A model for deciding on the supply chain structure of the perishable products assortment of an online supermarket with unmanned automated pick-up points

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Award date:
2014

Barendrecht, 14 July 2014

A model for deciding on the supply chain structure of the perishable products assortment of an online supermarket with unmanned automated pick-up points

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in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management & Logistics

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Series Master Theses Operations Management and Logistics

Subject headings: supply chain management, e-retailing, inventory control, perishables

ABSTRACT

This report describes the design, input and results of a model that explores the best possible supply chain design for an online retailer with automated unmanned pick-up points at a certain moment in time. The aim of the model is to strategically design the perishables supply chain of an e-retailer at a certain moment in time while taking into account lost sales, outdating and operational costs. Furthermore, the model can be used on a daily basis in order to decide whether emergency shipments must be placed for products of specific suppliers. Moreover, a business case for the perishable supply chain of Superdirect.com will show insights on how to design the perishables supply chain at specific moments in time and it is shown how this model can be implemented and which adjustments in the process have to be made in order to let the model be useful.

MANAGEMENT SUMMARY

This report is the result of a master thesis project conducted for Specialized Consumer Logistics B.V. (in sequence SCL) and Hollander Barendrecht (in sequence HB). Both of which are subsidiaries of The Greenery, which is a large international vegetables and fruit company. HB is a logistic service provider of fresh and semi-fresh products for the retail industry. On a daily basis it delivers cooled products to its customers, approximately 270 PLUS-supermarkets, throughout the Netherlands. Recently, The Greenery founded a new subsidiary company, under the name SCL, to be the logistic service provider of all products (fresh, dry groceries, frozen goods) for the new online retailer Superdirect.com (in sequence SD). SD developed a new supply chain concept that should be faster and more efficient than those of existing grocery supply chains as SD is an online supermarket at which one can order daily groceries online and can be picked up at a completely automated pick-up point the next day. Orders can be picked up 24/7. SCL installed a complete warehouse to store inventory at three different temperatures (room, cooling and freezing temperature) in a very simple way. Unlike HB, SCL picks orders on consumer level instead of on supermarket level. This means that consumer units are collected and are put in boxes instead of case packs put onto roll containers. Picked products are put into consumer-specific cardboard boxes. Until now, one pick-up point had been fully operational since the end of September 2013 and was located in Eindhoven. It was SD's aim to have ten pick-up points operational at the end of 2014. Unfortunately, at May 1st 2014 Superdirect.com announced to quit the pilot in Eindhoven. This master thesis, however, still is aimed at this specific concept as the outcome of the research is of importance if Superdirect.com decides to relaunch its operations.

Problem definition

In contrast to the average general online merchandise order, which comprises one to three separate items, the average online grocery order contains much more items, many of which are perishable and need rapid picking and delivery. This requires localized order picking either in an existing shop or a dedicated warehouse (Fernie et al., 2010). The PUPs of SD are supplied from the latter one. A disadvantage of fulfilment from a dedicated warehouse is that investment costs of new PUPs are quite high. However, doubts have been expressed about the long-term sustainability of store-based fulfilment as conflicts between conventional and online retailing are likely to intensify. To be cost-effective, dedicated pick centers must handle a large throughput. In order to reach the break-even point in the online food industry it is expected that SD needs approximately 700,000 products sold each month (Verweij, 2014). As on average 4,000 products were sold at the pick-up point in Eindhoven per week, upscaling needs to take place quickly in order to become profitable. The threshold level of throughput required for viability also depends on the breadth of the product range. It is very costly to offer an extensive range in the early stages of an e-tailing operation when sales volumes are low. Offering a limited range can cut the cost of the operation but makes it more difficult to lure consumers from conventional retailing. Another inventory-related problem which retailers using pick centers have encountered is the difficulty of disposing of excess stocks of short-shelf life product, because stimulating demand at short notice using price reductions is not possible. Therefore, fresh products are much more sensitive to outdating than in stores. A price reduction promotion indicated that demand is quite price sensitive and that cost leadership in online grocery retail is very important. As 71% of the SKUs that outdated at least once in the first few months could be regarded as perishable products and that average relative outdating was equal to 52%, focus is needed on the perishable product assortment as they create the largest costs.

In order to become efficient demand must increase through 1) the opening of more PUPs and 2) an improved design of the perishables supply chain. As a result, costs should decrease and demand might become higher because of the higher service to customers. Since the first decision is made by SD, the second decision is the only one that can be influenced by SCL. The contribution of this model-based research is aimed at designing a cost-efficient supply chain for perishable products for SD that performs under a predefined service level. Moreover, SCL strives to optimal freshness and minimal outdating.

Research design

The most basic supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in stock using the EWA-replenishment logic with FIFO or LIFO withdrawal (see Figure 0.1) by Broekmeulen and Van Donselaar (2009), which t takes into account the full age distribution of the inventory regarding order decisions. In case the total customer demand is above the current inventory level, demand is lost and the consumers get their money back from the products that could not be delivered. The red box defines the part of the supply chain which is included in the scope of the project.

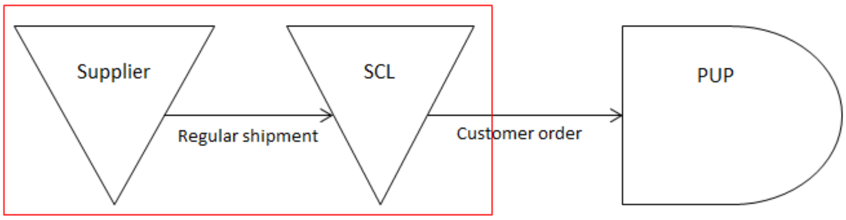

Figure 0.1– Supply chain with inventory point without emergency shipments

A more complicated supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in using the EWA-replenishment logic with FIFO or LIFO withdrawal by Broekmeulen and Van Donselaar (2009). The reorder level is set in the same way as in the previous supply chain structure. However, in case the total customer demand is above the current inventory level, demand is not lost and an emergency order is placed (exact shortage quantity) just after all customer orders are known (see Figure 0.2). The shortages are delivered some hours before the customer orders are transported to the PUP with a delivery reliability of x%. As the direct service level is set the same as in first structure, relative outdating is expected to be equal, although the actual service level is at least as high as in the previous structure. This is because products are ordered with emergency when the costs of the emergency shipments are below the costs of not selling the product (cost of lost sales).

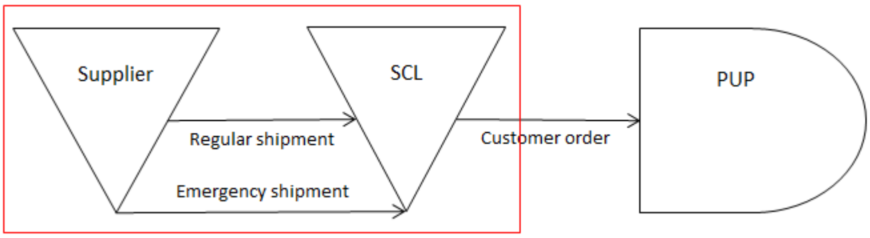

Figure 0.2 – Supply chain with inventory point with emergency shipments

The last supply chain structure is one in which no inventory is held at the warehouse. When customer orders are known, the exact amount of products is equal to the number of products ordered by all the customers together (see Figure 0.3). Products that are delivered as 'pick-to-zero' have not yet been assigned to a final consumer. Those products are delivered on a pallet and must be put on a location from which the products have to be picked, just like products that are held in stock. Pick-to-zero orders are delivered some hours before the customer orders are transported to the PUP with a delivery reliability of y%. As no inventory is held at the distribution center, relative outdating is equal to 0% and the actual service level is in principle equal to y%.

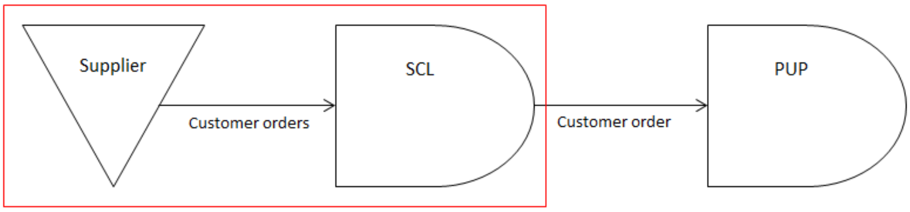

Figure 0.3 – Supply chain with pick-to-zero operations

Since it is not that straightforward to decide which supply chain structure is best for each product, this research elaborated on this issue. Therefore, the major question of the model-based research can be formulated as follows:

How can a supply chain for an assortment of perishable products of an online retailer be designed best in order to minimize relevant costs while meeting predefined customer service levels?

Quantitative model

Relevant costs related to the problem context can be divided into costs on SKU-level, i.e. outdating costs, operational costs and costs of lost sales and into extra transportation costs. First, outdating costs were estimated by making use of approximations of relative outdating developed by Van Donselaar and Broekmeulen (2012). Absolute outdating was computed by multiplying these approximations with the average demand. Next, multiplying this with the sum of the wholesale price, costs related to taking products out of stock and the physical disposal costs resulted in the total outdating costs. Second, operational costs considered as relevant for all structures were inbound costs per order line and order picking costs per product and additionally for products held on inventory, costs related to checking inventories. Third, costs of lost sales were estimated by making use of fill rate approximations by Van Donselaar and Broekmeulen (2012). Multiplying 100% minus the fill rate by average demand and then multiplying this with a lost sales costs parameter (dependent on how costly lost sales are) resulted in the relevant lost sales costs. Besides the costs made on SKU-level, costs are also made on supplier-level. In case multiple supply chain structures resulted in multiple delivery moments per day, extra transportation costs were made. For each product the best structure was the one with the lowest relevant costs. However, in case products of a supplier were supplied via pick-to-zero and regular shipments, extra transportation costs were made. In case the extra transportation costs were higher than the cost savings of supplying all products via pick-to-zero or via the EWA-policy, an aggregate decision was made on the supply chain structures. Emergency decisions can be made on a daily basis in order to fulfil demand of items for which shortages have arisen due to higher than expected demand. The decisions are made based on costs of lost sales and the costs made when placing an emergency shipment (operational cost and (extra) transportation cost).

Results and conclusions

The different types of analyses showed that a higher percentage of the assortment is optimally supplied via pick-to-zero operations when demand variability is higher. As the performance of pick-to-zero operations are not influenced by demand variability (at least not at the retailer DC) compared to inventory policies (due to higher relative outdating), it has become better for a larger proportion of the assortment to be supplied via pick-to-zero operations. A straightforward finding is that fewer products are supplied via pick-to-zero when demand increases, as relative outdating becomes so small for inventory policies that relevant costs of inventory policies shoot underneath the costs of pick-to-zero operations because the lost sales costs incurred with pick-to-zero are larger. In case it is possible for all suppliers to deliver products in pick-to-zero operations and PTZ-capacity would be ample, it would be best to supply the whole current assortment via pick-to-zero, although relative costs made are twice the margin on the product. Regardless of the other costs made than the relevant costs captured in the model and taking into account the margin on the product of 35%, at least 20 PUPs are needed to only bear for the relevant costs made according to the cost model. As it is expected that order pick productivity will increase in concurrence with the demand, relative relevant costs are expected to be almost below the margin when 10 PUPs are operational. However, at least 50 PUPs are needed if no other than the current PTZ suppliers are willing or able to supply via PTZ.

Next, it is concluded that higher case pack sizes result in wider demand intervals and longer shelf lifes result in shorter demand interval at which pick-to-zero is cost efficient. Moreover, it can be concluded that PTZ will not become cost efficient again when demand is extremely high as the lost sales cost are ever increasing due to the fixed fill rate, which is much lower than the EWA target fill rate and outdating costs for EWA will approach zero as demand become extremely high. Although the analyses show that EWA LIFO might be cost efficient in some situations, the relevant costs for EWA LIFO can only be equal to the costs for EWA FIFO when the case pack size is many times larger than the expected demand during the shelf life. However, it that case the average number of batches is almost always equal to 1. It makes then no sense to withdraw products in LIFO manner, as all products in stock have the same shelf life. Moreover, it can be concluded that average demand is the most important factor in determining the relative costs of products kept on inventory. Besides, it can be noticed that extreme high case packs and short shelf lifes are having a large influence in the resulting costs.

It can be concluded that the cost savings of emergency shipments are not expected to be large enough to cover the extra transportation costs when only few PUPs are operational. Although the analysis showed on average in which situations and for which suppliers emergency shipment might be profitable. As in reality shortages are not constant, the execution of emergency shipments is based on the actual shortages. Therefore, it might occur that the actual shortages of products of a specific supplier are way larger than expected and that emergency shipments are incidentally profitable in the early stage of operation. It can be concluded that emergency shipments are especially beneficial for suppliers which supply a large assortment with relatively high average retail prices. In this way, extra transportation costs made by performing emergency shipments can be covered. They are expected to be profitable for a high regular fill rate (> 0.99) when at least 20 PUPs are operational.

Recommendations

The recommendations are based on the results and the knowledge obtained throughout this research project. It can be seen as an advice for the entrepreneurs starting a business in the online grocery retail domain and for logistic service providers of perishable goods, such as SCL and Hollander Barendrecht.

- *Sales volume:* average demand is a large factor in costs made due to high levels of outdating; operational process must fit sales volume; retailer should quickly scale up to benefit from economies of scale
- *Online assortment:* offer comparable assortment to conventional retailers; keep enriching assortment when upscaling takes place; start at least with fast and medium movers
- *Suppliers and supply chain structures:* starting online retailers need to find suppliers which are willing to supply via pick-to-zero if this is needed; shift of ordering time window of customers in order to lengthen supplier lead time for pick-to-zero operations.

Future research

This research is one of the first quantitative studies on supply chain management of online supermarkets. In order to improve the supply chain management of online grocery retail several future studies can be performed. For example, conducting a marketing research on reactions of customer time might be interesting as pick-to-zero operations can be used without any constraints if suppliers have additional time when the customer order lead is increased with one day. Future research can also be conducted into the economies of scale of the order picking process of online grocery retailing, since this process differs a lot from conventional retail order picking. Another future research direction would be developing a capacitated decision model, as the model developed in this project is uncapacitated regarding pick-to-zero capacity. Finally, future research could incorporate the production, packaging and order-pick process and planning of suppliers in the decision model, as it was experienced that decisions cannot just be solely made by retailers themselves. It might therefore be interesting to investigate what the optimal supply chain would be taking into account the cost structure of both parties and what contract approaches the optimal centralized costs.

PREFACE

This master thesis project is the final part of my study Industrial Engineering, performed in partial fulfilment of the requirement for the degree of Master of Science in Operations Management and Logistics at the Eindhoven University of Technology. The paper is the result of a research project conducted for Specialized Consumer Logistics B.V., former logistic service provider of the total assortment of the online grocery retailer Superdirect.com. The research project was started at February 2014 and finished in July 2014.

Before, we move on the research I would like to thank everyone who made this project possible. Pascal Piepers, my supervisor at SCL, who assisted and guided me towards the final research direction and who provided many insights in the environment of SCL. Additionally, I would like to thank Albert, Leo and Tijmen, who also provided many insights on SCL by the useful discussions.

Furthermore, I would like to thank my first supervisor, Rob Broekmeulen, who guided me through the project and always enthusiastically shared his knowledge about the retail environment. Moreover, he provided helpful insights and literature on which I was able to move on with. Also I would like to thank my second supervisor Marco Slikker for providing critical feedback on my thesis proposal and concept versions of my master thesis.

Finally, I would like to thank my family, friends, and especially my girlfriend for their support during my study and graduation project; especially during the period in which I had to cope with some heavy setbacks in personal life. Despite that, I have succeeded to graduate without any delays at which I am proud of.

Willem Gerbecks

Barendrecht, July 2014

LIST OF ABBREVIATIONS

CML	Cross-Dock-Managed-Load
CODP	Customer Order Decoupling Point
CV	Coefficient of variation
DC	Distribution center
EWA	Estimated Withdrawal and Ageing
FDC	Fresh Distribution Center
FIFO	First In First Out
HB	Hollander Barendrecht
JML	Joint-Managed-Load
LIFO	Last In First Out
LSP	Logistic Service Provider
MTO	Make-To-Order
MTS	Make-To-Stock
Pre-C	Pre-distribution cross-docking
Post-C	Post-distribution cross-docking
PTZ	Pick To Zero
PUP	Pick Up Point
SD	Superdirect.com
StDev	Standard deviation
SCL	Specialized Consumer Logistics
SKU	Stock keeping unit
SML	Supplier-Managed-Load
WMS	Warehouse Management System

CONTENTS

1 INTRODUCTION

This first chapter functions as the introduction of my master thesis. It presents information about the company, the research context and motivation, the problem statement and the importance of study. Furthermore, the report outline is discussed.

1.1 COMPANY DESCRIPTION

Hollander Barendrecht (from now on named as “HB”, see *List of abbreviations* for all other abbreviations) is a subsidiary of The Greenery, which is a large international vegetables and fruit company. HB is a logistic service provider of fresh and semi-fresh products for the retail industry. On a daily basis it delivers cooled products to its customers, approximately 270 PLUS-supermarkets, throughout the Netherlands. This operation is executed from its fresh distribution center in which almost all fresh and semi-fresh products of PLUS are stored. Another part of the assortment is delivered via a cross-dock operation or is picked-to-zero at the distribution center (see Chapter 2.2 for definitions). The Fresh Distribution Center delivers ready-made orders at store level directly to the stores. Recently, The Greenery founded a new subsidiary company under the name Specialized Consumer Logistics to be the logistic service provider of all products (fresh, dry groceries, frozen goods) for the new online retailer Superdirect.com. SCL leases the system and the facilities of HB. Moreover, staff of SCL and HB are working at the same office and some staff even works for both subsidiaries. The only reason why SCL and HB are two different subsidiaries is that they are a logistic service provider for a different retailer, and therefore operations are designed differently.

SD was founded by Peter Pompen and Henk Niemansverdriet in 2011. They developed a new supply chain concept that should be faster and more efficient than those of existing grocery supply chains. Sligro Food Group has got a minority interest in SD so that retail expertise is guaranteed. SD is an online supermarket at which one can order daily groceries online. Groceries ordered before 10 p.m. can be picked up at pick-up points the next day from 11 a.m.. Within a couple of minutes one is served with all their ordered groceries, since pick-up points are completely automated and sufficient docks are present. Orders can be picked up 24/7. Its marketing policy makes use of the fact that its products are fresher than those in supermarkets due to the faster and more efficient supply chain. SCL installed a complete warehouse to store inventory at three different temperatures (room, cooling and freezing temperature) in a very simple way. Unlike HB, SCL picks orders on consumer level instead of on supermarket level. This means that consumer units are collected and are put in boxes instead of case packs put onto roll containers. Picked products are put into consumer-specific cardboard boxes.

Until now, one pick-up point had been fully operational since the end of September 2013 and was located in Eindhoven. It was SD’s aim to have ten pick-up points operational at the end of 2014. Unfortunately, at May 1st 2014 Superdirect.com announced to quit the pilot in Eindhoven. This master thesis, however, still is aimed at this specific concept as the outcome of the research is of importance if Superdirect.com decides to relaunch its operations in the future.

1.2 RESEARCH CONTEXT AND MOTIVATION

The mission of HB is “to be the most sustainable fresh service provider in the Netherlands, which assists in all aspects”. The challenge that SCL was facing by being the logistic service provider of SD fits well with this mission. Although not only fresh and semi-fresh products are handled, the image of SD to be “super fresh” goes near the vision of HB.

The mission of HB is focused on sustainability. The new supply chain for SD that has arisen contributes to a more sustainable handling of perishable products. Since perishable products are expected to arrive earlier at the customer on average compared to other existing grocery supply chains, the probability of outdating should be lower and this would contribute to a more sustainable food industry.

Moreover, the vision entails the desire to be the most sustainable fresh service provider in the Netherlands. By responding to the need of SD of having a logistic service provider, SCL shows that it wants to jump into a new market in order to improve their footprint of sustainability.

1.3 PROBLEM STATEMENT

In contrast to the average general online merchandise order, which comprises one to three separate items, the average online grocery order contains much more items, many of which are perishable and need rapid picking and delivery. According to Fernie et al. (2010), this requires localized order picking either in an existing shop or a dedicated warehouse. The pick-up points of SD are supplied from the latter one. A disadvantage of fulfilment from a dedicated warehouse is that investment costs of new PUPs are quite high. However, doubts have been expressed about the long-term sustainability of store-based fulfilment. As the volume of online sales expands, conflicts between conventional and online retailing are likely to intensify (service levels of both groups). At the "front end" of the shop, aisles may become increasingly crowded with staff picking orders for online customers (Fernie et al., 2010). Picking from stores is generally considered expensive when compared with the logistical efficiencies that can be achieved through state-of-the-art automated centers. Therefore, long-term feasibility of picking and delivering stores is questioned from a cost-perspective (Morganosky & Cude, 2002).

An advantage of supplying PUPs by a warehouse is that the inventory is dedicated to the online service; home shoppers can check product availability at the time of ordering and, if necessary, alter their shopping list. The order picking function should also be faster and more efficient in fulfilment centers as they are particularly designed for the multiple-picking of online orders. To be cost-effective, dedicated pick centers must handle a large throughput. The threshold level of throughput required for viability also depends on the breadth of the product range. It is very costly to offer an extensive range in the early stages of an e-retailing operation when sales volumes are low. Offering a limited range can cut the cost of the operation but makes it more difficult to lure consumers from conventional retailing. Another inventory-related problem which retailers using pick centers have encountered is the difficulty of disposing of excess stocks of short-shelf life product, because stimulating demand at short notice using price reductions is not possible. It is more difficult using electronic media to clear excess inventory of fresh produce from fulfilment centers that consumers never visit (Fernie et al., 2010).

Verweij (2014) mentioned the following five operational issues in an internal business report of HB:

- The order picking process is expensive because this must be done in multiple shifts and mainly in the evening and at night.
- The logistic process is expensive because products must increasingly arrive faster at the consumer.
- The returns flow of freezer boxes is difficult to handle.
- The warehouse is expensive because it must be large to meet demand and to store returns of freezer boxes.
- Food products are expensive and sensitive to outdating.

In order to reach the break-even point in the online food industry an online retailer needs between 22,000 to 25,000 orders a month in total according to the former general manager of Truus.nl, which is a former online food retailer. Truus.nl went bankrupt because of too high logistic and operational costs (Verweij, 2014). Since the average customer order of SD was equal to 31 products, this would have meant that SD needs on average 682,000 to 775,000 products to be sold each month. Actual demand during the period from week 41 in 2013 until week 5 in 2014 (see Figure 1.1) remained rather stable (between 3,500 and 4,500 products per week), except for week 50 in 2013 until week 1 in 2014 (see Figure 1.1). However, this could be explained by the fact that during these weeks all products were in promotion and had a 25% reduction on the selling price. Moreover, the Christmas holiday may have a pushed up the demand in those weeks because such pattern is common in grocery sales. Surprising was the fact that 18 of the 20 most sold products were perishable products while Verweij (2014) concluded from interviews with potential consumers that they were more eager to buy dry groceries than perishable products like fruit, vegetables, meat and dairy products.

