

## MASTER

### Fulfilment distribution network design at a Dutch food wholesaler

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Eindhoven, August 2015

# **Fulfilment Distribution Network Design at a Dutch Food Wholesaler**

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in partial fulfilment of the requirements for the degree of

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in Operations Management and Logistics**

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## **Abstract**

This project aimed to provide quantitative and qualitative insights in the trade-offs that exist between the costs of handling and warehousing activities, the holding of inventory and transportation for a fulfilment supply chain of a Dutch food wholesaler. With these insights, a recommendation was given on how this distribution network should be designed to achieve the minimum sum of these costs, under the constraints that product quality should be at least equal to the current situation, as well as product availability and customer order lead times. A business case and Excel-based model was built around a cross-docking scenario and compared against several other scenarios, in which the current design of the supply chain is optimised with varying degrees. The results suggested that for most items the potential operational costs savings could be significant (up to a total of €2.68 million per year). For a small fraction of items though, representing a large share in total sales volume the potential savings were minor, if not negative. It was found that not only sales (in units) and a large physical size are important predictors for potential cost savings, but also demand volatility and cost price. On top, switching to a cross-dock scenario would also require significant investments in a new warehouse, it could affect the existing operations negatively and introduces additional exposure to risks, among which is a loss of control over transport efficiency. It is up to the management to decide how the total potential cost savings and all other elements add up; further studies were recommended.



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# Management Summary

## Problem introduction

As set out in its annual report 2014, the Dutch food wholesaler aims to increase its market share in Foodservice from 22.9% to 30%. To achieve this goal, most of the necessary revenue growth is expected to come from its delivery operation, for which revenues grew with about 11% during 2014.

The delivery operation of recent years however has been associated with returns that are declining in relative terms, and growth in sales has been accompanied by a similar rise in costs. In other words, there seem to be no economies of scale taking place. Higher management therefore started thinking how the fulfilment supply chain should develop over the next years in order to remain competitive in Foodservice. This thesis project is therefore part of a larger effort to provide more quantitative and qualitative insights into the further development of the food wholesaler’s fulfilment supply chain.

## Problem Statement

In accordance with the supply chain design and planning manager, the following research question was developed:

*"How should the supply chain for the delivery operation of the Dutch food wholesaler look like, so that the objectives for customer order lead time, product availability and product shelf life norms are achieved with minimal costs for the sum of holding of inventory, transportation and related handling activities?"*

Throughout the time-span of the project, a concrete scenario was brought up to provide a business case in which the trade-offs of these three costs elements would become more apparent. This scenario, which entailed the cross-docking of items from a hypothetical central warehouse instead of keeping them in stock at the delivery service distribution centres (DCs) was based on certain strong, but non-restrictive assumptions. These assumptions were addressed later in the report.

## Problem Scope

The scope of the research project was defined as to include the items that are currently being shipped between the central distribution centre (CDC) and the delivery service DCs. They excluded any client-only items, regional items that are sold to multiple customers but supplied from only one delivery service DC, tobacco and items that are currently being shipped directly to the delivery service DCs (thus skipping the CDC echelon). The scope is displayed in Figure 1.

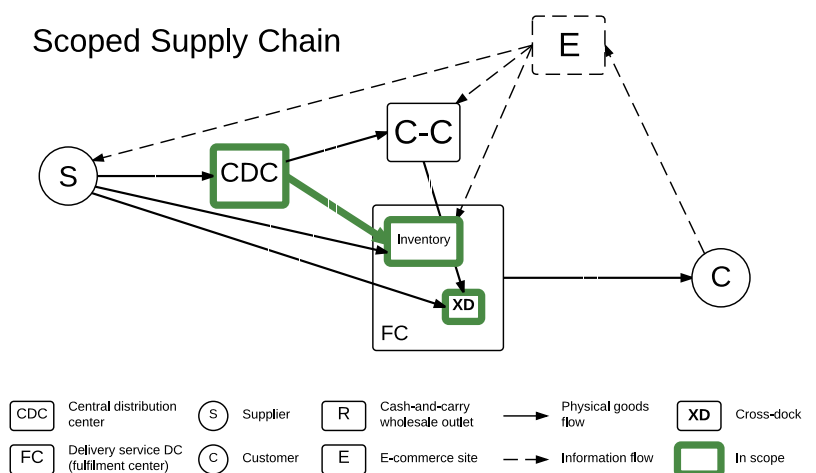


Figure 1 - Project scope

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## Problem Analysis

Currently a lot of activities are needed to get the scoped items from the CDC to the delivery service DCs. These activities are the picking of replenishment orders at the CDC, its subsequent transportation downstream using (eco-)trailers, followed by the final replenishment process in the delivery service DCs. On top there are also the costs of inventory in the two echelons, not only for cycle stock but also safety stocks to protect against demand volatility and additional buffers to protect against other sources of uncertainty. For specific CDC- and DC areas the costs of these activities were approximated by field studies and data analysis and corrected for potential improvements suggested by academic studies.

