawal in period i using (a) and by assuming demand in period i was equal to <u>the expected demand</u>.
2. Determine the estimated remaining batches available for the next period and the estimated outdating in period i using (b) and (c) and by assuming the withdrawal in period i is equal to the estimated withdrawal as determined in Step 1.
3. While $i < t + L_R + R_R - 1$ do i: $= i + 1$ and continue with Step 1, otherwise stop.

Figure E.1: EWA heuristic of Broekmeulen and Donselaar (2009).

Demand for each weekday was forecast by simple exponential smoothing techniques and used for the determination of the order-up-to level. The safety stock was set by using the article of Donselaar & Broekmeulen (2011), by setting the desired fill-rate at 98 %.

The order of events was as following on a daily level:

1. Demand is withdrawn from on-hand inventory in FIFO manner.
2. Lost sales are determined.
3. Products are aged and outdated products are removed from the system.
4. Order quantity is determined, at review moment, and delivered at the end of the next day after the demand is withdrawn.

The fill-rate (percentage of total demand fulfilled from on-hand inventory) and relative outdating (percentage of total ordered products that is outdated) are determined at the end of the run for each product-store combination. Whereby the first 5 weeks are excluded, due to the warm-up period.

Dynamic replenishment policy

For the ordering decisions, the dynamic replenishment policy of Minner & Transchel (2010) was used. For the orders, the ordering quantity (q_t^i) depends on the on-hand inventory (X_t), on the future demand realizations ($D_t \dots D_{t+R+L_{is}-1}$), outstanding orders, and the set fill-rate constraint. The minimal order quantity that achieves the fill-rate was calculated as follows:

$$q_t^i = \min_{q\geq 0}\left\{\sum_{x=0}^{\infty} g_{t+L}(x) * \left(\sum_{d=0}^{x+q} f_{t+L,t+R+L}(d) + \sum_{d=x+q+1}^{\infty} \frac{x+q}{d} f_{t+L\,,t+R+L}(d)\right) \geq \beta\right\} \quad \text{(E.2)}$$

Where in Formula E.1, g_{t+L} is the probability distribution of X_{t+L} , which depends on the withdrawal behaviour of the shelves and on-hand inventory at time *t*. And where $f_{t+L\,,t+R+L}$ is the probability distribution of the cumulative demand between $t + L$ and $+R + L$. Minner & Transchel (2010) use the following method to determine the distribution of the random variable X_{t+L}, with $L = 1$, FIFO withdrawal, and an arbitrary *n*:

$$X_{t+L_{is}} = \left(X_t^{j-1} - \left(D_t - \sum_{i=j}^{n-1} X_t^i\right)^+\right)^+ \quad \text{for j} = 1, \dots, \text{n} - 1 \quad \text{(E.3)}$$

$with$:

$$X_t^0 = q_{t-L} \quad \text{(E.4)}$$

The order of events was as following on a daily level:

1. Demand is withdrawn from on-hand inventory in FIFO manner.
2. Lost sales are determined.
3. Products are aged and outdated products are removed from the system.
4. Order quantity is determined, at review moment, and delivered at the end of the next day after the demand is withdrawn.

The fill-rate constraint was set at 98 % and run the model until the correct safety stock settings were found. Thereby determining the corresponding relative outdating figures for all store-product combinations.