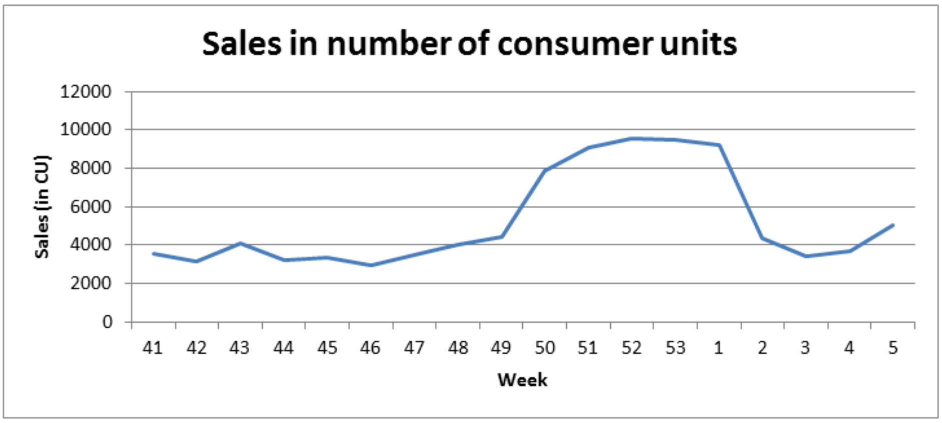

Figure 1.1 - Sales in number of consumer units

It turned out to be that the average relative outdating (outdating relative to demand) of all products was equal to 52% in the same period (see Figure 1.2). This is extremely high compared to average relative outdating in the retail industry. This could be explained by the fact that demand was very uncertain and could not be accurately estimated in the early stage of operation of SCL. Since SD only had one PUP operational, the coefficient of variation was larger than when demand of multiple PUPs could be pooled. Moreover, Figure 1.1 and 1.2 show that in the period of high demand, relative outdating is relatively low and vice versa. Relative outdating is thus moving opposite to sales.

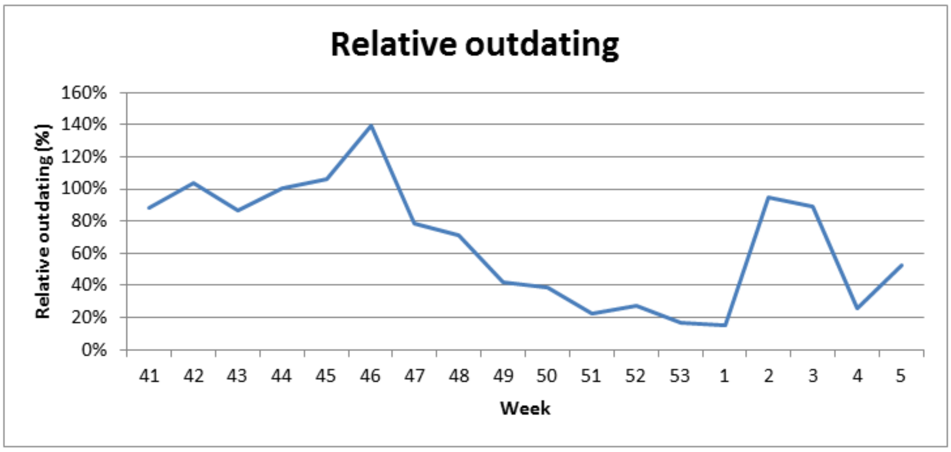

Figure 1.2 – Relative outdating

Since on average 71% of the outdated products were perishable products (see Figure 1.3), a large part of outdating was caused by those products. Because those products have shorter shelf lifes, the probability of outdating is much higher. Therefore, it is important that attention is paid to perishable products.

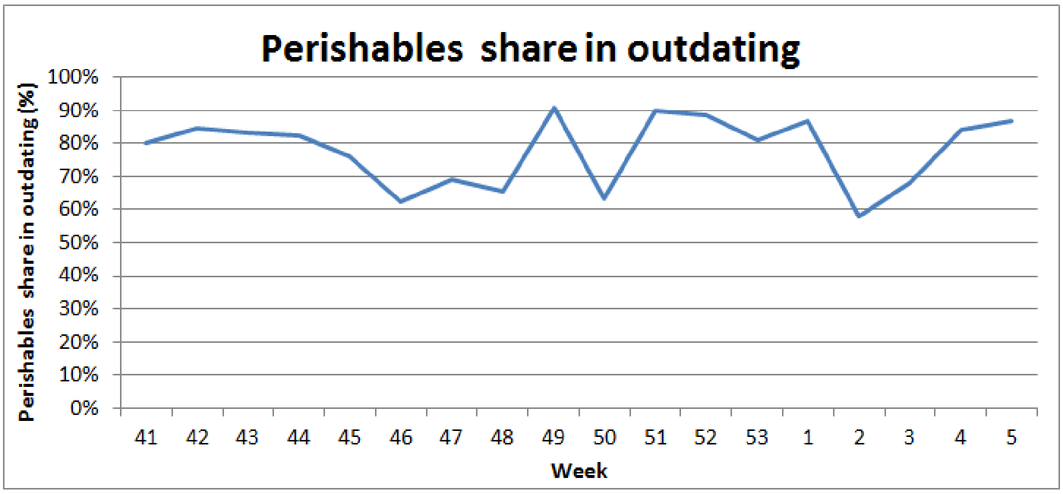

Figure 1.3 – Perishables share in outdating

The gross service level in the same period was equal to 98.44% (see Figure 1.4). This means that in total 98.44% of all ordered products by customers were delivered to the customer in time. In about half of the instances of not being able to deliver a product to a consumer this was not caused by SCL, but by failures in deliveries of suppliers or exceptional high orders of consumers (e.g. 120 packs of sugar). The net service level is thus defined as the percentage of products which were ordered by customers which are delivered to the customer and which could not be delivered because of other reasons mentioned before. The average net service level was therefore equal to 99.42%, which is almost according to guidelines (> 99.60%).

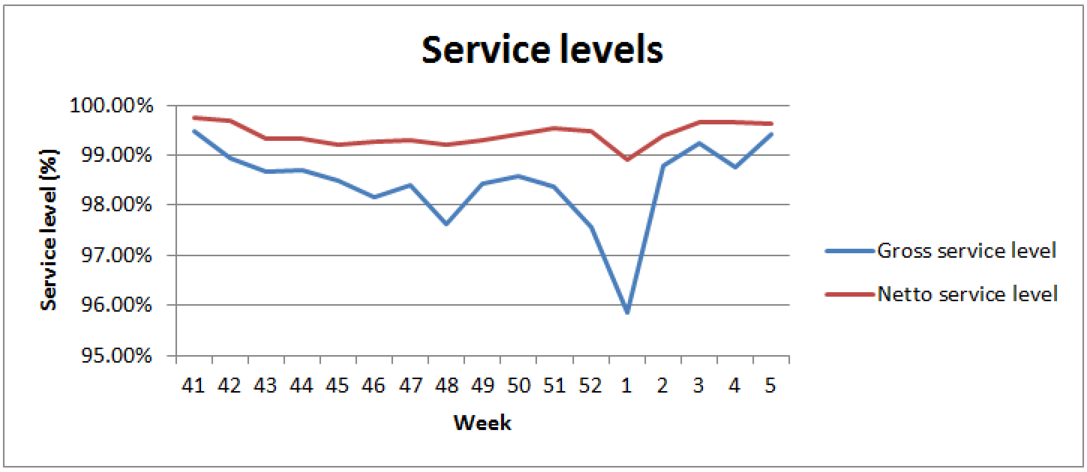

Figure 1.4 – Service levels

It can be concluded from Figure 1.1 that the products are very price elastic. The number of products sold was doubled in the period a 25% reduction was applied. Although in general December had a higher average sales compared to other months in the year, 12.5% compared to the average monthly sales in 2013 (ABN Amro, 2014), the increase in demand is predominantly caused by the price reduction in December. This indicates that focussing on price is key in order to increase the number of products sold.

In order to become efficient, demand must increase through 1) the opening of more PUPs and 2) an improved design of the perishables supply chain. As a result costs should decrease and demand might become higher because of the higher service to customers. Since the first decision is made by SD, the second decision is the only one that can be influenced by SCL. The contribution of this model-based research is aimed at designing a cost-efficient supply chain for perishable products for SD that performs under a predefined service level. Moreover, SCL strives to high freshness and minimal outdating.

The major question raised by the company is as follows:

How must the supply chain for perishable products for Superdirect.com be designed in order to let the supply chain be cost-efficient and to perform under a predefined customer service level?

1.4 IMPORTANCE OF THE STUDY

In the first place, this study is contributing and of importance to the management of SCL. The improved supply chain for perishable goods decreases outdating of perishable products because supply chain structures fit better to specific products. Consequently costs related to outdating decrease. Collo and Lapoule (2012) state that customers declare that they would buy more fresh products if they were convinced of its quality (higher freshness). Higher demand ensures that order pickers can work at a higher utilization, which is also cost-effective. Collo and Lapoule (2012) state that the time required to prepare orders should be kept to a minimum in order to control prices, improve margins and profitability, and to provide an improved level of customer service. Finally, Fernie et al. (2010) state that offering a limited range can cut the cost of the operation but make it more difficult to lure consumers from conventional retailing. Therefore, it is expected that offering specialties which SCL cannot carry themselves would help to lure more consumers. Collo and Lapoule (2012) state that managers recognize that a deeper and wider product range – with more fresh products, particularly fruit and vegetables – would make it possible to generate larger purchase baskets and increase the frequency of purchases and customer loyalty.

1.5 REPORT OUTLINE

The report started with this introduction chapter on the company involved and the initial problem statement. The second chapter deepens into the perishable supply chain of Superdirect.com, thereby looking at the assortment, supply chain network and the main activities. The third chapter describes the research assignment, thereby looking at literature on possible solution directions, the research methodology and data collection methods. After that, chapter four provides a thorough analysis on the current problem and validates the initial problem statement. In Chapter 5 the quantitative model is proposed as a solution direction and is discussed and tailored for Superdirect.com. Chapter 6 describes the input and results of several model solving analyses conducted for this solution direction. This thesis ends with Chapters 7 and 8, in which the implementation for SCL and the conclusions of the research project are described and discussed.

2 THE PERISHABLES SUPPLY CHAIN OF SUPERDIRECT.COM

This chapter describes the perishables supply chain of Superdirect.com. First, the assortment of perishable products is defined. Second, the perishables supply chain network is described. Finally, the main activities of SCL, which the master thesis discusses, are described.

2.1 PERISHABLES ASSORTMENT

A perishable product at SCL is a food product with a certain lifetime; this means that the product can become unacceptable for consumption or obsolete. According to Van Donselaar et al. (2006) perishable products can be divided into two subcategories: days-fresh and weeks-fresh. Days-fresh products are perishable products with a life-time less than 10 days after production. Weeks-fresh products have a life-time between 10 and 30 days after production. This research project focuses on both days-fresh and weeks-fresh products. This means that all products which were delivered to SCL 30 days or less before the product had to leave the DC again were included into the scope. Products have two parameters related to the expiration date. Suppliers had to deliver products which had a shelf life at that moment of at least x days. SCL then had to deliver those products at least y days before expiration date to the customer. As a consequence a product could be hold in stock at the DC in any case for at least x-y days.

The perishables assortment of SD consisted of dairy products, fresh sauces, fresh fruit, fresh potatoes, fresh vegetables, ready-made meals, fresh meat (substitutes), fresh sandwich fillings, fresh bread, fresh fish, butter & margarine, eggs, fresh fruit juices, fresh herbs and fresh savoury snacks. Mid-February 2014, 902 of the 6160 products were considered as perishable products.

2.2 PERISHABLES SUPPLY CHAIN NETWORK

SCL was the dedicated logistic service provider of SD for all types of products. No other logistic service provider existed that delivered grocery products to SD. The physical flow of goods towards SD's PUPs is depicted in Figure 2.1.

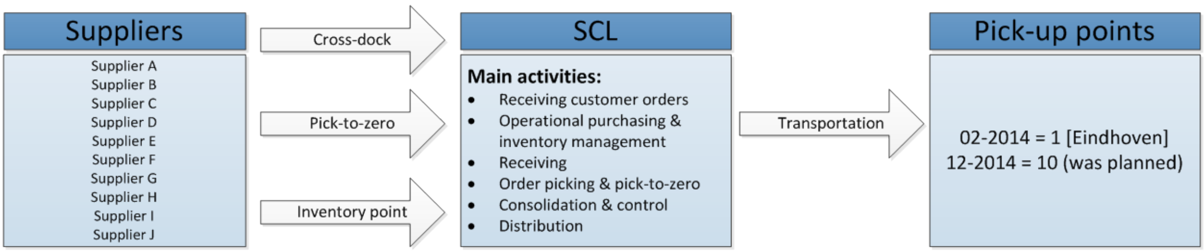

Figure 2.1 - The perishables supply chain (see Appendix A for real supplier names)

Approximately ten suppliers were delivering products to SCL via two types of supply chain structures. Most products were delivered to SCL in order to restock the warehouse. However, for some days-fresh products two other logistics forms could be applied. Cross-docking and pick-to-zero both imply that the supplier delivers the exact number of products needed a couple of hours before delivery to the PUP. The difference is, however, that in case of cross-docking the supplier has already prepared the customer orders separately, while in case of pick-to zero SCL has to prepare the customer orders itself. Therefore, cross-docking is more expensive than pick-to-zero, but it has the advantage that products can arrive somewhat later at the warehouse. For two of its suppliers, Supplier C and Supplier E, pick-to-zero was used. Cross docking was not yet used for any products of Superdirect.com.

2.3 MAIN ACTIVITIES

In the next sections a short description is provided of each part of the main activities in the process of SCL. All these activities were focused on achieving the service level (> 99.6%) by minimizing relevant costs. The main activities consisted of receiving customer orders, operational purchasing and inventory management, receiving, order picking and pick-to-zero, consolidation and control, and distribution (see Figure 2.2).

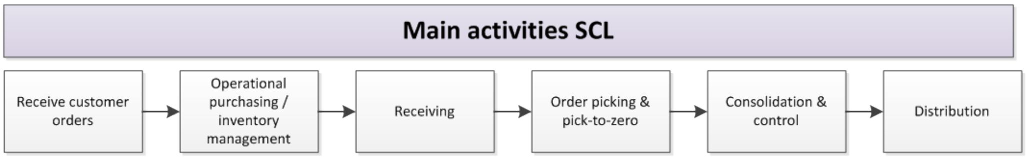

Figure 2.2 - Main activities SCL

Operations at SCL started on a regular working day at 10 p.m. with preparations, in which all customer orders were received and picking shortages were emailed to Supplier H. At 11 p.m. the night shift began with order picking. In the meanwhile, some pick-to-zero orders arrived and the shortages which could be picked up at Supplier H arrived. At 7.30 a.m. the truck was loaded and left to the PUP. From that moment several activities were done, e.g. folding boxes, checking inventory, decanting and location replenishments. All these activities are visually represented on a time scale in Appendix B.

Receiving customer orders

When a product was going to be offered on the web shop, several steps had to be followed. First, one packaging unit was ordered in order to make a photo for the web shop and to fill out the product details in the system. After that, a product was offered on the web shop by the time the inventory of the product had become positive. From then on, products could be ordered by customers on the web shop. When inventory was equal to zero, the product was still displayed on the web shop. This resulted in customer orders which could not be delivered when no further actions were taken (cancelling the order or place emergency shipment). Moreover, no check was carried out on the order size in case the inventory position was larger than zero. Therefore, it often occurred that consumers ordered more products than that were actually in stock. As a way to avoid having lost sales, SCL performed several emergency operations in order to be able to satisfy customer demand. As the PUP in Eindhoven had been the only one, this emergency solution worked. However, when the number of PUPs had increased this solution would not have been feasible anymore.

Operational purchasing & inventory management

Products of two suppliers were picked-to-zero at SCL. Supplier C delivered their products at 6.30 a.m. on Tuesdays to Saturdays when products were being ordered before 10.15 p.m. on the previous day. On Sundays no deliveries took place, and deliveries on Monday had to be ordered on Saturday before 10.15 p.m. Therefore, sometimes inventory had to be held for products of Supplier C. Supplier E delivered their fresh breads between 5.00 a.m. and 6.00 a.m. every day when products were being ordered before 10.30 p.m. on the previous day. However, their other products were not delivered on Sundays. Therefore, sometimes inventory must be hold for these products of Supplier E. Table C.1 (in Appendix C) shows the general ordering and delivery system for which order day 1 is defined as a Monday, etc..

Products from all other suppliers were ordered and kept in stock at the warehouse. Since the demand had been very volatile over the last months due to the single PUP, no clear inventory policy was applied for these products. Dependent of the average demand per products an order was placed equal to (usually) 1 packaging unit when the inventory was very low (1 or 2 CU for slow movers or 10 to 20 CU for fast movers) or when many products were expected outdate the next day based on generated lists. Review periods and lead times were (mostly) equal to 1 or 2 days, dependent on the weekday at which an order is placed (no delivery on Sundays and delivery on Monday must be ordered at Saturday). An exception applied for Supplier J, which only delivered twice a week.

Differences in purchasing prices existed between the different logistic forms, but these were not known by SCL since SCL received a compensation from SD for each packaging unit handled. The products that were purchased by SCL were paid by SD itself and were not known by SCL. However, the compensation SCL received from SD differed in the way products were supplied. Compensation was higher for products which were kept in stock compared to products which were picked-to-zero and much higher compared to in case products would have been cross-docked. Outdated products were paid by SD because outdating was predominantly caused by the high level of demand uncertainty and SCL was not responsible for the high uncertainty. Table C.2 (in Appendix C) shows the logistic form and the weekend policy of a supplier.

Receiving

When a regular delivery or a pick to zero delivery arrived, several checks were performed, e.g. control on quantity, damage, EAN-code, temperature, expiration date, etc.. In the early phase of the operation products were delivered per product group on as few as possible pallets per supplier (multiple products on one pallet). After that, products that met all checks were put on locations (also pick to zero deliveries). The process in which multiple products from one pallet were put away on multiple locations is called ‘decanting’.

Order picking and pick-to-zero

As mentioned before, order picking started at 11 p.m. since all customer orders and possible shortages were known by then. SCL had organized the warehouse in such a way for the cooled area as well as for the regular area that products with the highest volume were closest to the elevator to the expedition. The traversal strategy was used in order picking and the order picker picked 3 boxes at the same time by use of voice picking. The traversal strategy means that any aisle containing at least one pick is traversed entirely (except potentially the last visited aisle). Aisles without picks are not entered. From the last visited aisle, the order picker returns to the depot (De Koster et al., 2007). SCL had, however, been experimenting with cluster order picking to improve their performance. With this strategy, three order picking lists (from different customers) were combined within a cluster (area of the warehouse) such that distance is minimized. Moreover, the objective had always been that the product with the shortest remaining shelf life that meets the requirement was picked and the supplier was not allowed to deliver products with an earlier expiration date as before. In other words, no overtaking took place. The WMS also used this principle for the inventory administration in its system. Pick-to-zero items were picked separately from stock items, with the result that at least one separate cardboard box was needed. This was the case because stock items were started to be picked by the time all customer orders were known, and were all picked by the time that PTZ items arrived at SCL.

Consolidation and control

Every box that was picked had to be transported to the consolidation area and had to be put away onto the right location. During the first few months many checks were performed in order to prevent picking errors. Because the picking orders had direct influence on customer satisfaction no picking errors could be permitted. Moreover, checks were performed on the expiration date. As stated before, all products that were sent to PUPs had to be the oldest ones, but must have a minimal shelf life of y days.

Distribution

The truck left at 8.00 a.m. to the PUP in Eindhoven and arrived at approximately 9.30 a.m. in order to have all the boxes installed at least before 11.00 a.m. Superdirect.com remarked that the automated PUP did not efficiently put away the boxes which caused longer waiting times at the docks. As the capacity use of the truck was quite low (mostly below 30%), a truck could deliver multiple PUPs in the future if this would be feasible within the timing constraints.

3 RESEARCH ASSIGNMENT

After describing the perishables supply chain of Superdirect.com, this chapter provides some academic insights on different aspects related to the problem statement, initial research question and the supply chain description. This is followed by the research direction and research methodology and this chapter ends with a short discussion on the different data collection methods that were used for the analyses.

3.1 LITERATURE REVIEW

This literature review deepens into academic insight related to the drivers of cross-docking and inventory holding, perishable inventory policies, the concept of emergency shipments and the assortment of an online retailer.

Cross-docking or holding inventory?

In order to maximize the freshness of the bread in the supermarket and to minimize waste, it is typically delivered directly on a daily basis. For items with a slightly higher shelf life, cross-docking at the retailer's DC may be an option. Both direct delivery and cross-docking aim to reduce the lead time (Van Donselaar et al., 2006).

Within "days-fresh items" certain items typically can be ordered only once every day (bread and newspapers) or once every week (weekly magazines) and this frequency exactly matches their maximum remaining shelf life. Moreover, those fresh items may typically face substitution in case a stock-out situation occurs within the product category. Therefore, the one period multi-item newsboy problem with substitution would basically apply here (Van Donselaar et al., 2006). However, bread was ordered after the customer orders are known by SCL. Just some hours before transportation, bread was picked-to-zero at the distribution center of SCL. Therefore, SCL could order the exact quantity at their suppliers. Besides, newspapers and magazines were not offered by SD.

Days-fresh dairy products and ready-to-cook vegetables may have products with different ages on the shelves. Moreover, since their shelf life is small (approximately one week), the risk for waste is clearly present. Therefore, the grocery chains may not only apply direct delivery or cross-docking, but also aim for substitution between products in the same category. Due to the perishability, the optimal reorder rule no longer is of a simple form. Rather than only taking into account the total inventory position, the reorder quantity depends on detailed information about the number of items in stock per age. This makes the analysis of these systems very complex. Adding the substitution aspect to it makes it even worse to analyze (Van Donselaar et al., 2006). However, substitution does not take place yet on the SD's web shop since all products are displayed even when the products are not in stock.

From the shelf life perspective, cross-docking is not a necessity for weeks-fresh items. Substitution and perishability may again play a role in controlling the inventories for these items, although the relative impact of both tends to be smaller compared with daily fresh items (Van Donselaar et al., 2006).

Perishable inventory control policies

When looking for inventory control policies, one has to take the following aspects into account. First, a lost sales environment has to be taken into account, which means that when on-shelf inventory is zero or when suppliers are not able to deliver the right quantity for pick-to-zero or cross-dock deliveries, demand is lost. Therefore, inventory models that consider backordered demand are not relevant. 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 or when demand is insufficient during a certain period, the product becomes inappropriate for selling to the consumer, resulting in a maximum available shelf-life. A good inventory control policy for perishables takes these different aspects into account.

Cost-effective control of inventories can cut costs significantly, and can at the same time contribute to the efficient flow of goods and services (Nahmias, 2011). 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 analyze. However, due to new information technologies like RFID, it now also becomes more economically feasible to register this type of information. Broekmeulen and Van Donselaar (2009) suggest a replenishment policy for perishable products which takes into account the age of inventories and assumes FIFO or LIFO. They set the reorder level as follows:

$$s_t = SS + \sum_{i=t+1}^{t+L+R} E[D_i]$$

where
$s_t = reorder\ level\ at\ day\ t;$
$SS = safety\ stock$
$\sum_{i=t+1}^{t+L+R} E[D_i] = the\ expected\ demand\ during\ the\ lead\ time\ (L)\ plus\ review\ period\ (R)$

In the so-called EWA policy, the inventory position is first corrected for the estimated amount of outdating and an order is placed if this revised inventory position drops below the reorder level s_t. The value of n_t is now determined as follows:

$$if\ IP_t - \sum_{i=t+1}^{t+L+R-1} \hat{O}_i < s_t\ \ then\ n_t = \left\lceil \frac{s_t - IP_t + \sum_{i=t+1}^{t+L+R-1} \hat{O}_i}{Q} \right\rceil$$

where
$n_t = number\ of\ case\ packs\ ordered\ at\ day\ t$
$s_t = reorder\ level\ at\ day\ t;$
$IP_t = inventory\ position\ at\ day\ t;$
$Q = case\ pack\ size$
$\sum_{i=t+1}^{t+L+R-1} \hat{O}_i = estimated\ amount\ of\ outdating\ during\ the\ next\ L + R - 1\ days$

The EWA-replenishment policy is used to determine the timing and quantity of orders since this policy performs well for perishable products. It is a relatively simple policy and applicable in situations with positive lead times and fixed case pack sizes. The EWA-replenishment logic estimates how much inventory will be available to meet demand in the next $(L + R)$ days. The expected inventory that would be outdated in the next $(L + R - 1)$ days can be estimated by assuming that demand in each of these days is exactly equal to the expected daily demand. This estimated outdating quantity is then subtracted from the actual inventory position.