## Research Design

An Excel-based model was developed in which a representative selection of 476 items were used to derive calculations that reflect the relevant yearly costs of handling, warehousing, transportation and inventory for the scoped supply chain. First, the VBA-based DoBr tool, developed by Van Donselaar & Broekmeulen (2014), was used to make calculations about the inventory levels for a periodic review policy with reorder level  $s$ , different base replenishment quantities  $Q$  and target fill rates  $\beta$ . From this tool, the expected number of order lines per year was derived and used to calculate the costs of handling per CDC- and DC area by also taking into account the base replenishment quantities. Transportation costs were calculated by assuming that they are linear to the distance travelled and were based on total yearly transportation volumes that were then translated into pallet positions in a trailer.

## Scenario

Five scenarios were created, the first four of them showing various degrees of optimisation of the current situation. The fifth scenario entailed the TO-BE cross-docking state, for which several assumptions needed to be made. One of them was the minimum volume increase assumption, which assumes that items picked in customer-specific crates see a volume increase in shipments of 45%. For items on roll container this is equal to 28%. Another assumption was that the central warehouse would be located near to the current CDC so that travel distances are equal across all scenarios. In the end, scenario 5 was compared against scenario 2, which most closely reflected an optimal state of the current situation. The other scenarios are more suited for reference purposes.

## Results

One of the immediate results obtained with a representative sample set of items, was that from a cost perspective 67.4% of the base replenishment quantity settings at the delivery service DCs were found to be lower than what can be considered cost-optimal. With optimal settings the combined costs of decentralised inventory and the handling activities could be reduced, but they would be associated with higher inventory levels downstream. This is reflected in Figure 2 by comparing scenario 1 and 2.

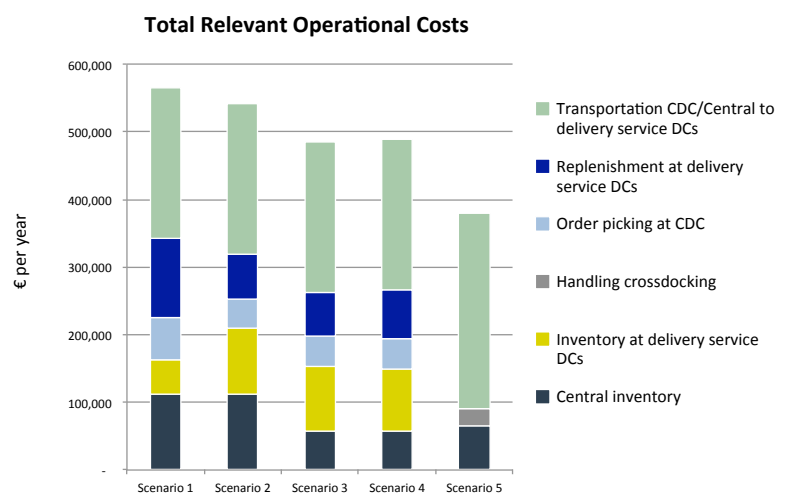


Figure 2 - Total relevant potential costs per scenario

Further, the results showed that potentially 30% savings on total operational costs can be achieved compared to scenario 2 when all items will be cross-docked (see Figure 2). However not for all items that would be a profitable switch; for 4% of items the cross-docking scenario was associated with increased costs (see Table 1).

Table 1 - Cost savings per item class for the sample set

Potential savings	Count	% of # items	Sales volume (L)	% of sales volume	# Suppliers (cum)
More expensive	18	4%	11,551,457	47%	15
Between 0-10%	6	1%	1,480,302	6%	21
Between 10-20%	13	3%	3,168,653	13%	29
Between 20-30%	17	4%	1,642,401	7%	38
Between 30-40%	57	12%	2,253,433	9%	77
Between 40-50%	76	16%	2,163,248	9%	117
Between 50-60%	101	21%	1,360,742	6%	155
Between 60-70%	96	20%	647,312	3%	180
Between 70-80%	61	13%	312,086	1%	192
Between 80-90%	22	5%	33,049	0%	202
Between 90-100%	9	2%	12,283	0%	205
<b>Total</b>	<b>476</b>	<b>100%</b>	<b>24,624,967</b>	<b>100%</b>	<b>205</b>

When deciding not to cross-dock the 18 items from Table 1 (under the minimum volume increase assumption), it meant that 4% of items needed to be excluded, accounting for 47% of sales volume in litres. With this heuristic improvement step, the final potential savings, up scaled to the entire delivery operation, could be in the region of €2.68 million per year compared to scenario 2, or 44% (see Figure 3). These savings can be used as a basis to decide on the investments in setting up a central warehouse, and a possible allowance for the actual volume increase in cross-dock shipments compared to the current shipments between the CDC and the delivery service DCs.