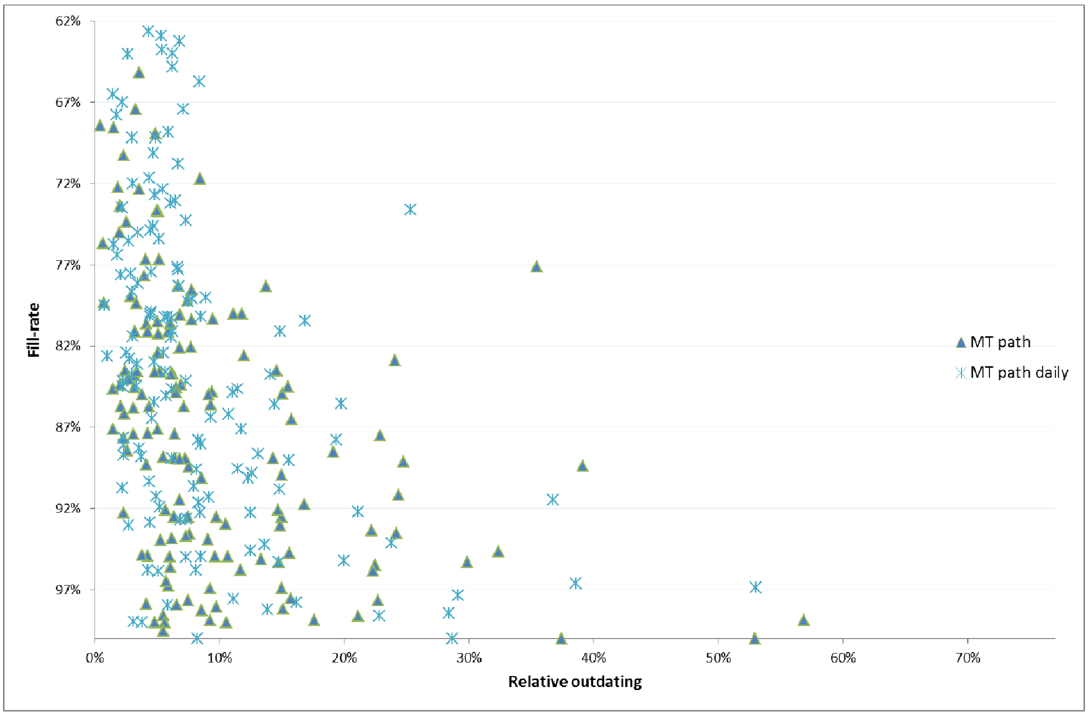

Figure E.2: MT-policy test results for the path and path daily methods.

Sequential newsvendor models

When demand is not stationary, data driven sequential newsvendor can be a good replenishment strategy. The data driven approach does not require an estimation of probability distribution parameters. The optimal order quantity for the upcoming period is based on the historical data and demand realizations of the previous periods. In the case of SPAR, only historical demand data was available for the explanatory variables. Therefore the models of Bertsimas and Thiele (2005), and Beutel and Minner (2011) were chosen for modelling the data driven sequential newsvendor approach.

Bertsimas and Thiele (2005) method in this case used the following notation and formulation for the newsvendor problem:

Table E.1: Variable description of Bertsimas and Thiele (2005).

Variable	Description
c	Unit cost
P	Unit selling price
s	Unit salvage price
mf=p/c-1	Markup factor
df=1-s/c	Discount factor
Q	Order quantity
D	Random demand
N	Number of current demand realizations
α	Trimming factor

$$N_\alpha = \lfloor N(1-\alpha) + \alpha \rfloor \quad \text{(E.5)}$$

$$Q = d_j \; with \; j = \left\lceil \frac{mf}{mf+df} N_\alpha \right\rceil \quad \text{(E.6)}$$

The newsvendor period is assumed to be one week, this corresponds to the maximum available shelf-life of a product. The weekly point-of-sales data of 2010 and 2011 (so far as registrated) were used as the random demand realizations. The model is then executed as follows, starting at the begin of the second period:

1. Determine j-th factor with N = 1, alfa, and mf/(mf+df).
2. Rank current demand realizations in non-decreasing order.
3. Order quantity is j-th factor in rank of current demand realizations.
4. Observe demand realization, and determine outdating and lost sales.
5. Go to next period and set N = N+1.

The fill-rate (percentage of total demand fulfilled from on-hand inventory) and relative outdating (percentage of total ordered products that is outdated) are determined excluding the first 25 periods, because the models need a setup period for the parameters. The results are shown in Table E.3.