Cross-docking policies

Cross-docking is a logistics technique that eliminates the storage functions of a warehouse while still allowing it to serve its receiving and shipping functions. The idea is to transfer shipments directly from inbound to outbound trailers without storage in between, and shipments typically spend less than a few hours in a cross-dock, sometimes less than an hour (Bartholdi & Gue, 2004). Cross-docks can add value to supply chains where potential exists to improve transport efficiency, reduce inventory, or speed movement of products. However, enabling a value added cross-dock operation first requires a clear understanding of the three types of cross-docks and the factors necessary to identify each type successfully (Vogt, 2010).

1. Cross-Dock-Managed-Load (CML) = Cross-dock company (LSP) takes pallet, labels items, and sorts item by item to customers
2. Joint-Managed-Load (JML) = Supplier picks and labels items for total order, but sends randomly packed in transport. The cross-dock company sorts items from pallet which may contain products for one or many customers.
3. Supplier-Managed-Load (SML) = Supplier picks by store and builds pallet load per store. Cross-dock company moves pallet to appropriate dispatch lane.

Yan and Tang (2009) constructed comparable analytical models for distribution strategies with two major types of cross-docking, pre-distribution cross-docking (Pre-C) and post-distribution cross-docking (Post-C). Pre-C is a pure cross-docking process in which goods are loaded onto trucks at the cross-dock to deliver to stores directly. Suppliers take charge of preparation and sorting to facilitate immediate loading and delivering at the cross-dock. Pre-C requires that the suppliers know the quantity of order placed by each store in every period so as to complete the jobs of preparation and sorting accordingly. In contrast, Post-C transfers the task from suppliers to the cross-dock. Unlike Pre-C, Post-C operations involve sorting of goods from the supplier to trucks destined for individual stores at the cross-dock. These heavy workloads often incur higher operations cost there. However, the retailer can benefit from Post-C through pooling the risk during the period from the supplier to the cross-dock. The performance of cross-docking is clearly dependent on the demand uncertainty level, lead time and other variables. Analytical results show that Pre-C is preferred for environments with shorter supply lead time and lower uncertainty of demand, without the benefits of risk-pooling. The Post-C mitigates the weakness of the Pre-C at the expense of higher operations cost spent at the cross-dock. Whether the two major types of cross-docking, Pre-C and Post-C, are preferred, highly depends on the business environment (Yan & Tang, 2009). SCL used JML/Post-C (called "pick-to-zero" within company) for products of Supplier C and Supplier E. "Cross-docking" is not efficient for SCL because this results in too many boxes for each customer as each cross-dock supplier needs at least one box. In contrast, pick-to-zero items of different suppliers can be combined in fewer boxes. Therefore, pure cross docking is excluded from scope, only pick-to-zero will be considered in this research as useful.

Emergency shipments

In a review paper, Minner (2003) discussed the supply chain concept of emergency shipments applied in supply chain inventory models. Instead of assuming that unsatisfied demand is lost, associated with a penalty, a different interpretation can be made; these customers are not satisfied from regularly replenished items but instead an emergency supply is initiated (associated with an extra cost). Minner (2003) discussed many studies of which the following four are most relevant to this master thesis.

Muckstadt and Thomas (1980) analyzed a multi-echelon system where all inventory points apply $(S-1, S)$ policies. If a retailer has zero on-hand inventory and an item is demanded, an emergency order is placed at the warehouse which implies a shorter resupply time compared to a regular order. The same applies for the replenishment policy at the warehouse. Moinzadeh and Schmidt (1991) analyze a policy that takes into account all available information, i.e. net inventory and the timing of all outstanding orders. Regular orders have a lead time of λ_1 whereas emergency orders only require λ_2 periods to be delivered. The cost for an emergency order exceeds the cost for a regular order. In the so called no-delay multi-echelon inventory models of Minner (2000), safety stocks at every stocking point are provided to cover against reasonable demand variability whereas extraordinary large orders are excluded from the analysis by assuming some kind of operating flexibility. This modelling approach implicitly assumes the presence of two supply alternatives, a regular one for demands not exceeding a predetermined level of variability and an emergency mode to deal with excessive variations. Tagaras and Vlachos (2001) analyzed a periodic review order-up-to-level type policy with a regular and an emergency replenishment mode. The regular mode is used to raise the inventory to a base-stock level whereas the faster emergency mode might be used within the replenishment cycle in order to avoid stock outs. The emergency mode is capacitated.

Based on these previous studies, Lammé (2010) conducted a research on emergency shipments within the perishable supply chain of SPAR. He modelled a dual supply system where regular shipments are complemented with emergency shipments. A certain part of the supply is distributed in the regular way; the remaining (uncertain) part can be delivered, when needed, with shorter lead time. The emergency shipments concept provides some advantages regarding improved freshness and reduced outdating because of increased delivery frequencies, reduced lead times and reduced demand uncertainties. A drawback is that costs are higher for the second source, mainly by added handling and transportation cost. Therefore, it is only recommended for a certain part of the total assortment to use emergency shipments, especially when average demand is high, demand variance is high, penalty costs are high, and when shelf life is short (Lammé, 2010).

Van Gessel (2012) developed 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. The adjustment is upwards and based on information gain during the regular review moment. The adjustment can be realized by ordering products which have a much shorter lead-time than the regular products. Van Gessel (2012) 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 ordered products are combined with the regular ordered products, by performing additional cross-dock activities. He also assumed that the lead-time between the stores and the cross-dock facility is not lengthened, due to the extra operations.

The last emergency shipment concept could be beneficial for the products of SD. Customer orders arrive until 10 p.m. and must be delivered at 11 a.m. the next day. As the web shop online displays all products (also products which are not in stock), consumers may order products which are not in stock and cannot be delivered directly from stock. Emergency shipments can be beneficial for products that are kept in stock at SCL, but for which both risk of outdating and risk of lost sales are very high. These products could then be ordered via emergency shipments and can then still be delivered to the customer. Because of the current low volume of sales, relative costs of emergency shipments are rather expensive compared to emergency shipments within supply chains handling much larger volumes. Moreover, the possibility of an emergency shipment is very dependent on the production policy (MTS/MTO) of the supplier and whether he is able to deliver product on such a short notice.

The assortment of an e-retailer

Fernie et al. (2010) state that offering a limited range can cut the cost of the operation but make it more difficult to lure consumers from conventional retailing. Therefore, it is expected that offering specialties which SCL cannot carry themselves would help to lure more consumers. Collo and Lapoule (2012) state that managers recognize that a deeper and wider product range – with more fresh products, particularly fruit and vegetables – would make it possible to generate larger purchase baskets and increase the frequency of purchases and customer loyalty. The supply chain design is closely linked with the assortment of an e-retailer because the larger the assortment is, the higher the costs of outdating are and the more an e-retailer is inclined to use cross-dock or pick-to-zero operations. Therefore, costs of outdating and purchasing must be weighted in to decide on the supply chain design for different products.

3.2 Research direction

Based on the problem statement and the literature review, the research questions were defined and the research model was discussed.

The most basic supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in stock using the EWA-replenishment logic with FIFO or LIFO withdrawal (see Figure 3.1) by Broekmeulen and Van Donselaar (2009). In case the total customer demand is above the current inventory level, demand is lost and the consumers get their money back from the products that could not be delivered. The red box defines the part of the supply chain which was included in the scope of the project.

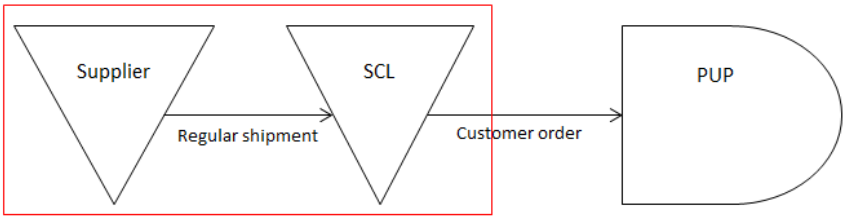

Figure 3.1 – Supply chain with inventory point without emergency shipments

A more complicated supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in using the EWA-replenishment logic with FIFO or LIFO withdrawal by Broekmeulen and Van Donselaar (2009). The reorder level is set in the same way as in the previous supply chain structure. However, in case the total customer demand is above the current inventory level, demand is not lost and an emergency order is placed (exact shortage quantity) just after all customer orders are known (see Figure 3.2). The shortages are delivered some hours before the customer orders are transported to the PUP with a delivery reliability of x%. As the direct service level is set the same as in first structure, relative outdating is expected to be equal, although the actual service level is at least as high as in the previous structure. This is because products are ordered with emergency when the costs of the emergency shipments are below the costs of not selling the product (cost of lost sales).

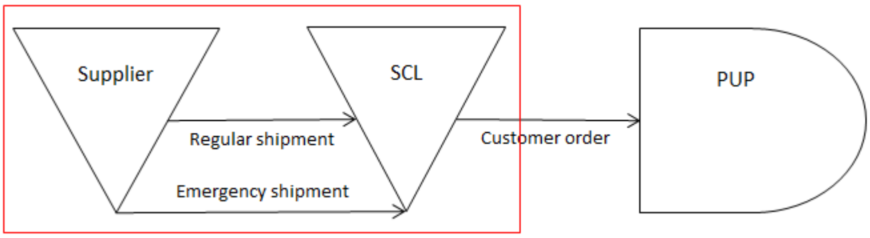

Figure 3.2 – Supply chain with inventory point with emergency shipments

The last supply chain structure is one in which no inventory is held at the warehouse. When customer orders are known, the exact amount of products is equal to the number of products ordered by all the customers together (see Figure 3.3). Products that are delivered as 'pick-to-zero' have not yet been sorted per final consumer. Those products are delivered on a pallet and must be put on a location from which the products have to be picked, just like products that are held in stock. Pick-to-zero orders are delivered some hours before the customer orders are transported to the PUP with a delivery reliability of y%. As no inventory is held at the distribution center, relative outdating is equal to 0% and the actual service level is in principle equal to y%.

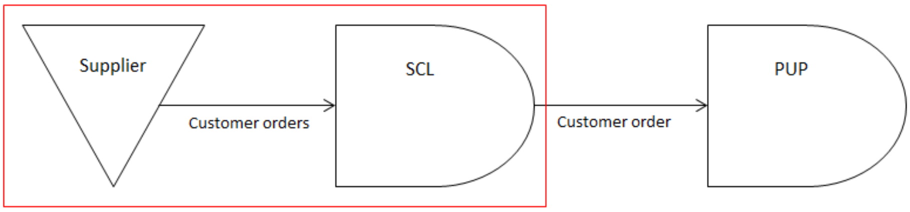

Figure 3.3 – Supply chain with pick-to-zero operations

Since it is not that straightforward to decide which supply chain structure is best for each product, this research elaborated on this issue. Therefore, the major question of the model-based research can be formulated as follows:

How can a supply chain for an assortment of perishable products of an online retailer be designed best in order to minimize relevant costs while meeting predefined customer service levels?

Sub-questions related to the major question can be formulated as follow:

1. *How can relevant costs be estimated and allocated, and how can these be incorporated into a quantitative model?*
2. *How can the operational constraints be included into the model?*
3. *Which products of the current assortment can be best supplied by which of the described supply chain structures?*
4. *What are the break-even points at which a product has to be supplied via a specific supply chain structures?*
5. *How can products that will be included in the assortment in the future be best supplied when no historic data is available as input for the model?*
6. *How can SCL handle a large assortment of perishable slow-movers which is needed within a short lead time but which cannot be stored in SCL's warehouse itself?*

The first question relates to the quantitative model; in particular how the estimated costs can be incorporated into the model. It must be investigated how relevant costs can be estimated and allocated to products in order to incorporate them into the model.

The second question relates to the operational issues of pick-to-zero. Relevant costs do not take into account the operational feasibility of the design. It might be that the optimal supply chain is to use pick-to-zero for every single product. However, one can imagine that this is not feasible within the short lead time.

The next question relates to the current assortment of Superdirect.com. The answer provides useful recommendations on how to design the supply chain for the existing product assortment. Model output gives the answer to these questions.

Since model input parameters and product characteristics influence the model outcome of how products can be best supplied, break-even points can be estimated at which it becomes better to change the supply chain of a specific product. Scenario analysis was performed in order to estimate these break-even points. One can imagine that demand variability might decrease when average demand increases. This way, the influence of future growth (more PUPs) on the supply chain design can be described.

The two final sub questions have a future goal. As the demand distribution is an important model input factor, it is difficult to decide directly on a new product's supply chain if no historic data is present. Industry data might help in categorizing specific products into specific groups of comparable products and in that way the best supply chain can be designed for it. As Collo and Lapoule (2012) stated that a deeper and wider product range would make it possible to generate larger purchase baskets and increase the frequency of purchases and customer loyalty, increasing the assortment of SD with specialties (e.g. coquilles, racks of lamb) could be beneficial for SD.

3.3 Research Methodology

The research conducted is a model-based quantitative research with the aim of developing a model that helps deciding which logistic forms are optimal for a supply chain of a specific perishable product and thereby implementing this model for the perishables assortment of Superdirect.com. Based on the Mitroff et al. (1974) research model (see Figure 3.4), four phases can be determined in model-based quantitative research:

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

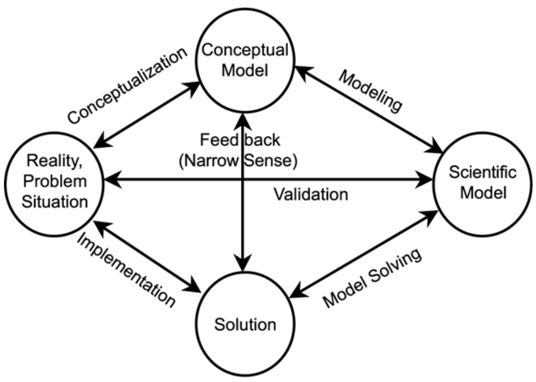

Figure 3.4 – Research model by Mitroff et al. (1974)

The research model of Mitroff et al. (1974) was used in order to correctly answer the research questions as stated in Chapter 3.2; thereby making sure that all aspects for doing proper model-based quantitative research were performed and reported. The conceptualization phase was performed by studying the perishable supply chain (Chapter 2) and by analyzing the aspects of the problem (Chapter 1.3) and by analyzing performance indicators (Chapter 4). The first feedback on the proposed solution direction is determined in Chapter 3.1, with a literature review. The modelling phase starts by presenting a quantitative model in Chapter 5 in order to eventually make a decision on the supply chain form of an e-retailing product assortment. Model solving takes place when performing scenario analysis on the model input parameters and product characteristics in Chapter 6. The implementation issue related to the model that is provided to SCL covers the implementation phase in Chapter 7.

4 ANALYSIS

For the analysis of past performance, data needed to be collected, e.g. demand characteristics, lead times, review periods, case pack sizes, reorder levels, shelf life, fill rates, relative outdating, purchasing prices and operational costs. In order to make the scope and the quality of the data manageable and reliable, first a product selection needs to be performed (case selection). After that issuing policies are analyzed. The next subchapter is the analysis of demand characteristics, in order to determine the predictability of the sales. After that, a description of the operational process is given and past performance is analyzed. With the sales and order data, the current inventory performance was analyzed. Finally, the last subchapter is dedicated to the shelf life and lead time adjustment of the different supply chain structures.

4.1 PRODUCT ASSORTMENT

A perishable product at SCL is a food product with a certain lifetime; this means that the product can become unacceptable for consumption or obsolete. According to Van Donselaar et al. (2006) perishable products can be divided into two subcategories: days-fresh and weeks-fresh. Days-fresh products are perishable products with a life-time less than 10 days after production. Weeks-fresh products have a life-time of less than 30 days. This research project focused on both days-fresh and weeks-fresh products. This means that all products which must be delivered at least 30 days or less before the expiration date to SCL by suppliers are used. Products had two parameters related to the expiration date. Suppliers had to deliver products which had a remaining shelf life at that moment of at least x days. Products could be ordered by customers until a product reached y days before expiration. As a consequence a product could be hold in stock in the warehouse in any case for at least x-y days. Customer demand was obtained from 30 September 2013 (see next paragraph), demand patterns were not that clear that demand from all products could be used properly. Therefore, data was only needed from products that had been available throughout the whole period SD had been operational. In other words, products which were available on 30 September 2013 and had not been remediated until the moment of data collection. Moreover, products that have been in promotion were excluded, because it is not desired to let the promotional demand influence the regular demand pattern. As discussed in Chapter 2.1, the perishables assortment consisted of products that have a maximum shelf life of 30 days when arriving at SCL or fresh products which are currently picked-to-zero. Since all products were ordered via de web shop of SD, no doubts existed about the accuracy of the data. Mid-February 2014, 902 of the 6160 products were considered as perishable products (shelf life less than 30 days), but not all products were used in the demand and performance analysis. Appendix D gives an overview of the different product categories with its corresponding suppliers and the number of products that met the requirement to be included in the data analysis.

4.2 ISSUING ON-HAND PERISHABLE INVENTORY

The objective has always been that the product with the shortest remaining shelf life that meets the requirement was picked. As this was also the case for the suppliers, products were delivered with at least an equal shelf life as the product on inventory with the longest shelf life. In other words, no overtaking takes place in both picking and replenishing. This means that all inventories in the warehouse were issued in FIFO manner. The advantage of this e-retailing concept is that not the customer but the logistic service provider decides which product is put in the basket. Compared to supermarkets, in which the FIFO issuing manner does not usually hold, outdating risk is relatively lower in the e-retailing concept. However, as current demand levels (see Figure 4.2) are very low, a large proportion of the ordered products are constantly outdating. In those cases, relative outdating does not differ much between LIFO and FIFO issuing policies. The advantage of LIFO is that customers receive fresher products on average. Therefore, it is interesting to include the LIFO policy in the quantitative model. Although fictive freshness costs are not taken into account in the cost model (see Chapter 5.4), it might be interesting to see in to which extent the LIFO policy performs worse compared to FIFO policy.

4.3 DEMAND ANALYSIS

Daily sales data from the cash-registration system (web shop) needed to be collected. For customer demand, this was done for a period of nearly 15 weeks, namely from 30-9-2013 to 9-2-2014 (excluding the period from 9-12-2013 until 5-1-2014 because of the overall price reduction). Demand analysis was performed only for products which met the requirements mentioned in Chapter 4.1. Notice that the early phase in which SD was finding itself in with only one PUP makes sales very volatile and unpredictable. Since the web shop had not been able to block customer orders for which the inventory level was not positive, lost sales could be captured quite easily compared to supermarket sales. For the analysis point-of-sales data of fifteen weeks was used. The POS data was first filtered for promotion data and for product availability on the web shop for the length of the period covered. After filtering the data, 424 products were left for the customer demand analysis. In Appendix E all products used for data analysis are listed.

Week demand pattern at Superdirect.com

It is known that grocery stores face a week pattern in sales. Is this also the case for e-retailing facilities? In Figure 4.1 can be seen that demand was not stable during the week. As products could be ordered and picked up on every day in the week, all days were included.

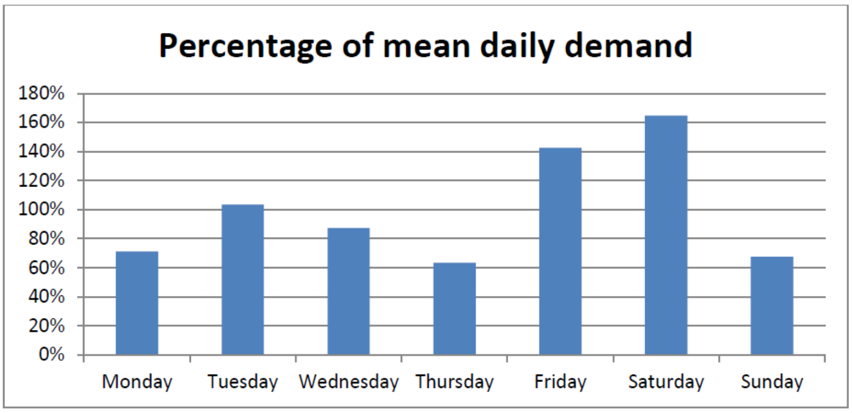

Figure 4.1 – Week demand pattern

The week pattern showed that demand was high on Friday and Saturday; average on Tuesday and below average on Monday, Wednesday, Thursday and Sunday. Since SD had only one PUP operational, no validation on the week pattern for other PUPs could be executed.

Demand characteristics

The demand characteristics were analyzed with the data of Saturday sales, because this day had the highest average sales and therefore was an important selling moment in the week. The variation due to the week pattern was thereby excluded from the analysis. Saturday demand was on average 0.47 units per SKU for the selected assortment. More than 89% of all products were sold less than one unit on each Saturday (see Figure 4.2).

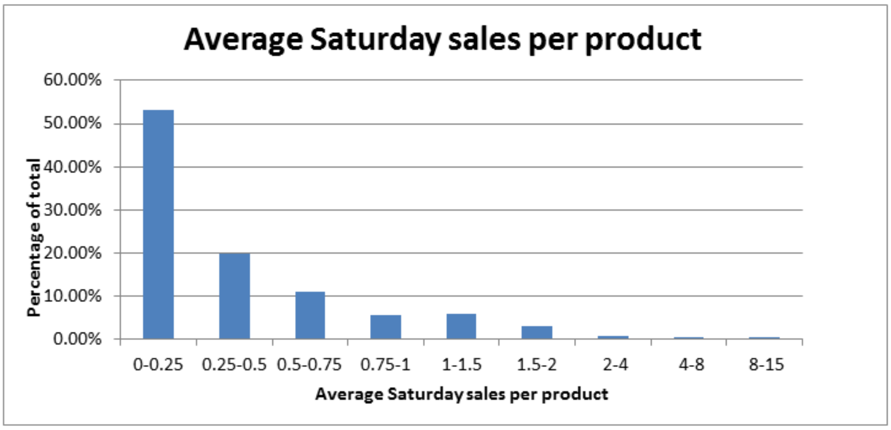

Figure 4.2 – Average Saturday sales per product

It can be concluded that sales are quite low and that the percentage of slow movers was very high. Since promotional items were not included in this analysis, the percentage of slow movers in reality was a little bit higher, because in general fast movers had been in promotion.

For effective decision making in supply chain structures, one needs good predictions of future demand. For determining the predictability of the demand, the variation of the demand series was analyzed. The coefficient of variation (CV) of the Saturday demand was calculated. The average CV was 2.23, with a maximum of 3.87 and a minimum of 0.21. This extremely high CV can again be explained by the fact that SD was in the starting phase and must create brand awareness and this was associated with lumpy demand. It must be noted that the CV can be misleading for low average demands levels (see Figure 4.3). Therefore some additional variation measures were calculated. The average kurtosis of Saturday sales was 2.06 and the average skewness was 4.90. This implied a high peak and a strong skewness to the right in the demand distribution. This shows an extreme level of variation in the demand series. The first conclusion was therefore that the predictability of perishable product demand was extremely difficult for purchasers. The products have a very low daily demand, even with often no demand on a day at all. The demand of almost all products also had a high coefficient of variation with a wide spread.

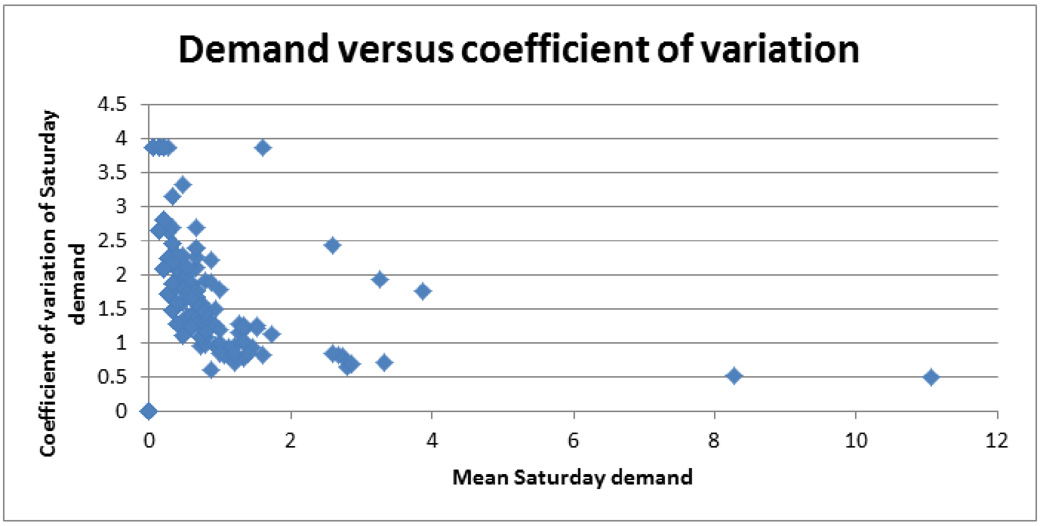

Figure 4.3 – Demand versus coefficient of variation

Fitting a discrete demand distribution

As demand is an important input for the model, it was determined how demand could be best modelled. Adan, Van Eenige and Resing (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: Poisson, mixtures of binomial, mixtures of negative-binomial and mixtures of geometric distributions. Most of the products' Saturday demands can be fitted best with a Poisson distribution (see Appendix F). In order to test this assumption a Chi-square test was performed. The null-hypothesis; that the demand was Poisson distributed, was not rejected in 82.5% 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 with λ equal to the mean daily demand. Test output and plots can be found in Appendix F.

4.4 DESCRIPTION OF OPERATIONAL PROCESS

This section discusses the past and intended future operational process at the distribution center for pick-to-zero items.

Past process

Each day at 10 p.m. orders were generated for both inventory items and pick-to-zero items. The orders for pick-to-zero items were forwarded to pick-to-zero suppliers so that they could begin their production/packaging operations. For both items picking orders were generated. From 11 p.m. the order picking process started for boxes for which no pick-to-zero items had been allocated to. Emergency shipments, which were placed and collected from some surrounding suppliers, arrived at approximately 2.00 a.m.. Approximately at 4.00 a.m. pick-to-zero orders arrived and were put into temporary regular storage locations. From then on, picking orders containing pick-to-zero items were collected, so that all boxes had been collected before 7.30 a.m. and that the truck could leave at 8.00 a.m.

Future process

In case operations would not have stopped, Superdirect.com wanted SCL to offer a lot of products via pick-to-zero operations (especially slow-moving specialties) in the near future. For those products, it was expected that the number of different pick-to-zero items processed on each day would be higher than the number of customer boxes to be filled for this operation. Therefore, SCL intended to build a so-called pick-to-zero lane (see Figure 4.4 for an example) in which fixed storage shelves were available for a maximum number of pick-to-zero items together with a roller conveyor over which (semi)-filled customer boxes could be filled one-by-one with the required pick-to-zero items. This means that all boxes which need to contain pick-to-zero items could already have been picked with inventory items and temporarily be stored in the neighborhood of the pick-to-zero lane (so-called 'single pick system').

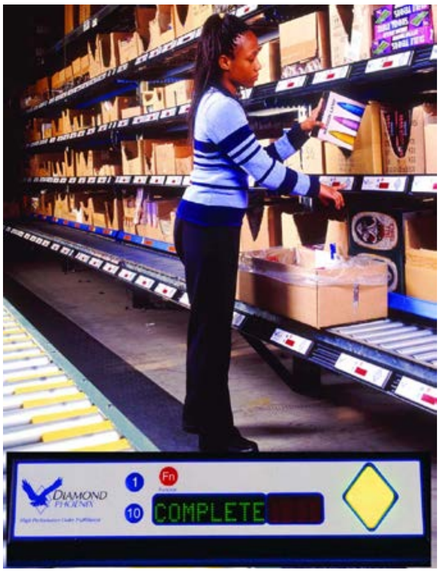

Figure 4.4 – Example of pick-to-zero lane with pick-to-light functionality

An advantage of this design compared to distributing the different pick-to-zero items one-by-one over the customer boxes is that each picking order is directly completed and that the pick-to-zero lane can be designed in such way that pick-to-zero items have a temporary fixed location (physical and in the WMS), which makes the use of order picking methods such as ‘pick-to-light’ more beneficial. A pick-to-light system uses rack mounted lights to direct pickers to specific stock locations. Each item has an individual numeric display with a light, an acknowledgement button, and a digital readout for indicating quantity. It is expected that the order pick productivity of the pick-to-zero lane is higher than the regular order pick productivity. However, it is expected that inbound costs are higher for pick-to-zero items as those products must be delivered each day demand is positive. Inventory items are ordered in case packs which results in higher order quantities, but is expected to result in less order lines throughout the year (unless outdating is extremely high). However, pick-to-zero items are not charged for stock control in contrast to inventory items. Other overhead costs related to the operational process (costs of cleaning, folding boxes, administration, meetings) are charged for both types of items. In case of emergency shipments the same procedure can be used as for pick-to-zero items since this way they are also able to benefit from the faster order pick productivity.

Unfortunately, a major problem was that many suppliers, who delivered inventory holding products to SCL, were not willing to switch to a pick-to-zero supply by no means. Demand was too low and too lumpy for those suppliers that they did not want to make such short production cycles within such a short lead time. A way to avoid these problems was to lengthen the customer lead time to two days in order to give suppliers more time to prepare their orders. This way, the pick-to-zero operation could have been maintained with similar or better performance (no outdating, probable higher delivery reliability). However, this would have had a huge impact on the customer service, as customers should have had to order their groceries two days in advance when a product of one of those suppliers had been ordered. It is uncertain which proportion of the current customers and how many potential customers would be lost by means of this change. Therefore, this option was not considered in the quantitative model. Instead, an option in the model was created to (de)select the pick-to-zero structure for specific suppliers. This way, the pick-to-zero structure can be excluded from cost calculations. As Superdirect.com quit their business May 1st 2014, this idea had not been implemented in reality. Due to the fact that no new suppliers were willing to supply product via pick-to-zero operations, capacity constraints considering the number of products that could be supplied via pick-to-zero operations are expected to be not necessary anymore.

4.5 PAST PERFORMANCE

Until the shutdown, operational purchasers made order decisions for perishable products using mostly intuition for their decisions. Due to the demand uncertainty and the low demand, no proper tools were used in order to make reasonable ordering decisions. Dependent on the average demand per product, an order was placed equal to usually 1 packaging unit when the inventory position was very low for slow movers. Sometimes 2 or more packaging units were ordered for fast movers when due to outdating or demand, the inventory position was likely to become close to zero. With sales and order data from the same period some analyses were performed in order to investigate the performance on customer service and outdating. For the comparison of point-of-sales data with the other data, the data-set for the period between 30-9-2013 and 2-2-2014 (excluding the period from 9-12-2013 until 5-1-2014 because of the overall price reduction) was used.

Outdating

The outdating of inventory was measured by making the number of outdated products relative to the total demand. Therefore, relative outdating was defined as the total number of outdated products divided by the total demand. The common outgoing flows are the sales plus waste. Waste 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 14 weeks of data was used. Within this method, the average relative outdating of SCL was 137% for the selected perishable products and the average outdating was 2.91 items per week per product. The relative outdating is extremely high, and this is again caused by the demand uncertainty and variability in the early phase of the company. Appendix G shows an overview of outdating performance of all selected products.

Customer service level

Since the web shop was not yet able to block customer orders for which the inventory level is not positive, lost sales could be captured quite easily compared to supermarket sales. Therefore, customer orders reflect real demand. Lost sales are thus defined as customer orders for a specific product which are eventually not delivered because the product was not in stock or suppliers were not able produce or deliver the right number of products in time for the pick-to-zero operation.

As SCL saved all order and delivery data, the fill rate could be calculated precisely. The fill rate is defined as long-run fraction of total demand, which is being delivered from stock on hand (Van Donselaar & Broekmeulen, 2014). The average fill rate of selected products was equal to 98.4%, which is below the target service level of 99.6%. Appendix G shows an overview of service level performance of all selected products.

Pick-to-zero delivery reliability

As pick-to-zero suppliers must deliver their orders within a lead time of several hours the assumption of 100% delivery reliability is not realistic. Therefore, data analysis was performed on historic data of two current pick-to-zero suppliers (Supplier C and Supplier E) in order to describe the delivery reliability behavior of pick-to-zero items in the quantitative model. During the period from 06-01-2014 until 08-04-2014, the delivery reliabilities of the pick-to-zero suppliers were distributed as stated in Table 4.1. A delivery reliability of x% means that x% of the products per order line was actually delivered in time. As there existed a finite number of pick-to-zero delivery reliabilities, no reliability intervals are used in Table 4.1. The average reliability denotes the percentage of customer units that was actually delivered in time.

Table 4.1 – Distribution of delivery reliability of pick-to-zero suppliers per order line per day

Delivery Reliability	Supplier C	Supplier E	Total
0.0%	5.63%	5.36%	5.51%
25.0%	0.16%	0.00%	0.09%
33.3%	0.16%	0.00%	0.09%
40.0%	0.08%	0.00%	0.04%
50.0%	0.63%	0.00%	0.35%
55.0%	0.08%	0.00%	0.04%
90.0%	0.08%	0.00%	0.04%
100.0%	93.19%	94.64%	93.83%
Average reliability	93.7%	94.6%	94.1%

It can be concluded that in case of no full delivery reliability (100%), almost 90% $\left(=\frac{5.51\%}{100\%-93.83\%}\right)$ of the instances the delivery reliability was equal to 0%, which means that there was no delivery at all. Therefore, the model assumption is made that a pick-to-zero supplier is able to deliver all products within a SKU-order in x% of the time and is not able to deliver anything in 100-x% of the time. So, it makes no sense to order more than the exact requested customer demand in order to achieve a higher customer fill rate.

Furthermore, the distribution of delivery reliability of pick-to-zero suppliers per day summed over all SKUs was analyzed, in order to see whether delivery reliabilities of different SKUs are related. This time, intervals were used as total delivery reliability is based on the whole PTZ assortment instead of just only one SKU. Table 4.2 shows that Supplier E was able to deliver all orders in time in 96.7% of the days and that in case of no full delivery two third of the time no delivery takes place at all. It seems that the delivery performances of those items are strongly related.

Table 4.2 – Distribution of delivery reliability of pick-to-zero suppliers per day

Delivery Reliability	Supplier C	Supplier E
0.0%	4.06%	2.20%
0.0% < Reliability ≤ 20.0%	1.35%	0.00%
20.0% < Reliability ≤ 40.0%	0.00%	0.00%
40.0% < Reliability ≤ 60.0%	0.00%	0.00%
60.0% < Reliability ≤ 80.0%	0.00%	1.10%
80.0% < Reliability < 100.0%	32.43%	0.00%
100.0%	62.16%	96.70%

Comparing 96.70% from Table 4.2 with the 94.64% in Table 4.1 indicates that on days with large demand this supplier is not able to deliver the whole order in time. Supplier C had only a full delivery reliability of 62.16%. However, in case of no full delivery Supplier C delivered more than 80% of the total order in time in about 86% of the instances. Therefore, it seems that this supplier leaves without having produced/packaged all products in order to arrive in time. Nevertheless, with 4.06% probability this supplier does not deliver any products in time.

Pick-to-zero productivity

In order to estimate operational costs, the productivity of pick-to-zero operations must be analyzed. During the period from 06-01-2014 until 08-04-2014 the average inbound productivity was 25 order lines per working hour. The average order picking productivity in the same period was 99 CU per working hour and the average outbound productivity was 32 boxes per working hour. In the same period a total of 97 pick-to-zero items had been available in the assortment. On average 21 different SKUs were demanded each day (with StDev=7, Min=6, Max=37). This were on average 39 CUs (StDev=18, Min=11, Max=106). Furthermore, on average 20 boxes had to be put-on-hold for the pick-to-zero operation (StDev=9, Min=6, Max=52).

4.6 SHELF LIFE AND LEAD TIME ADJUSTMENT

The official shelf life is the time from production until the latest day consumption is possible. As the production date and the latest possible consumption date are not equal to the time the product arrives at the DC and the time a product must have left the DC, the shelf life parameter has to be adjusted. The supply chain structures can be split into two different groups. One group consists of structures for which the customer order decoupling point (CODP) lies at the DC and the other groups consists of structures for which the CODP lies at the supplier. To simplify the statement above, supply chain structures can be divided in ones for which a product is allocated to a customer at the retail DC or for which a product has already been allocated to a customer at the supplier DC/production plant. For all products, it has been agreed that they have to arrive with minimal a days of remaining shelf life at the DC and are allowed to leave the DC for demand fulfilling with minimal b days remaining shelf life. This means that all products can remain at least $m' = a - b$ days at the DC. For products with the CODP at the supplier, additional time is available as the lead time from the supplier to the customer is shorter, which lengthens the shelf life at the DC, although they require less shelf life. The difference in lead time is the additional time (rounded in days) that the product is allowed to remain longer at the DC. For example, products with the CODP at the DC for which demand fulfilment takes place on Wednesday must be ordered Monday afternoon in order to let them arrive Tuesday afternoon. In contrast, product which have the CODP at the supplier must be ordered Tuesday evening in order to let them arrive Wednesday night/morning for demand fulfilment several hours later. As those products are supplied via pick-to-zero operations, the extra shelf life does not influence the probability of outdating, but increases the freshness of the product with one day compared to inventory products which are depleted at the first day after arrival and even more days compared to inventory products that are depleted after several days. Figure 4.5 and 4.6 show the shelf life adjustments for the two types of structures, where ΔL stands for the difference in lead time between the two type of structures.

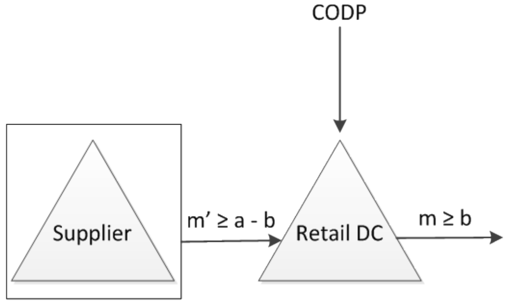

Figure 4.5 – Shelf life adjustment for inventory items

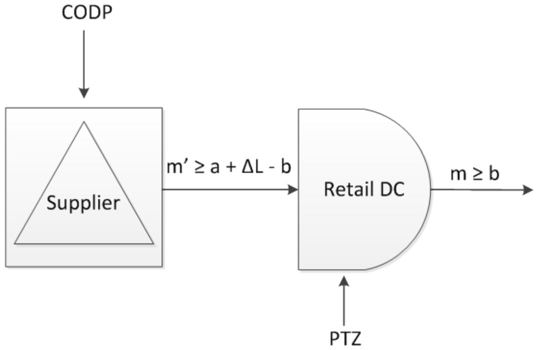

Figure 4.6 – Shelf life adjustment for pick-to-zero items

5 QUANTITATIVE MODEL

In this chapter a description of the quantitative model is provided. It starts with an extensive description of the different supply chain structures used in the model. Second, model assumptions are stated and approximations are provided for fill rates and relative outdating. Next, the cost structure of the different supply chains structures are described in a mathematical way. Finally, the suitability of the model is discussed.

5.1 SUPPLY CHAIN STRUCTURE DESCRIPTIONS

The model that is aimed to be developed is a supply chain structure decision model that decides on how a specific product within a perishable e-retailing assortment must be supplied, taking into account the customer service level constraint and relevant costs, i.e. outdating costs, operational costs, costs of lost sales, and (extra) transportation costs. As discussed in the research design, a distinction is made between two main structures (plus one extension).

1. Products are kept in stock at the distribution center of the logistic service supplier using the EWA-replenishment policy with FIFO or LIFO withdrawal
2. Products are ordered at suppliers when customer orders are known and products are picked-to-zero at the distribution center

An extension is, however, possible on the first structure. In case of insufficient inventory, it is not possible to fulfil customer demand. In that case, it is possible to place an emergency order in order to prevent lost sales. In fact, it is a backorder that is still delivered in time due to the shorter lead time of the emergency order. Within and for a given assortment, products are allocated to a specific supply chain structure in order to minimize the relevant costs associated with the allocations, taking into account a product specific fill rate constraint.

EWA-replenishment policy (+ possible emergency shipment)

The most basic supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in stock using the EWA-replenishment logic with FIFO or LIFO withdrawal by Broekmeulen and Van Donselaar (2009). A detailed description of this inventory policy can be found in Appendix H. The reorder level is set such that the fill rate of the specific product is equal to or above the target fill rate. Products are outdated when demand was not able to get the products sold before the agreed expiration date. Products are ordered at day 1 (and every R days) and are delivered with a lead time of L days. In case the total customer demand is above the current inventory level, demand is lost and the consumers get their money back for the products that could not be delivered. A more complicated supply chain structure is an inventory point at the distribution center of the logistic service supplier at which products are kept in stock using the EWA-replenishment logic by Broekmeulen and Van Donselaar (2009). However, in case the total customer demand is above the current inventory level, demand is not lost and an emergency order is placed (exact shortage quantity) just after all customer orders are known. The shortages are delivered some hours before the customer orders are transported to the PUP with a delivery reliability of x%. As the direct service level is set the same as in the first structure, relative outdating is expected to be equal, although the actual service level is at least as high as in the previous structure. This is because products are ordered with emergency when the costs of the emergency shipments are below the costs of not selling the product (cost of lost sales). The order of events before a shipment to the PUPs is as follows (see also Figure 5.1):

1. The LSP places a regular order at the perishable good supplier at the first review moment (R_R). The order is based on the, at that moment, inventory status, fill rate constraint, expected outdating in the next $R_R + L_R - 1$ days and the expected demand of the regular order horizon ($R_R + L_R$).
2. L_R time after R_R, the regular order arrives at the DC of the LSP.
3. After all customer orders for the next day are known, a (possible) emergency order is placed at the perishable good supplier. This is at the emergency review moment (R_E). The emergency order is based on the number of product shortages. The exact number of shortages is ordered.
4. L_E time after R_E, the emergency order arrives at the DC of the LSP.
5. Customer orders are prepared from the time all customer orders are known (R_E) or the arrival of emergency orders (L_E time after R_E) until demand fulfilment moment D_C and transported to the PUPs. After that, outdated products are discarded.

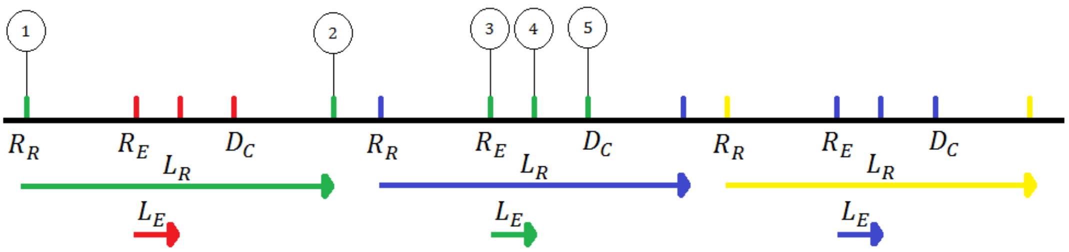

Figure 5.1 – Timeline of products which are held on inventory with EWA

The inventory status is depicted in Figure 5.2 for cases in which emergency shipments are actually performed. In case the emergency shipments are not performed due to the fact that the costs of lost sales are lower than the emergency shipment costs, demand is lost.

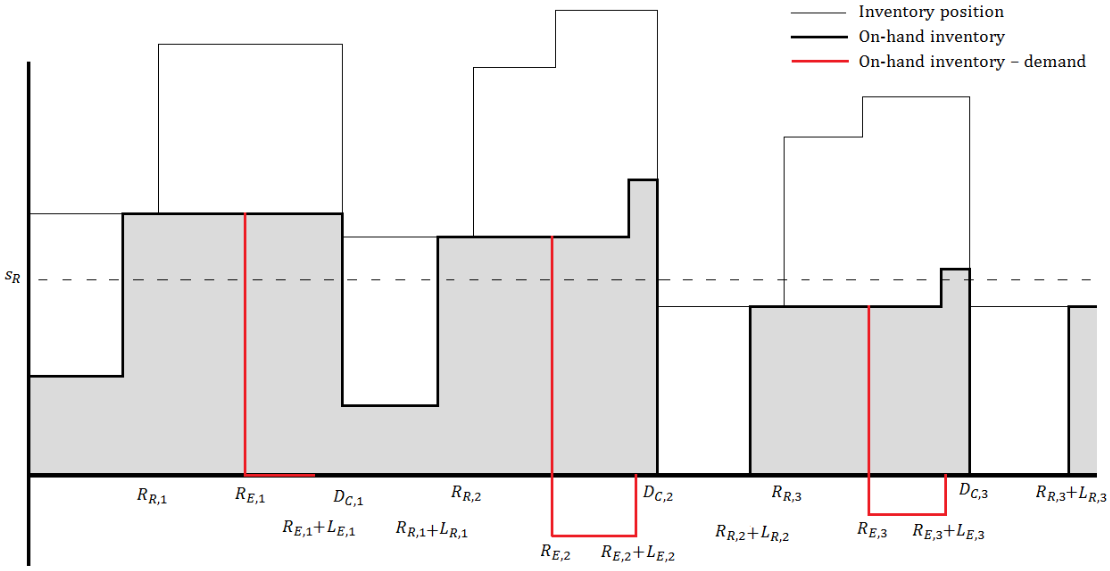

Figure 5.2 – Inventory status of products which are held on inventory with EWA

As customer demand for the next day is known from the time after which customers cannot order anymore, regular order decisions are made based on the on-hand inventory without subtracting customer demand up to then. Operational buyers are not able to obtain sales data on a specific day until the moment regular orders have to be placed, as this is only possible at the end of the order period of the customer (in this case 10 p.m.)

Pick-to-zero

The other supply chain structure is one in which no inventory is held at the warehouse. When customer orders are known, the exact amount of products is equal to the number of products ordered by all the customers together. Products that are delivered as 'pick-to-zero' have not yet been assigned to a final consumer. Those products are delivered on a pallet and must be put on a location from which the products have to be picked, just like products that are held in stock. Pick-to-zero orders are delivered some hours before the customer orders are transported to the PUP. As no inventory is held at the distribution center, relative outdating is equal to 0% and the actual fill rate is equal to the delivery reliability of the supplier as it is assumed that no picking mistakes are made due to the strict checks before expedition. The order of events before a shipment to the PUPs is as follows (see also Figure 5.3):

1. After all customer orders for the next day are known, a pick-to-zero order is placed at the perishable good supplier, this is at the pick-to-zero review moment (R_C). The pick-to-zero order is based on the number of product shortages. The exact number of shortages is ordered.
2. L_C time after R_C, the pick-to-zero order arrives at the DC of the LSP.
3. Customer orders are prepared between arrival (L_C time after R_C) and the demand fulfilment moment D_C, and are then transported to the PUPs.

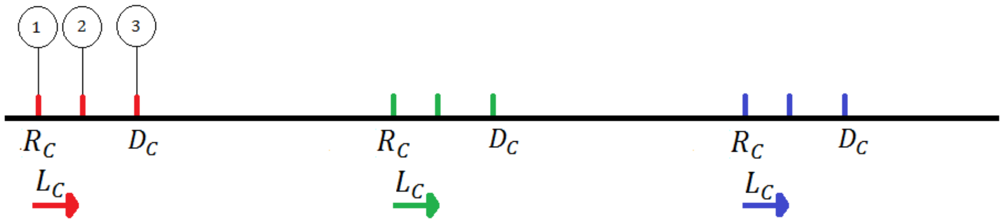

Figure 5.3 – Timeline of products which are picked-to-zero.

The inventory status is depicted in Figure 5.4.