Beutel and Minner (2005) method used the following notation and formulation for the newsvendor problem:

Table E.2: Variable description for Beutel & Minner (2005).

Variable	Description
C	Total inventory holding costs
y	On-hand inventory at end of period
h	Holding costs
D	Demand realization
s	Satisfied demand
$\boldsymbol{\beta_0}$	Required inventory level
n	Number of demand observations
$\boldsymbol{P_2}$	Targeted fill-rate

The required inventory level only depends on the historical demand observations, therefore the required inventory level was the parameter β_0. The linear programming model was as following, when using the fill-rate as service level constraint:

$$Min\ C = \sum_{i=1}^{n} h * y_i \quad \text{(E.7)}$$

Subjected to:

$$y_i \geq \beta_0 - D_i \; for \; i = 1, \ldots, n \quad \text{(E.8)}$$

$$s_i \leq D_i \; for \; i = 1, \ldots, n \quad \text{(E.9)}$$

$$s_i \leq \beta_0 \; for \; i = 1, \ldots, n \quad \text{(E.10)}$$

$$\sum_{i=1}^{n} s_i \geq P_2 * \sum_{i=1}^{n} D_i \quad \text{(E.11)}$$

$s_i, y_i \geq 0$ and $\beta_0 \in \mathbb{N}$ (E.12)

The decision variable is parameter β_0 and determines the inventory level and satisfied demands for each demand observation. The holding cost factor is neglected, because this has no influence on the fill-rate and relative outdating. The model is executed as follows, starting at the second period:

1. Determine the order quantity for the second period (β_0), by solving the LP problem with the previous observed periods (*n*).
2. Observe demand realization, and determine outdating and lost sales.
3. Go to next period, and set n = n + 1.

Again the fill-rates and relative outdating of the first 25 periods were excluded from the results. The results are shown in Table E.4.

Table E.3: Current store policy and sequential newsvendor policy (by Bertsimas and Thiele (2005)).

Store	Current (store owner)		Newsvendor (m/m+t)=.95, α=.05		Newsvendor (m/m+t)=.9, α=.05		Newsvendor (m/m+t)=.75, α=.05		Newsvendor (m/m+t)=.5, α=.05	
	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate
Store_An	9,5%	91,1%	35,2%	95,6%	30,9%	94,0%	22,6%	89,1%	13,8%	79,6%
Store_Ha	8,1%	92,6%	29,6%	95,8%	25,8%	94,8%	18,2%	91,3%	10,3%	84,1%
Store_Ma	12,2%	91,7%	32,1%	95,6%	28,6%	94,6%	22,0%	91,0%	14,8%	82,7%
Store_Ze	15,4%	94,4%	31,9%	94,1%	27,8%	92,9%	20,4%	88,9%	12,2%	80,7%
Store_Wa	8,4%	90,9%	27,8%	97,8%	24,3%	96,8%	17,5%	93,8%	10,1%	86,8%
Store_Sp	11,3%	94,0%	30,3%	97,2%	26,9%	96,0%	19,1%	91,1%	11,1%	81,7%
Store_Ho	14,4%	93,4%	31,4%	96,4%	27,4%	95,0%	19,9%	91,1%	11,2%	82,1%
Average	11,3%	92,6%	31,2%	96,1%	27,4%	94,9%	19,9%	90,9%	11,9%	82,5%

Table E.4: Current store policy and sequential newsvendor policy (by Beutel and Minner (2011)).