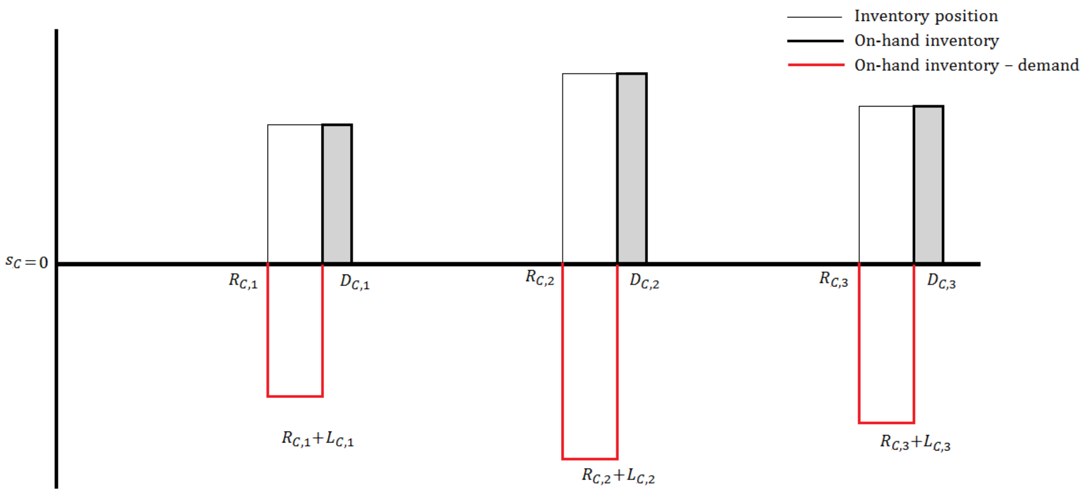

Figure 5.4 – Inventory status of products which are picked-to-zero

5.2 MODEL ASSUMPTIONS

In order to make this model more generalizable and applicable, several model assumptions were made:

- Demand can be approximated with a discrete distribution with a fixed mean and standard deviation.
- Demand is independent and identically distributed between the periods t.
- A week demand pattern is ignored.
- The reorder policy for inventory items is the EWA-replenishment policy. The supplier is always able to deliver inventory items with a fixed lead time equal to L days and is able to deliver a pick-to-zero order (on OL level) with a 94% service level. In the other 6% of the cases, no delivery of the item takes place.
- Emergency shipments arrive with y% probability in time at the distribution center.
- Backordering is possible for pick-to-zero items and in case emergency shipments can be placed. Not satisfied demand is not lost in those cases.
- Order quantity is equal to a multiple integer of the case pack size for EWA-replenishment policy.
- The product has a distribution center shelf life of m days starting on arrival at the distribution center. Outdated products are removed from the inventory at the end of the day when no customer demand is allocated to the product.
- On-hand inventory at the distribution center is withdrawn in FIFO or LIFO manner, dependent on supply chain structure.
- Deviations in the fixed delivery schedule (fixed lead time and review periods) in real life are neglected (e.g. Sunday deliveries are neglected).

5.3 APPROXIMATIONS FOR FILL RATE, RELATIVE OUTDATING AND NUMBER OF ORDER LINES

In this subchapter approximations for fill rates relative outdating and number of order lines are provided.

Fill rate

As the objective of the model is to decide on the best supply chain structure per product for a minimum fill rate per product, the fill rate must be approximated per product for the inventory holding structure. The fill rate for pick-to-zero products is equal to 94% (as concluded from Chapter 4.5) since the exact needed quantity is ordered and delivered in time in 94% of the cases in order to fulfil demand.

For the EWA-replenishment policy, the fill rate (P_2^*) is approximated by making use of the third approximation in Van Donselaar and Broekmeulen (2014) for the fill rate. This approximation for the fill rate in a lost sales system improves the accuracy of the first two approximations in Van Donselaar and Broekmeulen (2014) using regression. The first approximation was made by first calculating the fill rate for a similar backordering system and then solving the fill rate for the lost sales system. The second approximation uses an iterative approach in order to capture the effect that sales are lower than demand in a lost sales system.

Van Donselaar and Broekmeulen (2014) identified two important factors which have a large impact on the performance of a lost sales system. These two factors are the extent to which the demand during the lead-time plus review period is uncertain and the number of orders outstanding. After identifying these two key variables, they used regression to improve the accuracy of the first two approximations, resulting in very accurate estimates for the fill rate in a lost sales system.

Basket shoppers are consumers who desire to purchase from multiple categories. If a basket shopper does not find an item that he or she wants in one category, he or she may purchase his of her entire basket from another retailer (Cachon & Kök, 2007). Especially online retail suffers from this as consumers are not able to substitute when it appears that a specific product could not be delivered. Therefore, a basket fill rate is also desired instead of a fill rate based on a product level. However, decisions still need to be made on item specific reorder levels for inventory items. Therefore, the target basket fill rate needs to be converted to fill rates on SKU-level.

Relative outdating

Relative outdating for product supplied via pick-to-zero is always equal to zero since always the exact needed quantity is ordered in order to end with zero inventory. For the EWA-replenishment policies (LIFO or FIFO), relative outdating for products with a shelf life of 1 day is calculated by using the non-optimized newsvendor problem. As unsold products outdate immediately, each day the same number of products are ordered, which is equal to $\left\lceil \frac{s}{Q} \right\rceil * Q$ products. Relative outdating is thus the expected leftover inventory divided by the average demand and is expressed as follows:

$$z_{m=1} = \frac{E\left[\left(\left\lceil \frac{S}{Q} \right\rceil \cdot Q - D_1\right)^+\right]}{\mu}$$

with
$z_{m=1}$ = *relative outdating for a product with shelf life equal to* 1 *day*
s = *reorder level*
Q = *case pack size*
D_1 = *daily demand which has a discrete distribution*
μ = *average daily demand*

When the shelf life of a product becomes longer ($m > 1$), the non-optimized newsvendor model does not apply anymore. In order to approximate relative outdating for products with longer shelf lifes, approximations by Van Donselaar and Broekmeulen (2012) are used. They first derived approximations in an analytical way and then used regression to improve these approximations (z_{regr}). In their article they report values of regression parameters which are helping in approximating relative outdating by using the derived approximations and several other constructs to estimate relative outdating based on simulations experiments. For each combination of review period ($R = 1{,}2$), lead time ($L = 1{,}2$) and shelf life ($m = 2{,}3, \ldots{,}30$), new regression parameter values were estimated in order to improve the quality of the approximations. The article was only based on FIFO issuing policy. Although the results of LIFO issuing policy were not published, the approximations for LIFO withdrawal are used in this research. As the simulation experiments were cut off at respectively 30% relative outdating and 50% relative outdating for FIFO and LIFO withdrawal, approximations are only valid in the area from 0% relative outdating until those two upper limits.

Number of order lines

As pick-to-zero deliveries occur each day customer demand is positive, the expected number of order lines for a SKU that is picked-to-zero is equal to the probability that demand is not equal to zero times the average delivery reliability, and is thus at most 0.94. It is more difficult to estimate the expected number of order lines for a SKU that is held on inventory since waste causes an increase in the total supply. The total supply on the long term is equal to the sales plus the waste. As the supply reflects the orders placed, the average daily demand is set equal to the average supply in the formula for the expected number of order lines in Van Donselaar and Broekmeulen (2014). Furthermore, it is assumed that the coefficient of variation stays the same, so as a result, the standard deviation of the demand changes too. Based on 102,549 simulation experiments in which the lead time, review period, mean demand, standard deviation of demand, case pack size, shelf life, reorder level and withdrawal policy were varied, the quality of the approximation can be evaluated. The adjusted R^2 turned out to be equal to 0.9661, which is quite accurate. In Figure 5.5 the approximation values are plotted against the simulation values for the expected number of order lines. It can be seen that in general the dots are located around the diagonal line. However, some unexplainable dots are located at 0.25, 0.33 and 0.50 on the horizontal axis.

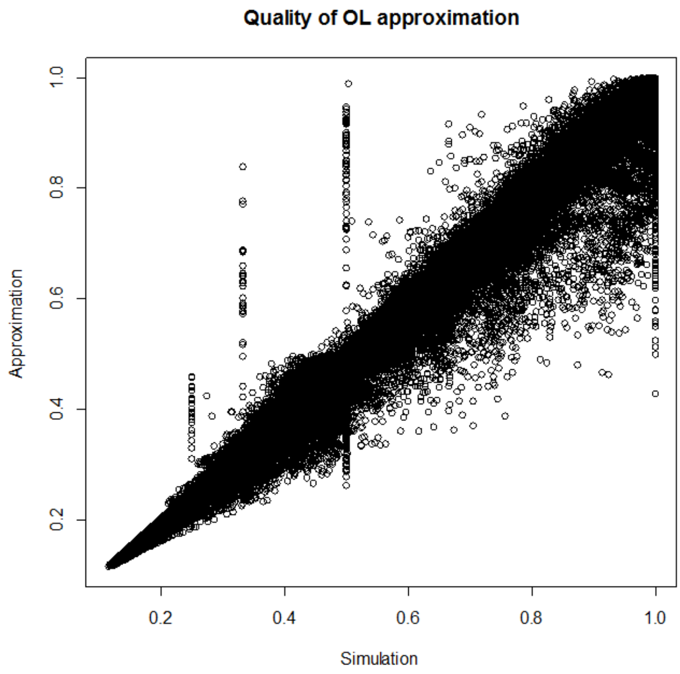

Figure 5.5 – Quality of approximation of expected number of order lines

5.4 Cost structure

This subchapter discusses the cost structure used in the supply chain decision model. As a decision has to be made between the different types of supply chain structure (+ possible emergency shipments), relevant costs are costs that differ between those different structures. First, it is discussed why certain costs are considered to be relevant. Next, the quantitative cost model is provided.

5.4.1 Relevant costs

Relevant costs are the costs that only depend on the choice of a specific supply chain structure and which are made by either Superdirect.com or SCL. Relevant costs can be divided into five types:

1. Outdating costs at the DC made by SCL
2. Costs of lost sales made by SD for being not able to deliver an ordered product
3. Operational costs made at the DC made by SCL
4. Extra transportation costs made by SCL to utilize multiple deliveries for different supply chain structures per supplier

5. Emergency costs made by SCL for handling (and transportation) and cost savings for SCL as a result of prevented lost sales

As products ordered with an emergency shipment or a pick-to-zero operation are transported to the PUP on the same day, products that outdate must have been purchased with a regular order. Therefore, the costs that are relevant are the wholesale prices of the product. Outdating could have been prevented by holding less inventory. Therefore, the outdating cost of one product is equal to its wholesale price. Moreover, additional costs are made when products get outdated. Disposal costs are made for outdated products as only dry groceries (relative long shelf life) are bought back by Supplier H and no other supplier buys back their products. Therefore, no products in the perishables assortment of SD are bought back (i.e. no salvage costs). As a result, disposal costs are made, which consists of handling costs of taking outdated products out of stock and costs related to the physical disposal of waste.

Costs of lost sales are costs made when demand cannot be fulfilled. These costs are relevant as the fill rate of the pick-to-zero policy is not equal to the fill rate of the inventory holding policy. In order to compare the two structures, costs of lost sales have to be taken into account. Costs of lost sales are combined with a fill rate constraint for inventory items as a higher fill rate is desired (see Chapter 5.3) for inventory items than for what for PTZ is possible. Ideally, for each product the costs of lost sales parameter is set in such a way that costs are minimized for the target fill rate. Calculations related to this procedure are however quite complex. Therefore, several values for the lost sales cost parameter are considered.

Operational costs are considered to be relevant costs as the operations of inventory items and pick-to-zero items differ. These costs concern inbound cost, order pick cost and stock control cost since order pick productivity and the number of order lines per day differ between each structure. Moreover, pick-to-zero item do not require periodical stock control. The reason that outbound costs are not taken into account is discussed in Chapter 5.4.2.

Extra transportation costs are considered to be relevant costs in case that emergency shipments or pick-to-zero shipments cannot be combined with regular shipments. Extra transportation costs are made for a supplier, which do not either use pick-to-zero or regular shipments, but use both. Extra transportation costs are different for each supplier and depend on the distance that needs to be covered by the supplier in order to deliver the products.

Emergency decisions are made on a daily basis in order to fulfil demand of items for which shortages have arisen due to higher than expected demand. The decisions are made based on costs of lost sales and the costs made when placing an emergency shipment (operational cost and (extra) transportation cost).

5.4.2 NON-RELEVANT COSTS

Although the lead time of an order made at the supplier is reduced when emergency or pick-to-zero orders are applied and the minimal order quantity has become equal to 1 (instead of the regular case pack size), the purchasing prices of these orders are not higher than the purchasing prices of regular orders, although the risk of outdating is transferred from the logistic service provider to the supplier. However, extra purchasing costs expressed as a percentage of the regular wholesale (purchasing) price could be used as an incentive to convince resistant suppliers to let them supply their products via pick-to-zero operations instead of regular shipments. Nevertheless, it is not common to vary in purchasing prices between different supply methods in the retail sector.

Moreover, outbound costs at the distribution center are considered as non-relevant since consolidation, control and loading operations do not depend on the supply chain structure. The outbound throughput (in CU), however, depends on the fill rate, as the fill rate of an item differs per supply chain structure. However, the assumption is made that this does not lead to fewer boxes that need to be handled, and thus leads to equal costs.

Inventory costs are considered because non-relevant as the those costs are expected to be approximately equal between the different supply chain structures. Although less space requirement is needed for pick-to-zero items compared to inventory items per SKU, the buffer zone that needs to be made in front of the pick-to-zero lane together with the investment costs of the pick-to-zero lane (see Chapter 4.4) are expected to eliminate the cost savings made with the smaller locations.

5.4.3 QUANTITATIVE COST MODEL

This subchapters start by mentioning that all notations used in this subchapter can be found in Appendix I. As mentioned in Chapter 5.3, a target basket fill rate is desired over a target fill rate per SKU. As decisions on item specific reorder levels for inventory items need to be made, the target basket fill rate needs to be converted to fill rates on SKU-level. The assumption is made that the basket size of a customer is fixed in order to convert the basket fill rate to a fill rate on product level. This can be done as follows:

$$P^*_{2,target} = P^*_{2,target}(basket)^{\frac{1}{M}}$$

In reality, this assumption is most of the time violated and results in a lower basket fill rate for consumers with a larger basket size and in higher basket fill rate for consumers with a smaller basket size. Fortunately, due to the fact that exponentiation takes place, the deviation of the target basket fill rate will be higher for lower basket size when the actual basket size would be normally distributed. As a result, the average basket fill rate will be somewhat higher than the target basket fill rate.

For each item i of supplier k and withdrawal policy W, reorder level $s_{W,k,i}$ is set such that $P^*_2(s_{W,k,i}) \geq P^*_{2,target}$. This means that the actual fill rate per item i of supplier k is at least as high as the target fill rate. Based on $s_{W,k,i}$, relative outdating is estimated for each product of each supplier, noted as $z(s_{W,k,i})$.

Outdating costs

As mentioned in Chapter 5.4.1, outdating costs consist of the wholesale price of a product which has not been sold before the product got outdated, and disposal costs, which consists of handling costs of taking outdated products out of stock and costs related to the physical disposal of waste. Taking products out of stock is performed at a speed of $P_{Outdate}$ per hour and costs $W_{Operator}$ euros per hour. Physical disposal costs are c_{disp} per kilogram and $G_{k,i}$ is the weight of the outdated product of item k of supplier i.

Relative outdating for the EWA-replenishment policy is approximated as is stated in Chapter 5.3. Multiplying the approximated value of relative outdating by the average daily demand results in the average daily waste. Multiplying the average daily waste by the outdating costs per single product results in the outdating costs for product held on inventory. As for pick-to-zero products the exact requested amount is ordered, no outdating costs are made for pick-to-zero.

$$Outdating\ costs\ per\ day\ for\ inventory\ items\ (EWA) = z(s_{W,k,i}) \cdot E[D_{k,i}] \cdot \left(c_{P,I,k,i} + \frac{W_{Operator}}{P_{Outdate}} + G_{k,i} \cdot c_{disp}\right)$$

$$Outdating\ costs\ per\ day\ for\ PTZ\ items = 0$$

Costs of lost sales

Costs of lost sales are costs made when demand cannot be fulfilled. These costs are relevant as the fill rate of the pick-to-zero policy is not equal to the fill rate of the inventory holding policy. In order to compare the two structures, costs of lost sales have to be taken into account. The cost of a single lost sale is at least equal to the margin on the product. As lost sales are not yet known by the customer at the moment of ordering, lost sales do not have an influence on the basket value of other products ordered that moment. However, lost sales might have influence on the future purchase intention of a customer. As a result, the real costs of lost sales might be much higher than the margin on the product. Therefore, a cost parameter is included in the cost structure for lost sales (c_{LS}), where $c_{LS} = 1$ means that the costs of lost sales are exactly equal to the retail price of the product. However, it is expected that the costs of having lost sales in an online environment are much larger.

$$Costs\ of\ lost\ sales\ per\ day\ for\ inventory\ items\ (EWA) = \left(1 - P_2^*(s_{W,k,i})\right) \cdot E[D_{k,i}] \cdot c_{R,k,i} \cdot c_{LS}$$

$$Costs\ of\ lost\ sales\ per\ day\ for\ PTZ\ items = \left(1 - P_{2,C}^*\right) \cdot E[D_{k,i}] \cdot c_{R,k,i} \cdot c_{LS}$$

Operational costs

As mentioned in Chapter 5.4.1, operational costs consist of the inbound costs, order pick costs and stock control costs (except for pick-to-zero).As mentioned in Chapter 4.4, costs of inbound operations are dependent on the number of order lines handled per time period. Therefore, the expected number of order lines per time period ($E[OL_{I,k,i}]$ or $E[OL_{C,k,i}]$) is divided by the average inbound productivity in order to estimate the average time needed. As discussed in Chapter 4.4, order pick productivity is expressed in the number of CUs that can be picked within a time period. Two factors (fill rate and order pick productivity) are causing differences in costs between the two supply chain structures. Due to the more efficient design of the pick-to-zero operation, order pick productivity is expected to be higher. The parameter O_{Fast} is defined as the ratio of higher productivity between the regular and pick-to-zero order pick operation. Moreover, a lower fill rate results in less CUs to pick. As fill rates differ between the different structures, it influences the average order pick costs.Costs of stock control can be estimated by dividing the average working hours per day spent on this operation by the number of current SKUs hold on inventory and which need periodical stock control.

$$Operational\ costs\ per\ day\ for\ inventory\ items\ (EWA) = W_{Operator}\left(\frac{E[OL_{W,k,i}]}{R_{k,i} \cdot P_{Inbound}} + \frac{E[D_{k,i}] \cdot P_2^*(s_{W,k,i})}{O_{Prod}} + E[T_R]\right)$$

with
$E[OL_{W,k,i}] = P(IP(t) - D_{R,k,i} < s_{W,k,i})$ *with* $D_{R,k,i}$ *adjusted for amount of waste*

$$Operational\ costs\ per\ day\ for\ PTZ\ items = W_{Operator}\left(\frac{E[OL_{C,k,i}]}{R_{k,i} \cdot P_{Inbound}} + \frac{E[D_{k,i}] \cdot P_{2,C}^*}{O_{Fast} \cdot O_{Prod}}\right)$$

with
$E[OL_{C,k,i}] = P[D_{k,i} > 0] \cdot P_{2,C}^*$

Total daily costs per SKU

As the online web shop is open 24/7 and all year long, total daily costs per SKU can be expressed as the sum of the outdating costs, costs of lost sales and operational costs per day. This results in total daily costs per SKU for inventory items equal to:

$$RC_{W,k,i}(EWA) = z(s_{W,k,i}) \cdot E[D_{k,i}] \cdot \left(c_{P,I,k,i} + \frac{W_{Operator}}{P_{Outdate}} + G_{k,i} \cdot c_{disp}\right) + \left(1 - P_2^*(s_{W,k,i})\right) \cdot E[D_{k,i}] \cdot c_{R,k,i} \cdot c_{LS} + W_{Operator}\left(\frac{E[OL_{W,k,i}]}{R_{k,i} \cdot P_{Inbound}} + \frac{E[D_{k,i}] \cdot P_2^*(s_{W,k,i})}{O_{Prod}} + E[T_R]\right)$$

And it results in total daily costs per SKU for pick-to-zero items equal to:

$$RC_{C,k,i} = \left(1 - P_{2,C}^*\right) \cdot E[D_{k,i}] \cdot c_{R,k,i} \cdot c_{LS} + W_{Operator}\left(\frac{E[OL_{C,k,i}]}{R_{k,i} \cdot P_{Inbound}} + \frac{E[D_{k,i}] \cdot P_{2,C}^*}{O_{Fast} \cdot O_{Prod}}\right)$$

Extra transportation costs

Extra transportation costs are considered to be relevant costs in case that emergency shipments or pick-to-zero shipments cannot be combined with regular shipments. Extra transportation costs are made by a supplier, who do not either use pick-to-zero or regular shipments, but use both. Extra transportation costs are different for each supplier and depend on the distance that needs to be covered by the supplier in order to deliver the products ($c_{T,i}$) where $c_{T,i} = 0$ means that for supplier I extra transportation costs are zero as pick-to-zero and regular shipments can be combined.

Total assortment costs

Optimal relevant cost for item k of supplier i are regardless of decisions on other items' supply chain structure equal to:

$$RC_{k,i} = \min(RC_{FIFO,k,i}(EWA), RC_{LIFO,k,i}(EWA), RC_{C,k,i})$$

The daily costs made when all items would be hold on inventory for supplier i are $RC_{I,i} = \sum_{k=1}^{K} \min(RC_{FIFO,k,i}(EWA), RC_{LIFO,k,i}(EWA))$ and $RC_{C,i} = \sum_{k=1}^{K} RC_{C,k,i}$ would be the daily costs made when all items would be picked-to-zero. However, if for each item the best structure for SCL is chosen, the daily costs made for all products of supplier i are $\sum_{k=1}^{K} RC_{k,i} + c_{T,i}$. The optimal cost for a supplier i is equal to:

$$RC_i = \min\left(RC_{I,i}, RC_{C,i}, \sum_{k=1}^{K} RC_{k,i} + c_{T,i}\right)$$

Summing these costs per supplier results in the total optimal assortment costs per day.

$$\boldsymbol{Total\ optimal\ assortment\ costs\ per\ day} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{I}} \boldsymbol{RC_i}$$

Emergency costs

Emergency decisions are made on a daily basis in order to fulfil demand of items for which shortages have arisen due to higher than expected demand. The decisions are made based on costs of lost sales and the costs made when placing an emergency shipment (operational cost and (extra) transportation cost). The step approach that is used to make the emergency decision is as follows:

1. Check supplier whether extra transportation costs are made due to emergency shipments.
- If $c_{T,i} = 0$ then no extra costs are made for supplier i
- If $c_{T,i} > 0$ and $O_{C,k,i,d} = 0$ then extra costs are made for supplier i
- If $c_{T,i} > 0$ and $O_{C,k,i,d} > 0$ then no extra costs are made for supplier i
2. Calculate emergency shipment savings for item k of supplier i. If extra transportation costs are made due to emergency shipments, calculate emergency savings for supplier i.
- Item k of supplier i: $E_{k,i,d} = P^*_{2,E} \cdot \left(LS_{k,i,d} \cdot c_{R,k,i} \cdot c_{LS} - W_{Operator} \left(\frac{1}{P_{Inbound}} + \frac{LS_{k,i,d}}{O_{Prod} * O_{Fast}} \right) \right)$
- Supplier i: $E_{i,d} = \sum_{k=1}^{K} \left(LS_{k,i,d} \cdot c_{R,k,i} \cdot c_{LS} \cdot P^*_{2,E} - W_{Operator} \left(\frac{1}{P_{Inbound}} + \frac{LS_{k,i,d}}{O_{Prod} * O_{Fast}} \right) \cdot P^*_{2,E} \right)^+ - c_{T,i}$
3. Place emergency shipment orders for (item k of) supplier I if $E_{i,d}$ or $E_{k,i,d}$ are positive

This means that first a check is performed whether pick-to-zero orders placed for a specific supplier. When this is not the case, extra transportation costs have to be made in order to perform the emergency shipment. In that case, possible emergency cost savings are also calculated for the supplier in total. Cost savings are positive if the costs of lost sales of not performing the emergency shipment are higher than the operational costs of performing them. Eventually, if no extra transportation costs are made for a supplier, all items which have positive cost savings must be ordered and in case extra transportation costs are made emergency shipments must be placed when the extra transportation costs are lower than the sum of the positive cost savings. All of these calculations are done based on a specific emergency shipment delivery reliability of $P^*_{2,E}$.