Store	Current (store owner)		Fill-rate = .95		Fill-rate = .90		Fill-rate = .75		Fill-rate = .5	
	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate	Rel. Outdating	Ready rate
Store_An	9,5%	91,1%	34,6%	96,1%	26,3%	92,4%	12,8%	78,8%	3,9%	55,5%
Store_Ha	8,1%	92,6%	26,5%	95,6%	18,2%	91,3%	6,7%	77,8%	1,1%	55,2%
Store_Ma	12,2%	91,7%	24,4%	95,8%	18,3%	91,6%	9,1%	79,1%	3,6%	56,0%
Store_Ze	15,4%	94,4%	32,3%	95,1%	23,4%	90,4%	10,0%	76,8%	2,4%	53,3%
Store_Wa	8,4%	90,9%	20,6%	96,0%	14,3%	91,8%	5,5%	78,3%	0,7%	55,5%
Store_Sp	11,3%	94,0%	17,8%	95,7%	13,2%	91,1%	6,3%	77,7%	1,6%	54,0%
Store_Ho	14,4%	93,4%	26,7%	95,5%	19,1%	91,2%	8,7%	77,7%	2,3%	54,8%
Average	11,3%	92,6%	26,1%	95,7%	19,0%	91,4%	8,4%	78,0%	2,2%	54,9%

Appendix F: Adjustment-policy with and without EWA

The use of an EWA-policy of the store owners is not always efficient, especially when demands are very low and shelves are depleted in FIFO-manner. The use of the EWA-policy could also result into a wrong adjustment decision. This is the case when the store owners order incorporates an high expected outdating. High expected outdating is than reduced due to the higher than expected demand and an adjustment is therefore not necessary, but is not noticed by SPAR which bases the adjustment decision only on sales information. For this reason the Adjustment-policy was tested with and without the EWA-heuristic (Adjustment versus AdjustmentNoEWA). The results are shown below and indicate that the Adjustment-policy with EWA does not result into undesired adjustment which lead to higher outdating.

Table G.1: Adjustment-policy compared to AdjustmentNoEWA-policy for 41011100-schedule with targeted fill-rate 85%.

Product parameters	Level	Fill-rate (Δ%)	Relative outdating (Δ%)
Mean demand (λ)	1	1,60	0,22
	2	0,35	0,01
	3	0,13	0,00
	4	0,03	0,00
	6	0,02	0,00
Shelf-life (*n*)	4	1,11	0,02
	5	0,62	0,01
	6	0,20	-0,02
	7	0,11	0,00
	8	0,08	0,01
Total	all	0,42	0,05

Appendix G: Outdating costs versus adjustment costs

For the EWA-policy of Broekmeulen and Donselaar (2009), the relative outdating and fill-rate can be approximated with the following formulas (Donselaar & Broekmeulen (2012)):

$$\frac{1-P_2^*}{P_2^*} = \frac{1}{QR\mu}\left(\sum_{i=1}^{Q}\sum_{d=i+S}^{\infty}(d-i-S+1)P(D_{L+R}=d) - \sum_{i=1}^{Q}\sum_{d=i+S}^{\infty}(d-i-S+1)P(D_L=d)\right) \quad \text{(G.1)}$$

$$z^A = \frac{1}{\rho\mu}E\left[\left(\left\lceil\frac{s-[L+n-\rho]\mu}{Q}\right\rceil Q - D_\rho\right)^+\right] \quad \text{with } \rho = \lfloor n/R \rfloor * R \quad \text{(G.2)}$$

$$z^B = \frac{1}{\rho\mu Q}\sum_{i=1}^{Q}E[(s-1+i-D_{L+n})^+] \quad \text{with } \rho = \lfloor n/R \rfloor * R \quad \text{(G.3)}$$

Table H.1: Variable description.

Variable	Description
Q	Case-pack size
R	Review period
L	Lead-time
μ	Average daily demand
D	Demand distribution
d	Demand
S	Order-up-to level
n	Shelf-life
$\boldsymbol{P_2}^*$	Fill-rate

Under idealistic assumptions, like no week pattern, no closing on Sundays, and FIFO withdrawal of the shelves, both formulas provide an accurate approximation of the fill-rate and relative outdating given certain safety stock levels. The daily demand was modelled Poisson and the lead-time and review period were set to one and two days respectively. For some product settings the approximated fill-rate and corresponding relative outdating were calculated (the average of z^A and z^B). The results are shown in Table G.2.

Table G.2: Approximate fill-rate and relative outdating.

	λ = 1 and n = 4		λ = 3 and n = 4		λ = 6 and n = 4	
SS	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate
0	5,72%	75,51%	1,47%	83,52%	0,46%	87,69%
1	14,12%	86,39%	2,67%	88,59%	0,74%	90,59%
2	27,40%	93,72%	4,49%	92,61%	1,14%	93,04%
3	45,07%	97,53%	7,06%	95,51%	1,69%	95,02%
4	66,00%	99,15%	10,47%	97,43%	2,41%	96,56%
5	88,98%	99,74%	14,75%	98,62%	3,35%	97,70%
6	113,07%	99,93%	19,89%	99,29%	4,51%	98,51%
7	137,70%	99,98%	25,81%	99,66%	5,93%	99,06%
8	162,57%	100,00%	32,40%	99,84%	7,63%	99,43%
9	187,52%	100,00%	39,52%	99,93%	9,60%	99,66%
10	212,51%	100,00%	47,05%	99,97%	11,85%	99,81%
11	237,50%	100,00%	54,87%	99,99%	14,38%	99,89%
12	262,50%	100,00%	62,89%	100,00%	17,17%	99,94%
13	287,50%	100,00%	71,04%	100,00%	20,21%	99,97%
14	312,50%	100,00%	79,28%	100,00%	23,47%	99,98%
15	337,50%	100,00%	87,55%	100,00%	26,92%	99,99%
16	362,50%	100,00%	95,86%	100,00%	30,54%	100,00%
17	387,50%	100,00%	104,18%	100,00%	34,29%	100,00%
18	412,50%	100,00%	112,51%	100,00%	38,16%	100,00%
19	437,50%	100,00%	120,84%	100,00%	42,11%	100,00%
20	462,50%	100,00%	129,17%	100,00%	46,12%	100,00%
	λ = 1 and n = 6		λ = 3 and n = 6		λ = 6 and n = 6	
SS	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate
0	0,85%	75,51%	0,03%	83,52%	0,00%	87,69%
1	2,62%	86,39%	0,08%	88,59%	0,00%	90,59%
2	6,26%	93,72%	0,17%	92,61%	0,00%	93,04%
3	12,35%	97,53%	0,34%	95,51%	0,01%	95,02%
4	21,11%	99,15%	0,64%	97,43%	0,01%	96,56%
5	32,37%	99,74%	1,12%	98,62%	0,03%	97,70%
6	45,63%	99,93%	1,85%	99,29%	0,05%	98,51%
7	60,32%	99,98%	2,90%	99,66%	0,08%	99,06%
8	75,93%	100,00%	4,34%	99,84%	0,13%	99,43%
9	92,08%	100,00%	6,22%	99,93%	0,20%	99,66%
10	108,50%	100,00%	8,58%	99,97%	0,31%	99,81%
11	125,07%	100,00%	11,43%	99,99%	0,47%	99,89%
12	141,69%	100,00%	14,76%	100,00%	0,68%	99,94%
13	158,34%	100,00%	18,54%	100,00%	0,96%	99,97%
14	175,00%	100,00%	22,72%	100,00%	1,33%	99,98%
15	191,67%	100,00%	27,25%	100,00%	1,80%	99,99%
16	208,33%	100,00%	32,06%	100,00%	2,38%	100,00%
17	225,00%	100,00%	37,09%	100,00%	3,09%	100,00%
18	241,67%	100,00%	42,28%	100,00%	3,95%	100,00%
19	258,33%	100,00%	47,60%	100,00%	4,96%	100,00%
20	275,00%	100,00%	53,01%	100,00%	6,12%	100,00%
	λ = 1 and n = 8		λ = 3 and n = 8		λ = 6 and n = 8	
SS	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate	Rel. outdating	Fill-rate
0	0,13%	75,51%	0,00%	83,52%	0,00%	87,69%
1	0,48%	86,39%	0,00%	88,59%	0,00%	90,59%
2	1,37%	93,72%	0,00%	92,61%	0,00%	93,04%
3	3,18%	97,53%	0,01%	95,51%	0,00%	95,02%
4	6,34%	99,15%	0,02%	97,43%	0,00%	96,56%
5	11,13%	99,74%	0,05%	98,62%	0,00%	97,70%
6	17,66%	99,93%	0,09%	99,29%	0,00%	98,51%
7	25,84%	99,98%	0,18%	99,66%	0,00%	99,06%
8	35,42%	100,00%	0,32%	99,84%	0,00%	99,43%
9	46,07%	100,00%	0,54%	99,93%	0,00%	99,66%
10	57,47%	100,00%	0,88%	99,97%	0,00%	99,81%
11	69,36%	100,00%	1,37%	99,99%	0,00%	99,89%
12	81,54%	100,00%	2,06%	100,00%	0,01%	99,94%
13	93,88%	100,00%	2,98%	100,00%	0,01%	99,97%
14	106,31%	100,00%	4,17%	100,00%	0,02%	99,98%
15	118,77%	100,00%	5,66%	100,00%	0,03%	99,99%
16	131,26%	100,00%	7,47%	100,00%	0,04%	100,00%
17	143,75%	100,00%	9,60%	100,00%	0,06%	100,00%
18	156,25%	100,00%	12,05%	100,00%	0,10%	100,00%
19	168,75%	100,00%	14,81%	100,00%	0,15%	100,00%
20	181,25%	100,00%	17,84%	100,00%	0,22%	100,00%