5.5 SUITABLE CONTEXT

The supply chain structure decision model is useful in situations when it is not clear whether it is more advantageous for a logistic service provider of an online supermarket to hold inventory (with the possibility to use emergency shipments) or to pick-to-zero. First, it becomes more advantageous to not hold inventory oneself when demand patterns become more lumpy, i.e. having low means and high variances, as safety stocks must be set higher, which increases relative outdating. Second, larger case packs sizes oblige purchasers to order high volumes through which relative outdating increases and which makes it more lucrative to not hold inventory. Moreover, products with shorter shelf lives are having a high risk of outdating. Due to pick-to-zero, lead-time and demand uncertainty are reduced, which results in less or no outdating at all. When the relevant costs of this structure for a product become lower than the relevant costs when holding inventory, it is more beneficial to switch from supply chain structure. However, the suppliers' willingness to operate in a pick-to-zero environment with low volumes is quite low. Therefore, the choice of this strategy does not only depend solely on the logistic service provider itself. Additionally, emergency shipments may become beneficial when costs of lost sales are higher than the cost of the emergency shipments itself. When looking at the perishable supply chain of SD (Chapter 2), and demand characteristics and past performance of SD products (Chapter 4.3 and 4.5), the proposed supply chain structure decision model could be a way to resolve the current business problem sufficiently, as for each product the best possible supply chain structure can be designed.

However, this supply chain structure decision model for the assortment of perishable products is not recommendable for every product as historic demand information is needed as input for the model. New perishable products that are incorporated in the online assortment should also be able to be put into the model in order to decide on the supply chain structure. The task is then to compare those products with a comparable product for which the supply chain structure has already been designed and for which demand is expected to behave similarly. In case new products are incorporated into the assortment, no historic demand data is available. A way to overcome this obstacle is performing Looks-Like Analyses (also called Analogous Forecasting). This method attempts to map sales of other products onto the product being forecasted. Typically, Looks-Like Analysis is employed for new product forecasting to determine what new product sales might be, given previous product introductions (Kahn, 2002). Another possible way to forecast sales for products without historic demand is to compare the sales of two products in industry. As Hollander Barendrecht is logistic service provider of fresh products for PLUS Retail, products that are available in the assortment of PLUS Retail and Superdirect.com can be compared and sales can be forecasted proportionally.

6 MODEL SOLVING

In this chapter results are presented of analyses performed using the quantitative model presented in the previous chapter. First, the model inputs and output are listed, such as product and supply chain characteristics and key performance indicators. Next, break-even analyses were performed in order to detect break-even points between the different supply chains structures for several input combinations. After that, sensitivity analysis was carried out in order to see what the impact of several cost and product parameters were. Scenario analyses were performed in order to see how the supply chains of products are designed at specific average demand levels and under certain variance. The last calculations were made in order to assess the usefulness of emergency shipments. This chapter is concluded with a discussion of results of the analyses.

6.1 MODEL INPUT

This subchapter discusses the model input. The following data of the perishable assortment needs to be used as input for the model:

- Product characteristics (product number, name, weight, supplier)
- Review period of order at supplier
- Lead time of order at supplier
- Mean of demand (per day)
- Standard deviation of demand (per day)
- Shelf life at distribution center (in days)
- Case pack size (in CUs)
- Price (retail price, wholesale price)

Based on assumptions, data analysis and figures available at SCL, several parameters considering costs and service levels need to be filled in in order to execute the model.

- Target basket fill rate for inventory holding policy
- Average number of products in customer basket
- Transportation costs per supplier per delivery
- Increased order pick productivity factor at pick-to-zero lane
- Average inbound productivity (order lines per hour)
- Average order pick productivity (CU per hour)
- Average out of stock productivity (CU per hour)
- Operator wage (€ per hour)
- Average time needed for stock control per day per inventory item
- Lost sales cost parameter
- Dump cost parameter
- Can regular orders be combined with pick-to-zero or emergency orders?
- Pick-to-zero delivery reliability
- Emergency shipment delivery reliability
- Is the supplier willing to supply via pick-to-zero operations in the first place?

6.2 MODEL OUTPUT

The supply chain structure decision model provides several output measures (on product level and overall).

The output measures for each SKU are:

- Supply chain structure choice
- Reorder level for EWA-policy
- Relative outdating
- Actual fill rate
- Daily outdating costs
- Daily costs of lost sales
- Daily operational costs
- Daily relevant costs
- Daily costs savings
- Relative daily cost savings

The overall output measures are:

- Average relative outdating
- Average fill rate per SKU
- Average basket fill rate
- Total daily outdating costs
- Total daily costs of lost sales
- Total daily operational costs
- Total daily extra transportation costs
- Total daily relevant costs (also per supplier)
- Relative relevant costs
- Total cost savings
- Relative total cost savings
- Percentage pick-to-zero (also per supplier)
- Percentage EWA FIFO (also per supplier)
- Percentage EWA LIFO (also per supplier)

6.3 BREAK-EVEN ANALYSES

This section discusses the break-even analyses at which average demand levels break-even points exist at which the costs of supply chain structures intersect. Average demand was varied from 0.1 CUs per day to 6.0 CUs per day as of almost all SKUs (except for 2 of the 1558 SKUs) max. 6 CUs were sold on average and demand was assumed to be Poisson distributed. First, a simple example is provided in order to see how the break-even analysis works After that, six break-even analyses were carried out in total. In three analyses the shelf life was kept constant: $m = 4, m = 8, m = 12$. And in the other three analyses the case pack size was kept constant: $Q = 3, Q = 6, Q = 12$. Costs made in the pick-to-zero structure were only dependent on the average demand level (and independent of m and Q) and thus not differed between the six graphs. Relevant daily costs made in the EWA FIFO and EWA LIFO structure varied with the different shelf life and case pack size settings.

An important notion has to be made about the approximations of relative outdating when the EWA-policy is used. They are based on simulation experiments which were cut off at 30% relative outdating for FIFO withdrawal and 50% relative outdating for LIFO withdrawal. As many products in the most recent assortment were having much higher levels of relative outdating and the fact that high fill rates are needed in online grocery retailing, combinations of parameters used in this break-even analysis result in relative outdating outside the validity intervals. Moreover, the assumption that Q/m had to be lower than μ was often violated. Therefore, it occurred that the LIFO withdrawal policy results in lower costs than the FIFO withdrawal policy in some situations. For some issues this was corrected, as it was known that when $Q/m \gg \mu$, the costs are independent of the withdrawal policy. Therefore, LIFO relative outdating was corrected when $Q/m \geq 3\mu$ to be equal to FIFO relative outdating in order to correct the most obvious unrealistic outcomes. All other cost and productivity parameters and product characteristics used in the costs calculations are stated in Table 6.1.

Fixed shelf life and case pack size

In order to find break-even points between the three supply chain structures for different values of the case pack size, the relevant daily cost lines are plotted for given case pack sizes and shelf life. The y-axis shows the relevant daily costs (in euros). The x-axis shows the average daily demand. By providing a simple example first in Figure 6.1, it can clearly be seen what the shapes are of the different cost lines and where the break-even points for $m = 8$ and $Q = 5$ are lying

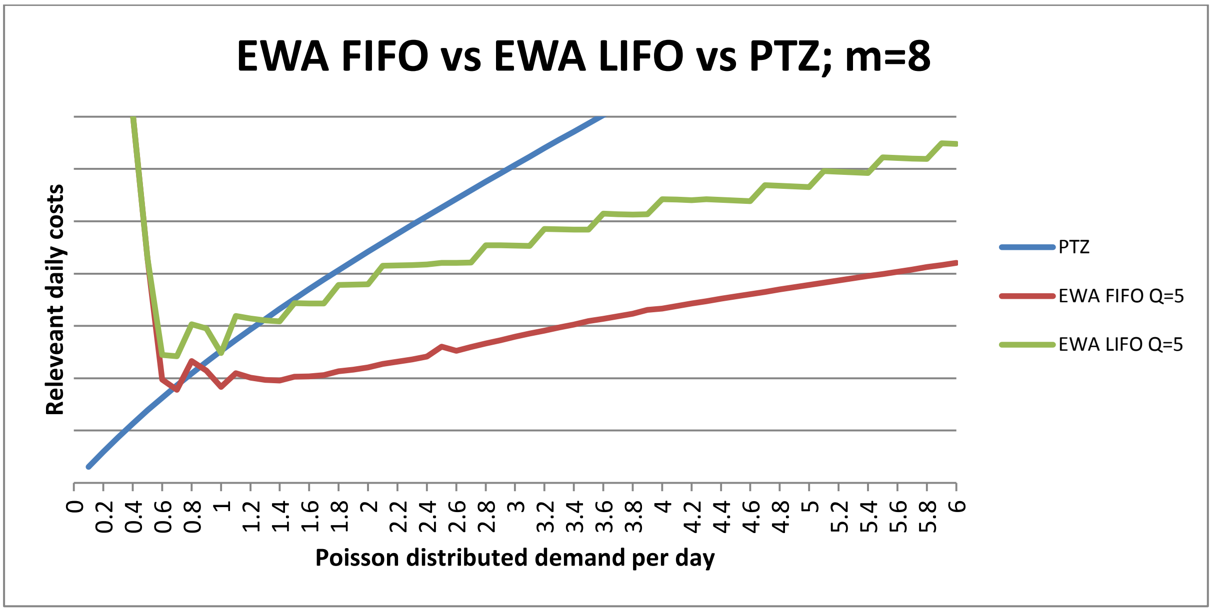

Figure 6.1 – Break-even analysis for m=8 and Q=5

It can be seen that the PTZ line is a concave increasing function. As the PTZ fill rate remains the same, lost sales costs will increase proportionally. Operational costs increase less rapidly as demand increasing as the average number of order lines per day approaches 1. After that, the PTZ line rises proportionally. The EWA FIFO and EWA LIFO lines move along until a certain demand level is reached at which demand during the shelf life has becomes that large that not a constant number of products is wasted anymore. As a result multiple batches are in stock and EWA FIFO outperforms from then on as the outdating costs of EWA LIFO are higher from then on. Both lines show fluctuations as a result of increasing reorder levels. In general, EWA FIFO will intersect PTZ for a lower average demand than EWA LIFO. And since the lost sales cost of PTZ are ever increasing due to the fixed fill rate, which is much lower than the EWA target fill rate and outdating costs for EWA will approach zero as demand become extremely high, PTZ will not become cost efficient again when demand is extremely high.

It can be seen that EWA FIFO and LIFO are having the same costs until $\mu = 0.6$ and that from then on EWA FIFO outperforms EWA LIFO. For $\mu \geq 0.9$ EWA FIFO is cost effective over PTZ. Due to the case pack size the EWA FIFO line dangles around the PTZ from $\mu = 0.6$ to $\mu = 0.9$. EWA LIFO turns out to be better than PTZ as $\mu \geq 1.3$. As for every combination these break-even point can be found, the next two paragraphs combine different values for m and Q in one graph.

Fixed shelf life

In order to find break-even points between the three supply chain structures for different values of the case pack size, the relevant daily cost lines are plotted for given case packs sizes (prime numbers from 1 until 13) of EWA FIFO and EWA LIFO. In Figure 6.2 the break-even points for $m = 4$ can be found.

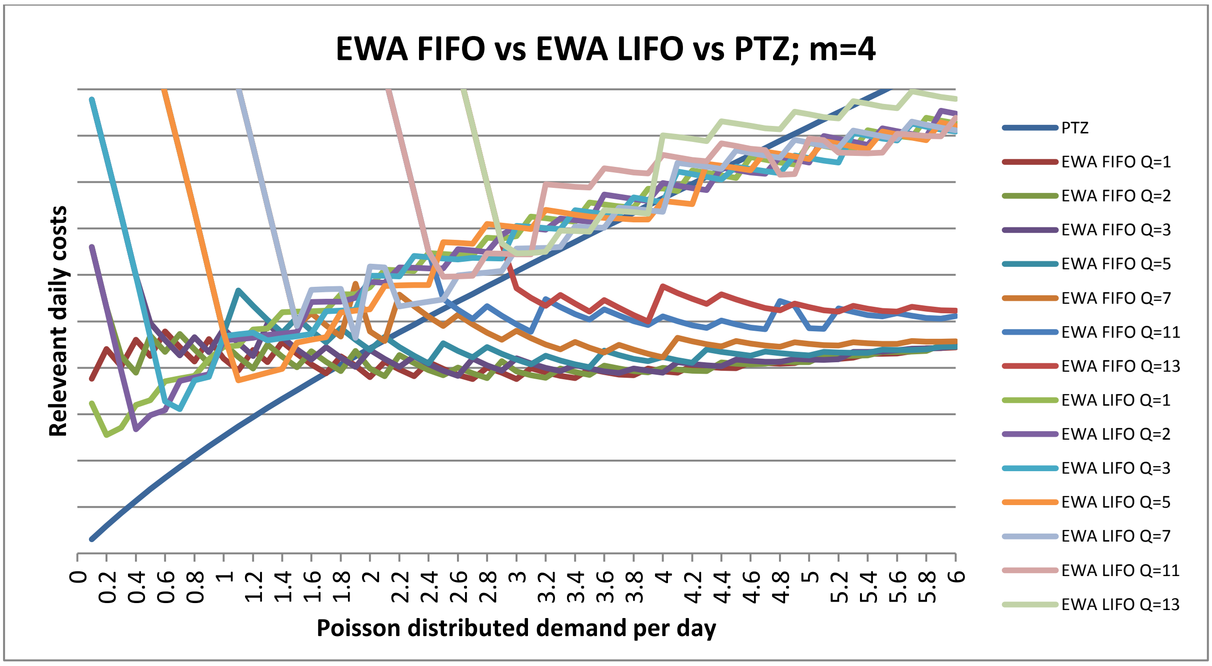

Figure 6.2 – Break-even analysis for m=4 and different values of Q

It can be seen in Figure 6.2 that the pick-to-zero structure performs best until an average Poisson distributed demand is reached equal to 1.6 CUs per day. At that moment an EWA FIFO policy with $Q = 1$ becomes cost efficient. After that all EWA FIFO policies with increasing case pack sizes are intersecting the PTZ cost line (between $\mu = 1.6$ and $\mu = 2.9$). As average demand increases, the cost lines of EWA FIFO approach each other since the influence of the case pack size on the total costs diminishes as Q becomes relatively small compared to μ. Unfortunately, Figure 6.1 shows that EWA LIFO with Q equal to 1, 2, 3, 5 and 7 perform better than the corresponding EWA FIFO policies when demand is low, due to the fact that the approximations are not valid in those areas. The almost straight diagonal lines represent EWA LIFO and FIFO for relative low demand. However, strange enough the EWA FIFO policies deviate earlier from that line and performs worse for a short average demand interval. As approximations become more reliable when average demand increases, it can be seen that EWA LIFO becomes better than PTZ at a certain point in time (between $\mu = 3.6$ and $\mu = 5.1$).

Next, in Figure J.1 (in Appendix J) the break-even points for $m = 8$ can be found. Compared to Figure 6.2 with $m = 4$, Figure J.1 shows that when $m = 8$ the EWA policy lines intersect the PTZ line much earlier. This can be explained by the fact that outdating risk is lower when the shelf life is higher. Therefore, lower costs are made for EWA policies. The EWA FIFO policies are intersecting the PTZ line between $\mu = 0.7$ and $\mu = 1.6$ and the EWA LIFO policies are intersecting the PTZ line between $\mu = 1.3$ and $\mu = 1.8$. As the shelf life is doubled in this situation, the problem of EWA LIFO being cost effective over EWA FIFO does not exist anymore. And again it can be seen that the EWA FIFO and EWA LIFO policies with different case packs sizes are approaching each other as average demand increases. Interesting to see is that policies with higher case pack sizes are performing better than policies with lower case packs sizes when average demand becomes relatively high. As outdating risks decrease at a certain point in time for policies with high case pack sizes and the difference in average number of order lines per day with policies with low case pack sizes increases, total cost become lower. At a certain point total costs approach each other again as demand has become so high that for both policies each day an order is placed.

Finally, in Figure J.2 (in Appendix J) the break-even points for $m = 12$ can be found. As the shelf life is again increased with four days, EWA policies lines are again intersecting the PTZ line for lower average demand levels. The EWA FIFO policies are intersecting the PTZ line between $\mu = 0.4$ and $\mu = 1.1$ and the EWA LIFO policies are intersecting the PTZ line between $\mu = 0.7$ and $\mu = 1.4$. Now that the shelf life is higher it becomes more clear that policies with low case pack sizes are only outperforming policies with high case pack levels when demand is relatively low.

Fixed case pack size

In order to find break-even points between the three supply chain structures for different values of the case pack sizes, the relevant daily cost lines are plotted for given shelf lifes (prime numbers from 2 until 17) of EWA FIFO and EWA LIFO. In Figure 6.3 the break-even points for $Q = 3$ can be found.

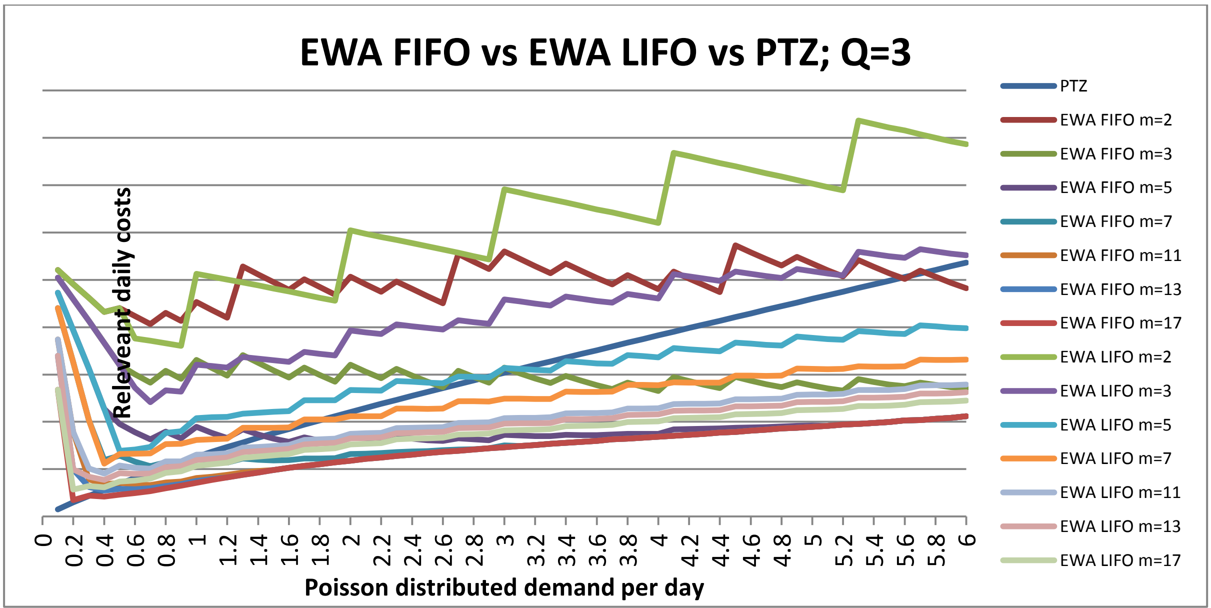

Figure 6.3 – Break-even analysis for Q=3 and different values of m

It can be seen in Figure 6.3 that the pick-to-zero structure performs better for a larger average demand interval than EWA policies as the shelf life becomes shorter. As EWA FIFO with $m = 2$ intersect the PTZ line $\mu = 5.6$, it intersects the PTZ line when $\mu = 0.2$ for $m = 17$. This can be explained by the fact that outdating risks are higher for shorter shelf lifes, and therefore, the costs incorporated are much higher. It can again be seen that for short shelf lifes EWA LIFO outperforms EWA FIFO when demand is relatively low, due to the fact that the calculations are outside the validity intervals.

Next, in Figure J.3 (in Appendix J) the break-even points for $Q = 6$ can be found. Compared to Figure 6.3 with $Q = 3$, Figure J.3 shows that when $Q = 6$ the EWA policy lines intersect the PTZ line much later. This can be explained by the fact that outdating risk is higher when the case pack size is higher, as the inventory after replenishment is on average higher. Therefore, higher costs are made for EWA policies. It can be seen that for $m = 17$ the pick-to-zero policy perform best until $\mu = 0.4$.

Finally, in Figure J.4 (in Appendix J) the break-even points for $Q = 12$ can be found. As the case pack size is doubled again, EWA policies lines are again intersecting the PTZ line for higher average demand levels. The EWA FIFO policy with $m = 17$ intersect the PTZ line now at $\mu = 0.7$.

Conclusion

Finally, an overall conclusion that higher case pack sizes result in wider demand intervals and longer shelf lifes result in shorter demand interval at which pick-to-zero is cost efficient. Moreover, it can be concluded that PTZ will not become cost efficient again when demand is extremely high as the lost sales cost are ever increasing due to the fixed fill rate, which is much lower than the EWA target fill rate and outdating costs for EWA will approach zero as demand become extremely high.

6.4 SENSITIVITY ANALYSIS

Table 6.1 gives an overview of input parameters which are varied with in the sensitivity analysis. In total for $4 \cdot 3 \cdot 6 \cdot 6 \cdot 3 \cdot 3 = 3888$ different combinations of input parameters relative relevant costs are calculated for the different supply chain structures together with the corresponding fill rate. As almost all products can be ordered each day ($R = 1$) and are delivered the next day ($L = 1$), these two input parameters are kept fixed. The same applies for the whole sales price p_W, which is a fixed proportion of the retail price p_R.

Table 6.1 – Input parameters and values used in sensitivity analysis

Input parameters	Values
Review period of order at supplier I	{1}
Lead time of order at supplier (L)	{1}
Mean of daily demand (µ)	{0.50. 1.00, 2.00, 4.00}
Squared coefficient of variation ($\boldsymbol{c_v^2}$)	{1.0, 1.5, 2.0}
Shelf life at distribution center (m)	{2, 4, 6, 8, 12, 20}
Case pack size (Q)	{1, 2, 4, 6, 10, 20}
Retail price ($\boldsymbol{p_R}$)	{€0.50, €2.00, €5.00}
Whole sale price ($\boldsymbol{p_W}$)	{$0.65p_R$}
Lost sales parameter ($\boldsymbol{c_{LS}}$)	{1, 5, 10}

The sensitivity analysis is aimed at individual supply chains structure decision making. Therefore, extra transportation costs are not taken into account as those costs depend on the decisions of other products of the same supplier and are not SKU-based. The aim of this sensitivity analysis is to see how sensitive the input parameters are on the relative relevant costs and to see what on average the break-even points are at which another supply chain structure must be chosen. As the cost of lost sales parameter is included in the relative relevant costs, different structures can be compared, despite its fill rates might not be equal. For the inventory policies fill rates are set such that relevant costs are minimized. For pick-to-zero it is assumed that the pick-to-zero delivery reliability of suppliers is fixed and equal to 94.0%. As the fill rate is fixed for the pick-to-zero structure, costs related to this fill rate are stated in Table 6.2.

Table 6.2 – Results of sensitivity analysis

Parameters	Level	Fill rate EWA FIFO	Relative relevant costs EWA FIFO	Fill rate EWA LIFO	Relative relevant costs EWA LIFO	Fill rate PTZ	Relative relevant costs PTZ
μ	0.50	97.85%	891.05%	97.82%	893.25%	94.00%	102.64%
	1.00	97.10%	329.16%	96.54%	338.34%	94.00%	91.58%
	2.00	97.87%	122.42%	96.02%	134.15%	94.00%	77.38%
	4.00	98.80%	53.74%	96.79%	66.10%	94.00%	64.06%
c_v^2	1.0	98.81%	342.89%	97.77%	351.78%	94.00%	83.95%
	1.5	97.89%	349.54%	96.73%	358.57%	94.00%	83.89%
	2.0	97.02%	354.63%	95.88%	363.33%	94.00%	83.91%
m	2	95.63%	572.27%	95.40%	577.08%	94.00%	83.88%
	4	97.18%	460.39%	96.45%	461.19%	94.00%	83.91%
	6	97.84%	379.47%	96.76%	389.75%	94.00%	83.91%
	8	98.46%	317.51%	96.88%	329.55%	94.00%	83.91%
	12	98.93%	232.50%	97.29%	246.35%	94.00%	83.91%
	20	99.38%	132.04%	97.98%	143.48%	94.00%	83.97%
Q	1	95.92%	116.44%	94.17%	130.60%	94.00%	83.91%
	2	96.33%	112.04%	95.01%	122.19%	94.00%	83.91%
	4	97.49%	134.87%	96.27%	145.62%	94.00%	83.88%
	6	98.46%	206.52%	97.28%	215.85%	94.00%	83.97%
	10	99.37%	415.64%	98.54%	421.79%	94.00%	83.91%
	20	99.84%	1108.11%	99.49%	1110.80%	94.00%	83.91%
p_R	€ 0.50	97.13%	523.68%	95.64%	535.30%	94.00%	147.39%
	€ 2.00	98.19%	285.78%	97.17%	293.72%	94.00%	60.85%
	€ 5.00	98.39%	237.71%	97.57%	244.77%	94.00%	43.53%
c_{LS}	1	96.10%	341.22%	93.10%	346.74%	94.00%	57.92%
	5	98.50%	350.14%	98.18%	360.39%	94.00%	81.89%
	10	99.11%	355.73%	99.09%	366.56%	94.00%	111.91%

Table 6.2 shows that relative costs decrease for all supply chain structures when average demand increases. Based on all combinations of the other parameters pick-to-zero turns out to result in the lowest relative costs when average demand is equal to 0.50, 1.00 and 2.00. However, EWA FIFO becomes cost-optimal when average demand is 4.00. When comparing EWA FIFO with EWA LIFO, it can be seen that relevant costs are almost the same when demand is low, but costs become significantly higher for EWA LIFO when average demand increases. Moreover, the average fill rate of EWA FIFO is on average higher than the fill rate of EWA LIFO and obviously of PTZ as that fill rate is fixed.

Next, it can be seen that demand variability does not influence the relative costs of PTZ since this structure can anticipate on actual demand. Moreover, it can be seen that again EWA FIFO performs just better than EWA LIFO, but the difference remains the same when demand variability increases. Interesting is that optimal fill rates decrease when demand variability increases. Apparently, the extra costs of lost sales are lower than the outdating risk of higher demand variability.

It can be observed that relative costs of PTZ are independent of shelf life and case pack size too. As no inventory is left after the pick-to-zero operation, outdating is always equal to zero. Moreover, case pack sizes do not influence the relative costs since PTZ products can always be ordered in consumer units. Relative costs are decreasing as the shelf life of products increases when EWA FIFO or EWA LIFO is applied and EWA LIFO increasingly performs worse compared to EWA FIFO as the shelf life increases. Fill rates increase as shelf life increases as risk of outdating becomes lower. The cost structure of different case pack sizes behaves not linear as minimal costs are made when $Q = 2$. This can be explained by the fact that the average number of order lines per review period is higher when $Q = 1$ and more inbound costs are made. As higher case pack sizes incur higher outdating risk, relative costs increase again.

It can also be seen that higher retail prices entail lower relative costs, as outdating costs relative to the retail price are almost equal for each product (except the disposal costs). As operational costs are higher compared to the retail price for cheap products the relative costs made are here higher. This result applies for all structures. Finally, it can be observed that fill rates increase as the cost of lost sales parameter is set higher. As it becomes more expensive to have lost sales, fill rates were set higher while having a little bit more outdating. Logically, relative costs increase while the cost of lost sales parameter becomes higher, just becomes a cost parameter is set higher.

Finally, it can be concluded that average demand is the most important factor in determining the relative costs of products kept on inventory. Moreover, it can be seen that extreme high case packs or short shelf lifes are having a large influence in the resulting costs.

6.5 SCENARIO ANALYSES

In this subchapter, several scenario analyses are performed in order see what the impact of average demand levels and variability (in combination with order factors) is on the decisions made on the supply chain structure of the perishables assortment. In all scenario analyses two levels of demand variability were considered. From the demand analysis in Chapter 4.3 it can be concluded that especially for 'current fast movers' demand can mainly be approximated with a Poisson distribution. However, the squared coefficient of variation of the most recent assortment was equal to 1.45. Therefore, those two levels of variability were used in the scenario analyses. It is expected that the results in case of Poisson distributed demand become more reliable when demand becomes higher. It was assumed that average demand increases directly proportional with the number of PUPs that are operational. The fact that demand would increase faster as a result of higher brand awareness was neglected. In the first scenario analysis the parameter values were set as stated in Table 6.4.

In this scenario the assumption is made that all suppliers are not resistant to change their supply structure. As in reality suppliers are resistant, this analysis provides the optimal solution without regarding suppliers' options and preferences. Another assumption is made that for any supplier extra transportation costs have to be paid when pick-to-zero operations are combined with any inventory policy. Table 6.3 shows the results of the first scenario analysis. Note that also here the correction for LIFO relative outdating was made when $Q/m \geq 3\mu$ in order to correct the most obvious unrealistic outcomes.

Table 6.3 – Results of scenario analysis if PTZ is possible for all suppliers

# PUPs	c_v^2	Relative Outdating	Basket Fill Rate	% EWA FIFO	% EWA LIFO	% PTZ	Relative relevant costs	Relative cost savings
1	1	0.00%	15.63%	0.00%	0.00%	100.00%	71.53%	3501.47%
2	1	0.00%	15.63%	0.00%	0.00%	100.00%	65.10%	1693.61%
5	1	1.10%	20.90%	15.28%	0.00%	84.72%	52.86%	629.16%
10	1	1.47%	26.06%	26.96%	0.00%	73.04%	39.61%	315.72%
20	1	8.19%	35.57%	43.32%	0.26%	56.42%	30.16%	136.31%
50	1	11.61%	54.98%	66.94%	0.19%	32.86%	21.62%	34.67%
1	1.45	0.00%	15.63%	0.00%	0.00%	100.00%	71.53%	3661.14%
2	1.45	0.00%	15.63%	0.00%	0.00%	100.00%	65.10%	1787.91%
5	1.45	0.92%	19.19%	10.78%	0.00%	89.22%	54.03%	663.77%
10	1.45	1.76%	24.92%	24.58%	0.00%	75.42%	40.90%	338.80%
20	1.45	1.81%	30.69%	35.69%	0.00%	64.31%	32.03%	144.00%
50	1.45	5.27%	50.48%	62.45%	0.06%	37.48%	22.67%	38.95%

It can be concluded from Table 6.3 that a higher percentage of the assortment is optimally supplied via pick-to-zero operations when demand variability is higher. As the performance of pick-to-zero operations are not influenced by demand variability (at least not at the retailer DC) compared to inventory policies (due to higher relative outdating), it has become better for a larger proportion of the assortment to be supplied via pick-to-zero operations. A straightforward finding is that fewer products are supplied via pick-to-zero when demand increases, as relative outdating becomes so small for inventory policies that relevant costs of inventory policies shoot underneath the costs of pick-to-zero operations. Moreover, higher fill rates are achieved when demand increases as a result of a higher proportion of the assortment is held on inventory. Due to the mediocre delivery reliability of PTZ, the fill rates of inventory policies are almost always better. Another straightforward finding is that higher relative costs are made when average demand is low and demand variability is high. Although relative outdating is low due to the large percentage supplied via PTZ, high inbound costs are made per product as average demand per SKU is low. At the same time, the relative costs savings are also higher in those situations, due to the fact that a large part of outdating is prevented due to PTZ. A final remark can be made about the EWA policy with LIFO withdrawal, as only a negligible part of the assortment is optimally withdrawn in LIFO manner. In practice, EWA LIFO can only perform equally best (together with EWA FIFO) in case the average number of batches on stock is equal to 1. Due to the low reliability of approximations if they are outside the validity intervals, it can occur that EWA LIFO outperforms EWA FIFO. However, since pick-to-zero is in those situations almost always the best option, only a negligible part of the assortment is optimally withdrawn in LIFO manner according to these figures. Regardless the other costs made than the relevant costs captured in the model and taking into account the margin on the product of 35%, at least 20 PUPs are needed to only bear for the relevant costs made according to the cost model.

As in reality suppliers can be resistant in changing the supply agreements into pick-to-zero operations, another analysis was performed. However, now it was assumed that only current pick-to-zero suppliers are able supply via pick-to-zero operations. The interesting point now is to see how fast average demand must grow in order to not need to make use of pick-to-zero operations for other suppliers and approach the same costs as in the previous analysis. By performing this analysis we can redeem ourselves from incorporating complicated capacity constraints concerning the maximum number of products that can be supplied via PTZ operations. This analysis will therefore provide a more realistic view on how to solve the business problem. The results of this scenario analysis are stated in Table 6.4.

Table 6.4 – Results of scenario analysis if PTZ is only possible for current PTZ suppliers

# PUPs	c_v^2	Relative Outdating	Basket Fill Rate	% EWA FIFO	% EWA LIFO	% PTZ	Relative relevant costs	Relative cost savings
1	1	34060.70%	89.54%	85.82%	8.09%	6.10%	2567.10%	0.36%
2	1	16440.62%	89.54%	83.83%	10.08%	6.10%	1161.46%	0.53%
5	1	5945.11%	89.53%	82.22%	11.68%	6.10%	382.17%	0.85%
10	1	2568.09%	89.55%	81.32%	12.58%	6.10%	163.41%	0.76%
20	1	965.22%	93.56%	84.40%	11.94%	3.66%	69.90%	1.96%
50	1	184.91%	93.55%	87.29%	9.05%	3.66%	27.64%	5.32%
1	1.45	34857.54%	89.55%	84.21%	9.69%	6.10%	2666.54%	0.90%
2	1.45	16849.57%	89.54%	81.19%	12.71%	6.10%	1213.62%	1.27%
5	1.45	6116.88%	89.50%	77.66%	16.24%	6.10%	404.92%	1.92%
10	1.45	2653.90%	89.51%	77.86%	16.05%	6.10%	175.38%	2.34%
20	1.45	997.78%	89.52%	78.05%	15.85%	6.10%	76.36%	2.36%
50	1.45	199.45%	93.49%	85.17%	11.17%	3.66%	29.93%	5.25%

It can be concluded from Table 6.4 that a higher percentage of the assortment is optimally supplied via pick-to-zero operations when demand variability is higher and average demand is lower (with an upper bound of 6.10% which is the largest possible percentage). Until having 10 PUPs for Poisson distributed demand and 20 PUPs for higher demand variability all products of Supplier C and Supplier E are optimally supplied with PTZ operations. In general, the same conclusions can be made as in the previous analysis. However, due to the fact that only 6.1% of the assortment can be supplied via PTZ relative outdating is much higher and accordingly the relative costs. Despite this big difference, relative costs when having 50 PUPs approach the costs in the previous analysis. Regardless the other costs made than the relevant costs captured in the model and taking into account the margin on the product of 35%, at least 50 PUPs are needed to only bear for the relevant costs made according to the cost model. The fact that EWA LIFO turned out the best between 8% and 17% of the products in the assortment, the relevant costs are in reality a little bit higher due to the fact that the LIFO approximations for relative outdating are too low.

Due to higher demand, walking distances in the distribution center while order picking become shorter. As a result the order pick productivity will increase in concurrence with the demand. As more boxes need to be picked more efficient combinations of customer boxes can be put together in order to minimize the walking distances. As walking distances decreases in concurrence with higher demand, it is expected that this will lead to directly proportional increase in order pick productivity to a certain level. It is expected that the order productivity can at least be doubled. In Table 6.7 the results of the scenario analysis with increased order pick productivity for higher demand are stated. Order pick productivity is 99 CUs/hour for 1 PUP and 198 CUs/hour for 50 PUPs and proportionally increases in between.

Table 6.5 – Results of scenario analysis if order pick productivity increases along with demand

# PUPs	c_v^2	Relative Outdating	Basket Fill Rate	% EWA FIFO	% EWA LIFO	% PTZ	Relative relevant costs	Relative cost savings
1	1	0.00%	15.63%	0.00%	0.00%	100.00%	71.53%	3501.47%
2	1	0.00%	15.63%	0.00%	0.00%	100.00%	64.90%	1698.74%
5	1	1.10%	20.90%	15.28%	0.00%	84.72%	52.00%	639.43%
10	1	1.53%	26.19%	27.21%	0.00%	72.79%	37.78%	330.76%
20	1	8.21%	35.66%	43.45%	0.26%	56.29%	26.74%	153.63%
50	1	11.70%	55.24%	67.20%	0.19%	32.61%	15.40%	48.82%
1	1.45	0.00%	15.63%	0.00%	0.00%	100.00%	71.53%	3661.14%
2	1.45	0.00%	15.63%	0.00%	0.00%	100.00%	64.90%	1793.32%
5	1.45	0.95%	19.22%	10.85%	0.00%	89.15%	53.21%	673.87%
10	1.45	1.80%	24.98%	24.71%	0.00%	75.29%	39.09%	354.21%
20	1.45	8.45%	32.59%	38.64%	0.26%	61.10%	28.66%	160.65%
50	1.45	5.44%	50.96%	62.97%	0.06%	36.97%	16.48%	53.59%

All general conclusions of the scenario analysis output of Table 6.5 are the same as those of Table 6.3. The only difference is that due to the order pick productivity increase for higher demand, a smaller proportion of the assortment is supplied via PTZ as more products can benefit from higher order pick productivity. The higher productivity results in higher relative cost savings and lower relative costs and this effect increases for higher demand levels. As a result, in case of Poisson distributed demand, relative relevant costs are now almost below the margin when 10 PUPs are operational.

6.6 Emergency shipments

In order to investigate in which circumstances emergency shipments might be useful in order to improve the fill rate several scenarios are analyzed. As emergency shipments are placed after customer demand is known, inventory statuses are checked in order to see if there are any shortages. The purpose of emergency shipments is to backorder these shortages within the lead time to prepare the customer orders in order to prevent having lost sales. The costs incorporated with these emergency shipments will determine whether it is beneficial to do so. It is assumed that extra transportation costs have to be made for every supplier when emergency shipments are carried out (i.e. emergency shipments cannot be combined with any pick-to-zero shipment). Since the tail distribution of emergency shipments per SKU are not known, it is assumed that the number of shortages is smaller than the number of SKUs per supplier, each SKU has only one shortage. As operational inbound costs are largest in this case, lower bounds are set at which emergency shipments are certainly effective. Finally, as these analyses only show what cost savings would be if suppliers are able to perform them, a delivery reliability of 50% was used in order to reflect on the supplier's (dis)ability to perform emergency shipments successful each day.

There are several factors that influence the savings potential of emergency shipments. In this section four important factors are analyzed: the lost sales cost parameter, the target fill rate of regular orders, the total demand per supplier, and the average retail price. The last two factors are stated in Table 6.8.

In the following analyses emergency cost savings are plotted against the product-specific fill rate. First, it is analyzed what the influence of the lost sales cost parameter and the average retail price per supplier are. Next, it is shown how total supplier demand influences the feasibility of emergency shipments for a specific supplier. Extra transportation costs are not included in the costs savings. Based on the supplier-specific transportation costs it can be estimated below which regular fill rate emergency shipments are profitable for a certain number of PUPs.

Lost sales cost parameter, average retail price and total supplier demand

The next three figures will show what the cost savings are for a specific fill rate for different values of the lost sales cost parameters for the assortment of different suppliers. Based on the assortment characteristics of different suppliers this will result in other cost savings. Figure 6.4 shows that when one PUP is operational and the lost sales cost parameter is set equal to 1 that cost savings are highest for Supplier G and lowest (even negative) for Supplier H for each target regular fill rate. This can be explained by the fact that the average retail price of the Supplier H assortment is below the emergency cost per product. Together with the relative high total demand, this results in the highest negative cost savings. In reverse way, it can be explained why Supplier G has the highest cost savings. However, it can be concluded that emergency shipments are not recommended when only 1 PUP is operational and the lost sales cost parameter is assumed to be equal to 1 as extra transportation costs are unlikely to be lower than € 1.00. Finally, it can be concluded that the lines are almost linear. Lost sales costs are linear to the fill rate. However, operational costs are not linear as the assumption was made that each SKU has only one shortage when the number of shortages is smaller than the number of SKUs per supplier. Somewhere in the line a breakpoint is present at which no more extra inbound cost are made.

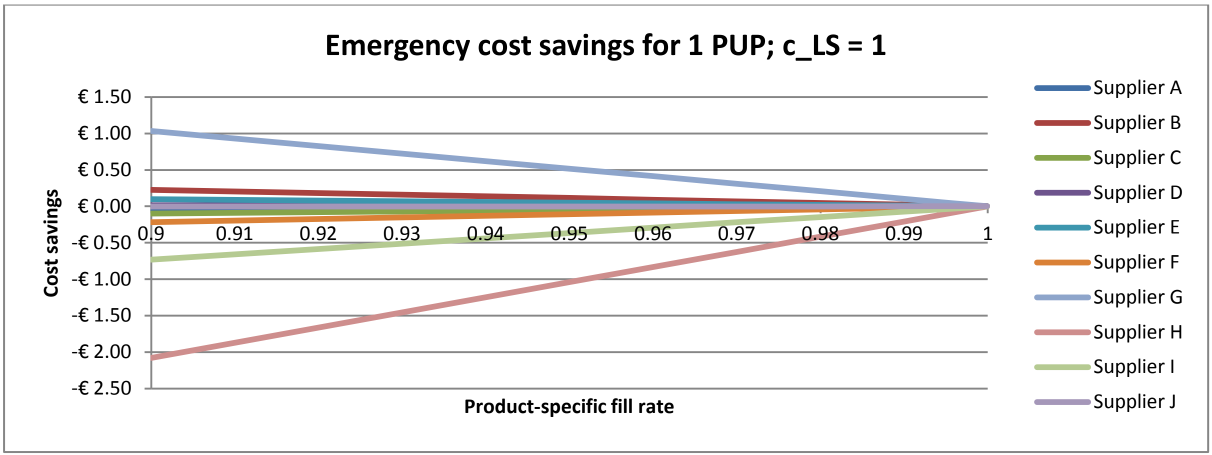

Figure 6.4 – Emergency cost savings for 1 PUP with $c_{LS} = 1$ for different suppliers.

Figure K.1 (in Appendix K) gives a different view on emergency shipments compared to Figure 6.4. It turns out to be that highest cost savings are made for Supplier H (as previously the no cost savings were made at all) now that the lost sales cost parameter is set equal to 5. As for all suppliers the average lost sales cost savings are now higher than the emergency costs, cost savings are all positive and increases as the regular fill rate declines. Emergency cost savings become higher as the product of total demand per supplier and the absolute cost savings per product (higher retail price) becomes higher. Figure K.2 shows comparable results as Figure K.1, however absolute cost savings are higher as the lost sales cost parameter is now equal to 10. Still, cost savings for a high regular fill rate (> 0.99) are still quite low and not profitable as transportation costs are not expected to be covered with the corresponding cost savings.

Number of pick-up points

In order to see at which number of PUPs emergency shipments are expected to be profitable, the cost savings for three suppliers at different levels of operational expansion are calculated. The lost sales cost parameter is set equal to 5 in these cases since it is expected that lost sales are quite expensive in online grocery retailing due to the fact that customers are not able to buy another comparable product.

Figure 6.5 shows that costs savings for Supplier H are doubled when the number of PUPs is doubled. Moreover, it can be seen that cost savings are large enough to cover the transportation costs when the regular fill rate is equal to 0.90 when 5 PUPs are operational. However, the feasibility of this structure is doubtful because a supplier is not willing to supply a relatively large part of his supply via emergency shipments. Therefore, attention has only to be paid at cost savings for fill rates higher than 0.99. It can be seen that cost savings are only large enough to cover the transportation costs on average when at least 20 PUPs are operational.

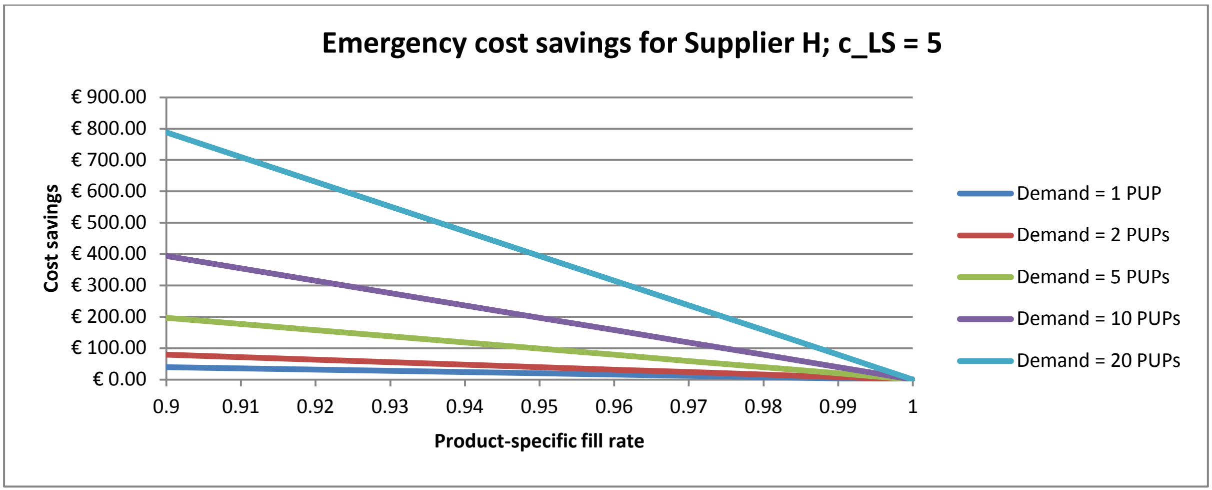

Figure 6.5 – Emergency cost savings for Supplier H with $c_{LS} = 5$ for different number of PUPs.

Figure K.3 gives an overview of the potential cost savings of performing emergency shipments for Supplier G. These cost savings are on average three times smaller. In order to achieve the same cost savings the regular fill rate must be set much smaller. The feasibility of performing emergency shipments is therefore a lot smaller.

Figure K.4 gives an overview of the potential cost savings of performing emergency shipments for Supplier F. As Supplier F only provides 3 products to Superdirect.com the cost savings are very low. Even when 20 PUPs are operational and the regular fill rate is set at 0.90, cost savings are still expected to be insufficient to cover the transportation costs.

In practice, emergency shipment decisions are made on actual shortages. The previous analyses only showed on average in which situations and for which suppliers emergency shipment might be profitable. As in reality shortages are not constant, the execution of emergency shipments is based on the actual shortages. Moreover, these analyses only showed what cost savings would be if suppliers are able to perform them. Therefore, a delivery reliability of 50% was used in order to reflect on the supplier's (dis)ability to perform emergency shipments successful each day. It can be concluded that emergency shipments are especially beneficial for suppliers that supply a large assortment with relatively high average retail prices. In this way, extra transportation costs made by performing emergency shipments can be covered. Moreover, it can be concluded that emergency shipments are certainly not profitable in early stages of operation. Important suppliers that deliver a very large assortment are expected to be profitable for a high regular fill rate (> 0.99) when at least 20 PUPs are operational.

6.7 DISCUSSION

In this subchapter, the model solving results from the different kind of analyses performed are discussed. From the break-even analyses results, it was found that higher case pack sizes result in wider demand intervals and longer shelf lifes result in shorter demand interval at which pick-to-zero is cost efficient. Moreover, it can be concluded that PTZ will not become cost efficient again when demand is extremely high as the lost sales costs are ever increasing due to the fixed fill rate. The reason for this is that fill rate is much lower than the EWA target fill rate and outdating costs for EWA will approach zero as demand becomes extremely high. As the relevant costs for EWA LIFO can only be equal to the costs for EWA FIFO when $Q / \mu \gg m$, the average number of batches is almost always equal to 1. It makes then no sense to withdraw products in LIFO manner, as all products in stock have the same shelf life. Costs are only equal when the average number of batches is equal to 1 and then all the benefits for the consumer are disappeared as the average age of the products does not depend on the withdrawal policy anymore.