Appendix H: Order-book method

The order-book method introduced in chapter 2 is further explained in this appendix chapter. This ordering procedure with the use of a registration book is used by store owners to registrate and make order decisions about the perishable inventory. The method is explained for one perishable product, but holds for all perishable products in the assortment of SPAR.

The following items are registrated: The current inventory level 'BV', outdating per day 'D', sales per day 'V', and the order quantity 'B'. Sales and outdating are registrated at the end of each selling day. The current inventory level and the order quantity are only registrated at the ordering moment. These four items are registrated continuously, but in the order-book only the last three till four weeks are depicted. This is to keep the book clear and manageable for order decisions (see Figure H.1).

		wk	maandag				dinsdag				woensdag				donderdag				vrijdag				zaterdag			
	panklaar	nr	**BV**	**B**	**D**	**V**	**BV**	**B**	**D**	**V**	**BV**	**B**	**D**	**V**	**BV**	**B**	**D**	**V**	**BV**	**B**	**D**	**V**	**BV**	**B**	**D**	**V**
art.nr	***baby leaf 100 gram***	39			0	2	4	5	1	1			0	2	5	8	0	3			0	4	2	3	0	4
		40			2	1	0	5	0	2			0	0	5	8	0	3			0	3	2	3	0	5
726001		41			1	1	3	4	2	1			0	2	2	10	0	2			0	3	2	3	0	5
		42			2	0																				

Figure I.1: Example order-book.

Sales and outdating are registrated at the shelves or are retrieved from the cash-registration system. Both are registrated in order to make a forecast for the demand in the upcoming periods and to control the outdating. The current inventory level is notated by counting the number of fresh products in the stores (backroom + shelves). The current inventory level at time *t* can be mathematical formulated as follows:

$$BV_t = B_{t-L} + BV_{t-L} - \sum_{i=t-L-R-1}^{t} (D_i + V_i) \quad \text{(H.1)}$$

The order quantity depends on the forecast of the demand (*F*), determined by the store owner, and the current inventory level. These decisions are a balance between outdating and customer service. The forecast made by the store owner is based on the sales and outdating of the past three till four weeks and a prediction of sales the upcoming periods. The forecast is not determined based on fixed rules or principles and therefore is not mathematically described. The order quantity at time moment *t* can be mathematical formulated as follows:

$$B_t = F - BV_t \quad \text{(H.2)}$$

Appendix I: Poster

Research facilitated and in cooperation with SPAR Holding B.V.