From the sensitivity analysis, it can be concluded that average demand is the most important factor in determining the relative costs of products kept on inventory, because when average demand increases from 0.5 CU per day to 4.0 CU per day the relative costs become 16 times smaller. Moreover, it can be seen that extremely high case packs and short shelf lifes are having a large influence on the resulting costs.

From the scenario analyses it can be concluded that a higher percentage of the assortment is optimally supplied via pick-to-zero operations when demand variability is higher. As the performance of pick-to-zero operations are not influenced by demand variability (at least not at the retailer DC) compared to inventory policies (due to higher relative outdating), it has become better for a larger proportion of the assortment to be supplied via pick-to-zero operations. A straightforward finding is that fewer products are supplied via pick-to-zero if demand increases, as relative outdating becomes so small for inventory policies that relevant costs of inventory policies shoot underneath the costs of pick-to-zero operations. Moreover, higher fill rates are achieved when demand increases as a result of a higher proportion of the assortment that is held on inventory. Due to the mediocre delivery reliability of PTZ, the fill rates of inventory policies are almost always better. In case it is possible for all suppliers to deliver products in pick-to-zero operations and PTZ-capacity would be ample, regardless of the other costs made than the relevant costs captured in the model and taking into account the margin on the product of 35%, at least 20 PUPs are needed to only bear for the relevant costs made according to the cost model. Since in reality suppliers can be resistant in changing the supply agreements into pick-to-zero operations, another analysis showed how fast average demand must grow in order to not need to make use of pick-to-zero operations for other suppliers than current PTZ-suppliers. It showed that at least 50 PUPs are needed to approach the same costs as in the first analysis. The fact that EWA LIFO turned out the best between 8% and 17% of the products in the assortment, the relevant costs are in reality a little bit higher due to the fact that the LIFO approximations for relative outdating are too low. Due to higher demand walking distances in the distribution center while order picking become shorter, order pick productivity will increase in concurrence with the demand. Compared to the first analysis with ample PTZ capacity and with all suppliers able to supply via PTZ, in case of Poisson distributed demand, relative relevant costs are now almost below the margin when 10 PUPs are operational.

In practice, emergency shipment decisions are made on actual shortages. The emergency shipment analyses only showed on average in which situations and for which suppliers emergency shipment might be profitable. As in reality shortages are not constant, the execution of emergency shipments is based on the actual shortages. Moreover, these analyses only showed what cost savings would be if suppliers are able to perform them. Therefore, a delivery reliability of 50% was used in order to reflect on the supplier’s (dis)ability to perform emergency shipments successfully each day. It can be concluded that emergency shipments are especially beneficial for suppliers that supply a large assortment with relatively high average retail prices. In this way, extra transportation costs made by performing emergency shipments can be covered. Moreover, it can be concluded that emergency shipments are certainly not profitable in early stages of operation. Important suppliers that deliver a very large assortment are expected to be profitable for a high regular fill rate (> 0.99) when at least 20 PUPs are operational.

7 IMPLEMENTATION

Although Superdirect.com has quit their business, this chapter will function as the implementation section and pretends that Superdirect.com still operates as before the discontinuation of Superdirect.com. From the results of Chapter 6, it can be concluded that the supply chain structure decision model is an appropriate model to design the best possible supply chain for a specific point in time given several demand and product characteristics and cost parameters (see Appendix L for screenshot of the output sheet of the model). This chapter will clarify how the model can be used in the context of an online retailer and will discuss which requirements are needed and how obstacles can be overcome.

7.1 MODEL IMPLEMENTATION AND USE

The implementation and use of the model are discussed in this section. First, the assortment will be discussed. Moreover, the implementation of emergency shipment in combination with the decision model will be discussed.

Assortment

The supply chain structure decision model should be used by SCL to periodically design the supply chain for their perishable products assortment as demand behavior is dynamic in reality. Therefore, SCL must adjust the demand and product characteristics and (possibly) also adjust changes in cost and productivity parameters. Based on historic demand data, demand can be forecasted for the next period. However, when new products are incorporated into the assortment, no historic demand data is available. A way to overcome this obstacle is performing Looks-Like Analyses (also called Analogous Forecasting). This method attempts to map sales of other products onto the product being forecasted. Typically, Looks-Like Analysis is employed for new product forecasting to determine what new product sales might be, given previous product introductions (Kahn, 2002). Another possible way to forecast sales for products without historic demand is to compare the sales of two products in industry. As Hollander Barendrecht is logistic service provider of fresh products for PLUS Retail, products that are available in the assortment of PLUS Retail and Superdirect.com can be compared and sales can be forecasted proportionally.

Superdirect.com wanted SCL to offer a lot of products via pick-to-zero operations (especially slow-moving specialties) in the near future. Dependent on the supply chain characteristics upstream (e.g. the location of fish catches for fish specialties), the supplier lead time must be set such that the operation is feasible. Given the fact that specialties are quite expensive and their average demand is quite low, one will easily conclude that inventory holding is not recommended, especially when the supplier lead time is large. Therefore, a pick-to-zero operation can be designed for those products, however, with a customer lead time equal to the supplier lead time plus one day. Since this was also the idea of SCL to do for products of suppliers which were not able to perform pick-to-zero operations within a short lead time, this is a good solution for specialties. Since average demand of specialties is low, and so, the probability that a customer order contains a specialty is also low, this does not affect the total concept of Superdirect.com. As Fernie et al. (2010) state, offering a limited range can cut the cost of the operation but make it more difficult to lure consumers from conventional retailing, the introduction of specialties in the online assortment makes it possible to attract more customers.

Emergency shipments

The daily ordering decision of emergency shipments can be arranged with the supply chain structure decision model. Every day after all customer orders are known, shortages can be filled in the excel sheet. The model will calculate for which products the emergency shipments must be executed. As emergency shipments can only be performed if suppliers are able to deliver the products or make it possible for SCL to pick-up the shortages, the calculations are only applicable for suppliers, which are actually able to do this. In the analyses a delivery reliability of 50% was used in order to reflect on the supplier's (dis)ability to perform emergency shipments successful each day. In practice, when it is known which suppliers are cooperating in the emergency shipment agreement, delivery reliability is expected to be much higher and is (possibly) supplier-dependent.

7.2 SUPPLY AND OPERATIONS

This section discusses the obstacles that need to be overcome and the actions that need to be taken in order to implement the decision model at SCL. First, it is discussed how collaborations with suppliers are essential in successfully utilizing the decision model. Second, the actions that need to be taken in order to utilize the pick-to-zero lane are discussed. Moreover, it is discussed how the warehouse management system need to be adjusted when products are recommended to be supplied via a specific structure (e.g. LIFO withdrawal or pick-to-zero). Next, it is discussed how SCL must deal with capacity without having capacity constraints in the decision model. Finally, it is explained how ordering decision for weekends need to be adjusted in order to cope with the longer review period and lead time as a result of no or fewer deliveries in weekends.

Suppliers

In the decision model that will be developed for SCL, the option exist for every supplier to include or exclude the pick-to-zero structure in the cost calculations. As the feasibility of the implementation of pick-to-zero operations will depend on the willingness of suppliers to adapt their production and transportation planning, SCL needs to go in conclave with their suppliers periodically in order to verify whether they are willing to supply their products via pick-to-zero operations.

Pick-to-zero lane

In order to accelerate the order pick process for pick-to-zero products, the building of a so-called pick-to-zero lane (see Chapter 4.4) is necessary. The start-up costs of regular pick-to-zero operations (without pick-to-zero lane) are assumed to be negligibly small, because all requirements should be arranged with the current staff and facilities of SCL. However, in case of designing a new pick-to-zero lane with pick-to-light functionalities, investment costs are made for this pick-to-zero lane. In any case the pick-to-light system needs to be connected to the voice picking system in order to receive orders and accept commands.

Warehouse management system

In order to benefit from the recommended changes in supply chain structures by the decision model, settings in the warehouse management system need to be adjusted. It must be possible to quickly change from withdrawal policy (e.g. FIFO to LIFO) when this is advised or adjust case pack sizes (e.g. from current Q to 1) when a product will be supplied via pick-to-zero. Moreover, operational buyers need to see which part of the stock is expected to outdate in the next review period because the EWA-replenishment policy takes ageing of products into account in ordering decisions. These are the requirements in order to approximately achieve the same performance as the decision model will prescribe. Fortunately, SCL meets these requirements, although some costs need to be made in order to do the adjustments in the WMS.

Capacity constraints

The supply chain structure decision model does not directly take into account capacity constraints regarding pick-to-zero capacity. While it is possible to restrict the model from choosing the option ‘pick to zero’ for specific suppliers, this is not an optimal way of capacitated model solving. In practice timing constraints can be ignored, as increased workforce can absorb the high intensity of orders during the period pick-to-zero items need to be collected. However, in practice, the number of SKUs that can be picked-to-zero is finite as space is also finite and the productivity of the pick-to-zero lane declines as the number of SKUs pick-to-zero increases. Therefore, an inventive way needs to be found to only use pick-to-zero operations for suppliers with the highest cost savings compared to the number of SKUs. As cost savings can be obtained from the output of the supply chain structure decision model, one can see which suppliers are having the highest relative cost savings and deselect the pick-to-zero option for the other suppliers and redo the calculations.

Ordering decisions in weekend

The supply chain structure decision model assumes that review periods and lead times are fixed. In reality, however, review periods and lead times are not fixed as most suppliers do not deliver on Sundays and some even not on Saturdays. This means that order lead times and review periods increase in weekends. Ordering decision made on Fridays or Saturdays in practice need therefore be adjusted as a result of the increased review period or lead time. By adjusting lead time and review parameters in the decision model, the corresponding adjusted reorder level for inventory items can be computed at which ordering needs to take place. In order to estimate the expected relevant costs, the review period can be adjusted to $7/6$ or $7/5$ in case of respectively 6 or 5 deliveries per week. Weteling (2013) showed that 6 deliveries per week does not perform much worse on relative outdating than 7 deliveries. Moreover, when suppliers are willing to supply via pick-to-zero operations but are not able to do this on Sunday mornings, deliveries on Saturday morning need to be adjusted with the expected sales plus safety stock to meet Sunday demand with the same probability as pick-to-zero operations. Leftover inventory on Sundays can be used to fulfil demand on subsequent days until m days have been past or when inventory is completely gone.

8 CONCLUSIONS AND DISCUSSION

The aim of the project was to develop a supply chain structure decision model, which can be used for determining the optimal supply chain structure of products within the perishables assortment of an online grocery retailer when considering the relevant operational costs, outdating costs and costs of lost sales. Based on the previous chapters a conclusion is provided for the findings, limitations of the research are discussed, recommendations are provided for implementation and ideas are proposed for future research.

8.1 CONCLUSIONS

At the start of this research project, the following research question was formulated:

How can a supply chain for an assortment of perishable products of an online retailer be designed best in order to minimize relevant costs while meeting predefined customer service levels?

The answer to this question starts by defining how relevant costs were estimated, allocated and incorporated into the quantitative model. Relevant costs related to the problem context can be divided into costs on SKU-level, i.e. outdating costs, operational costs and costs of lost sales and into extra transportation costs. First, outdating costs were estimated by making use of approximations of relative outdating developed by Van Donselaar and Broekmeulen (2012). Absolute outdating was computed by multiplying these approximations with the average demand. Next, multiplying this with the sum of the wholesale price, costs related to taking products out of stock and the physical disposal costs resulted in the total outdating costs. Second, operational costs considered as relevant for all structures were inbound costs per order line and order picking costs per product and additionally for products held on inventory, costs related to checking inventories. Third, costs of lost sales were estimated by making use of fill rate approximations by Van Donselaar and Broekmeulen (2012). Multiplying 100% minus the fill rate by average demand and then multiplying this with a lost sales costs parameter (dependent on how costly lost sales are) resulted in the relevant lost sales costs. Besides the costs made on SKU-level, costs are also made on supplier-level. In case multiple supply chain structures resulted in multiple delivery moments per day, extra transportation costs were made. For each product the best structure was the one with the lowest relevant costs. However, in case products of a supplier were supplied via pick-to-zero and regular shipments, extra transportation costs were made. In case the extra transportation costs were higher than the cost savings of supplying all products via pick-to-zero or via the EWA-policy, an aggregate decision was made on the supply chain structures. Emergency decisions can be made on a daily basis in order to fulfil demand of items for which shortages have arisen due to higher than expected demand. The decisions are made based on costs of lost sales and the costs made when placing an emergency shipment (operational cost and (extra) transportation cost).

The supply chain structure decision model does not directly take into account capacity constraints regarding the pick-to-zero capacity. While it is possible to restrict the model from choosing the option ‘pick-to-zero’ for specific suppliers, this is not an optimal way of capacitated model solving. In practice, timing constraints can be ignored, as increased workforce can absorb the high intensity of orders in the period pick-to-zero items need to be collected. However, in practice the number of SKUs that can be picked-to-zero is finite as space is also finite and the productivity of the pick-to-zero lane declines as the number of SKUs pick-to-zero increases. Therefore, an inventive way needs to be found to only use pick-to-zero operations for suppliers with the highest cost savings compared to the number of SKUs. As cost savings can be obtained from the output of the supply chain structure decision model, one can see which suppliers are having the highest relative cost savings and deselect the pick-to-zero option for the other suppliers and redo the calculations.

In Chapter 6, the model solving results from the different kind of analyses performed are discussed. It was found that a higher percentage of the assortment is optimally supplied via pick-to-zero operations when demand variability is higher. As the performance of pick-to-zero operations are not influenced by demand variability (at least not at the retailer DC) compared to inventory policies (due to higher relative outdating), it has become better for a larger proportion of the assortment to be supplied via pick-to-zero operations. A straightforward finding is that fewer products are supplied via pick-to-zero if demand increases, as relative outdating becomes so small for inventory policies that relevant costs of inventory policies shoot underneath the costs of pick-to-zero operations as the lost sales costs incurred with pick-to-zero are larger. In case it is possible for all suppliers to deliver products in pick-to-zero operations and PTZ-capacity would be ample, it would be best to supply the whole current assortment via pick-to-zero, although relative costs made are twice the margin on the product. Regardless of the other costs besides the relevant costs captured in the model and taking into account the margin on the product of 35%, at least 20 PUPs are needed to only bear for the relevant costs made according to the cost model. As it is expected that order pick productivity will increase in concurrence with the demand relative relevant costs are expected to be almost below the margin when 10 PUPs are operational. However, at least 50 PUPs are needed if no other than the current PTZ suppliers are willing or able to supply via PTZ.

Next, it is concluded that higher case pack sizes result in wider demand intervals and longer shelf lifes result in shorter demand interval at which pick-to-zero is cost efficient. Moreover, it can be concluded that PTZ will not become cost efficient again when demand is extremely high as the lost sales cost are ever increasing due to the fixed fill rate, which is much lower than the EWA target fill rate and outdating costs for EWA will approach zero as demand become extremely high. Although the analyses show that EWA LIFO might be cost efficient in some situations, the relevant costs for EWA LIFO can only be equal to the costs for EWA FIFO when $Q / \mu \gg m$. However, in that case the average number of batches is almost always equal to 1. It makes then no sense to withdraw products in LIFO manner, as all products in stock have the same shelf life. Moreover, it can be concluded that average demand is the most important factor in determining the relative costs of products kept on inventory. Besides, it was noticed that extreme high case packs and short shelf lifes are having a large influence in the resulting costs.

It can be concluded that the cost savings of emergency shipments are not expected to be large enough to cover the extra transportation costs when only few PUPs are operational. Although the analysis showed on average in which situations and for which suppliers emergency shipment might be profitable. As in reality shortages are not constant, the execution of emergency shipments is based on the actual shortages. Therefore, it might occur that the actual shortages of products of a specific supplier are way larger than expected and that emergency shipments are incidentally profitable in the early stage of operation. The conclusion can be made that emergency shipments are especially beneficial for suppliers which supply a large assortment with relatively high average retail prices. This way, extra transportation costs made by performing emergency shipments can be covered. They are expected to be profitable for a high regular fill rate (> 0.99) when at least 20 PUPs are operational.

In case new products are incorporated into the assortment, no historic demand data is available. A way to overcome this obstacle is performing Looks-Like Analyses (also called Analogous Forecasting). This method attempts to map sales of other products onto the product being forecasted. Typically, Looks-Like Analysis is employed for new product forecasting to determine what new product sales might be, given previous product introductions (Kahn, 2002). Another possible way to forecast sales for products without historic demand is to compare the sales of two products in industry. As Hollander Barendrecht is logistic service provider of fresh products of PLUS Retail, products that are available in the assortment of PLUS Retail and Superdirect.com can be compared and sales can be forecasted proportionally.

Superdirect.com wanted SCL to offer a lot of products via pick-to-zero operations (especially slow-moving specialties) in the near future. Dependent on the supply chain characteristics upstream (e.g. the location of fish catches for fish specialties), the supplier lead time must be set such that the operation is feasible. Given the fact that specialties are quite expensive and their average demand is quite low, one will easily conclude that inventory holding is not recommended, especially when the supplier lead time is large. Therefore, a pick-to-zero operation can be designed for those products but with a customer lead time, equal to the supplier lead time plus one day. As this was also the idea of SCL to do for products of supplier which were not able to perform pick-to-zero operations within a short lead time, this is a good solution for specialties. Since average demand of specialties is low, and so the probability that a customer order contains a specialty is also low, this does not affect the total concept of Superdirect.com. As Fernie et al. (2010) state that offering a limited range can cut the cost of the operation but make it more difficult to lure consumers from conventional retailing, the introduction of specialties in the online assortment makes it possible to attract more customers.

8.2 LIMITATIONS

The limitations of the research can be divided into the determination of the data collection and the decision model.

Data collection and analysis

The analysis for determining the demand characteristics was based on research on data from the only PUP that had been operational. In combination with the short length of the period in which data had been gathered, it can be concluded that the validity of the demand analysis is not high. If more PUPs had been operational, the validity of the data analysis would have been improved.

Decision model

An important notion has to be made about the approximations of relative outdating when the EWA-policy is used. They are based on simulation experiments which were cut off at 30% relative outdating for FIFO withdrawal and 50% relative outdating for LIFO withdrawal. As many products in the most recent assortment were having much higher levels of relative outdating and the fact that high fill rates are needed in online grocery retailing, combinations of parameters used in this break-even analysis result in relative outdating outside the validity intervals. Moreover, the assumption that Q/m had to be lower than μ was often violated. Therefore, it occurred that the LIFO withdrawal policy results in lower costs than the FIFO withdrawal policy in some situations.

Next, the cost model only partly reflects the reality for SCL and Superdirect.com. As denoted in the model assumptions, it was assumed that lead times and review periods were constant. In reality, almost no suppliers deliver on Sundays and a large part not even on Saturdays and for delivery on Monday an order must be placed almost always on Friday or Saturday. Furthermore, a typical week pattern demand was not included, while it was clearly present in reality (see Table 4.1). Next, the way higher order pick productivity was taken into account in the scenario analysis (see Table 6.7) does not reflect the real increase in productivity. As boxes related to end customers are picked, the reduction in walking distance can only be achieved by better combining boxes or by increasing the number of boxes picked together. Economies of scale are not so large in order picking on consumer-level compared to store-level. Due to the relative short time available in this master project it was not possible to perform a large investigation in the benefits of economies of scale on order pick productivity. Finally, the supply chain structure decision model does not directly take into account capacity constraints regarding pick-to-zero. While it is possible to restrict the model from choosing the option ‘PTZ’ for specific suppliers, this is not an optimal way of capacitated model solving.

8.3 RECOMMENDATIONS

The recommendations are based on the results and the knowledge obtained throughout this research project. It can be seen as an advice for the entrepreneurs starting a business in the online grocery retail domain and for logistic service providers of perishable goods, such as SCL and Hollander Barendrecht.

Sales volume

The business case of Superdirect.com shows that cautious entering the online retail market (i.e. not scaling up fast enough) has not been very effective. Roughly seven months after start operating for the whole consumer market they had to quit their activities. The research showed that average demand is a large factor in the costs made. Although the risks of scaling up quickly are high if consumers are not attracted to this way of grocery shopping, a retailer should quickly scale up in order to benefit from economies of scale and so get rid of outdating costs. The operation that was designed at the distribution center for the only PUP Superdirect.com had, was way to large compared to the sales. Competitors in the retail business are using the stock in their brick and mortar stores to fulfil online customer demand. They do not utilize a large distribution center and moreover can use their existing stores as pick-up points. As Collo and Lapoule (2012) describe, the costs related to this operation are much lower than to the operation of Superdirect.com. However, he also states that the operation at physical stores is not everlasting as online demand will increase the coming years. Huge queues will appear in front of supermarkets and supermarket personnel is typically order picking from the stores. Typically, a cut-off point exists at which the operation with unmanned automated PUPs become cost effective compared to the defensive operation current retailers are using.

Online assortment

In order to compete with conventional retailers, an online retailer should offer a comparable assortment. A disadvantage of offering quite expensive slow-movers is that outdating costs are very large if the product cannot be supplied via pick-to-zero operations. The considerations that an online retailer needs to make is to what extend his assortment must be enriched in order to attract new customers taking into account the extra costs of outdating. A recommendation that can be provided is that the assortment size must certainly not decline as upscaling takes place. In any case a retailer should start with a standard assortment with at least all fast movers and medium movers of conventional retailers in order to be somewhat competitive and not having huge outdating costs. The fact that some products at Superdirect.com were only sold once per twenty to fifty days indicates that those products do not contribute to the advantages of having a large assortment and only cost money.

Suppliers and supply chain structures

Problems in the business case of Superdirect.com are known. A major problem was that, except for two suppliers, no suppliers were willing to supply products via pick-to-zero operations, while it was known that outdating of products can be prevented this way. Initially, only bread was supplied with a pick-to-zero operation. After a few months also fresh cut vegetables were supplied via this way as it was observed that outdating figures were very high for these products. After that, Superdirect.com was not able to find more suppliers to switch to pick-to-zero. Therefore, it is recommended for starting online retailers to find suppliers of perishable goods which are willing to supply via pick-to-zero if this is needed. As high cost savings can be achieved this way, it is very important to have the opportunity to supply many products this way. In order to find appropriate suppliers, the time window in which customer can order their groceries can be shifted so that enough suppliers are able to produce/package their products in time.

8.4 FUTURE RESEARCH

This research is one of the first quantitative studies on supply chain management of online supermarkets. In order to improve the supply chain management of online grocery retail several future studies can be performed.

Marketing research on customer order lead time

As stated in Chapter 4.4, a way to avoid supplier-related problems regarding the pick-to-zero operation is to increase the customer order lead time with one day for products of several suppliers. As many suppliers are not able or willing to perform pick-to-zero operations within a very short lead time, an increase of the customer order lead time make a pick-to-zero operation possible without any constraints. It is, however, still unclear what the customer reaction would have been on this decision. Future research could, therefore, explore what the influence of this action would be on customer behaviour (i.e. sales).

Economies of scale in order picking

As stated in Chapter 8.3, economies of scale in order picking on customer-level are lower compared to on store-level. In order to precisely estimate the increase in order pick productivity due to increased demand, it must be found out whether the order pick process is similar to processes in regular e-commerce DCs.

Capacitated decision model

This decision model developed in this master thesis project is uncapacitated regarding the number of products supplied via pick-to-zero operations. As lead time is very short, the total assortment cannot be supplied via only pick-to-zero. While it is possible to restrict the model from choosing the option ‘pick to zero’ for specific suppliers, this is not an optimal way of capacitated model solving. Therefore, future research needs to be done on capacitated decision making, in which only those products are supplied via pick-to-zero that are having the largest cost savings compared to the capacity they occupy.

Multi-echelon supply chain optimization

Another option for future research could be to incorporate the production, packaging and order-pick process and planning of suppliers in the decision model. It was experienced that decisions cannot be just solely made by retailers themselves. When specific decision is cost optimal for retailers, then this does not need to be this way for suppliers. It might therefore be interesting to investigate what the optimal supply chain would be taking into account the cost structure of both parties. After that, a contract needs to be found in order to approach the optimal centralized costs.

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