Technische Universiteit Eindhoven University of Technology

Order adjustment strategy for highly perishables products

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Introduction

The order decisions of stores were insufficient to achieve high customer service at low costs. The in-store availability of perishable products was lagging around 90%. Whereby, the relative outdating of these perishable products was between 6 and 11%. A long order forecast horizon in combination with a high demand variation was the main cause of the poor inventory performance.

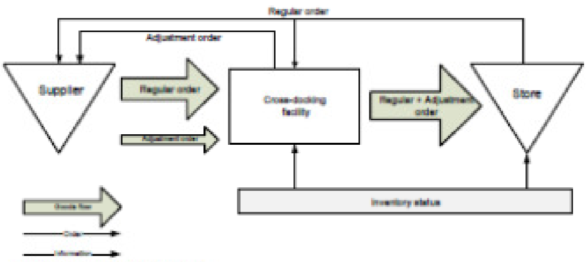

Figure A: Order adjustment supply chain model

Research question:

"Is an order adjustment upwards and additional cross-dock operations, in order to reduce the out-of-stock rate at the stores beneficial for SPAR and the franchisee, when considering the total relevant cost of outdating and additional operations?"

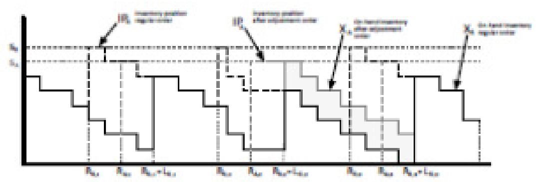

Figure B: Inventory trace with and without an order adjustment.

Design & Methodology

Stores use the EWA-policy of Broekmeulen & Donselaar (2009)* for order decisions for the regular order. The adjustment order quantity is the positive difference between the realized demand and the forecasted demand by SPAR, between the store order moment and the adjustment order moment.

With a Discrete Event Simulation this adjustment replenishment strategy was simulated for several SPAR tailored inputs.

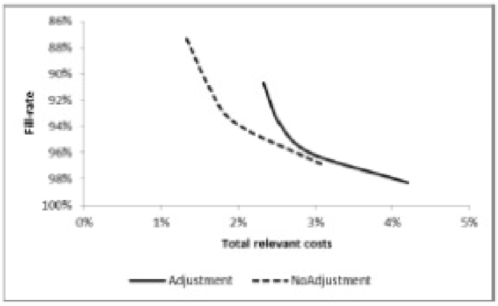

Figure C: Overall performance of Adjustment and NoAdjustment strategy for selected SPAR products.

Results

In general the adjustment strategy was not beneficial for SPAR and the franchisee. The NoAdjustment strategy, that uses the EWA-policy, reached already high customer service levels with lower total relative costs, than the design Adjustment strategy. The adjustment costs were relatively high, due to a high amount of adjusted orders. The improvement in fill-rate was too marginal to justify the higher costs and complexity of the adjustment strategy.

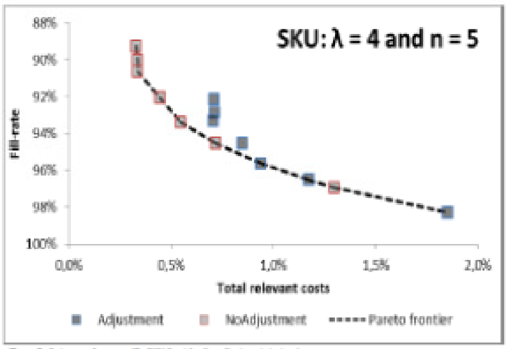

Figure D: Outcomes for a specific SKU (best for the adjustment strategy).

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* Broekmeulen, R.A.C.M., Donselaar, K.H. van (2009). *A heuristic to manage perishable inventory with batch ordering, positive lead-time and time-varying demand.* Computers & Operations Research 182, 696 – 703.