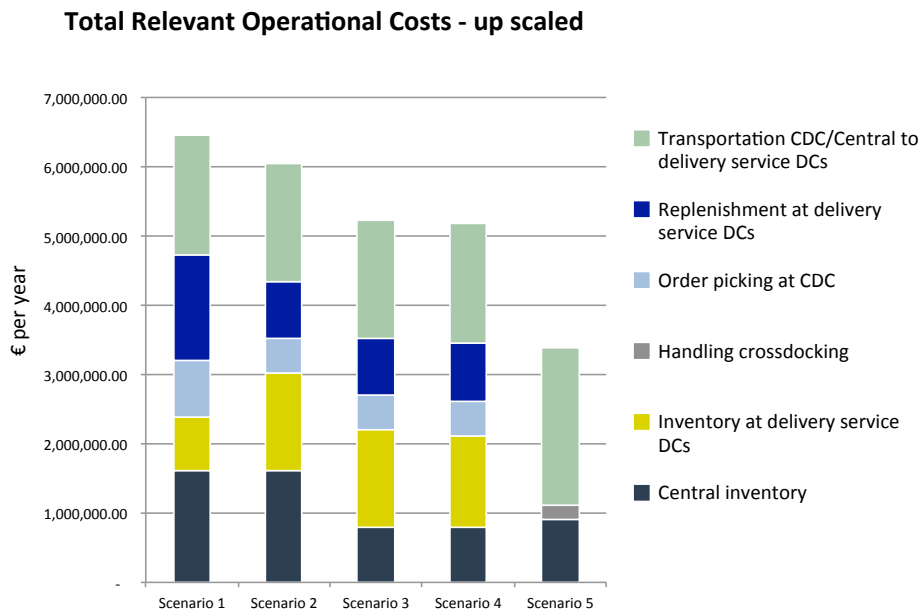


Figure 3 - Up scaled potential cost savings for 458 out of 476 items.

Cross-docking in relation to the product quality would be the preferred option because handling, and thus risk for damage, is minimised and a longer shelf life can be provided to the final customer since the inventory days in the delivery service DCs are eliminated and inventory turnover rates in the

central warehouse will be higher. It is however also associated with a reduction of control on transport efficiencies compared to the current distribution network design. Therefore the minimum volume increase assumption from scenario 5 was relaxed by performing a sensitivity analysis on transportation volumes.

It showed that once volumes in scenario 5 increase by another factor 2.3, no more costs savings are obtained for cross-docking for the  $476 - 18 = 458$  items under research (see Figure 4).

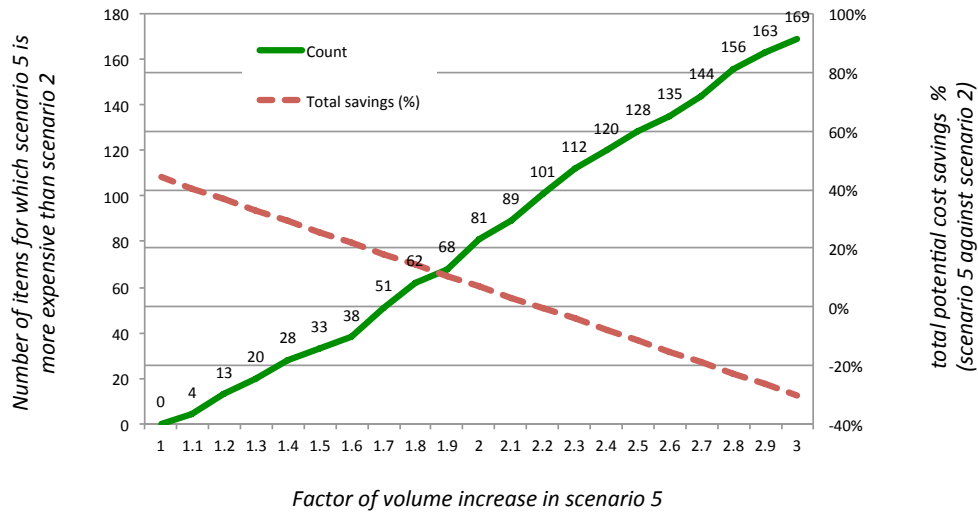


Figure 4 - Sensitivity analysis on transportation costs for 458 out of 476 items

Thus, being able to control and minimise transportation volumes in the cross-docking scenario is crucial to obtain the potential cost savings.

## Recommendation

It is recommended that items with a large physical size (above 30 litres per sales unit), and items with high sales (above 80.000 units per year) are never a candidate for a cross-docking scenario because for these items the costs for transportation dominate the logistic cost structure. These items are typically also associated with optimal base replenishment quantities that are relatively large compared to mean demand. For these items, either current practices should be continued or better, have the suppliers ship them directly to the delivery service DCs.

For the remaining items cross-docking could be a possibility since most items show potential cost savings in the range of 50 to 70%, especially for items that observe a high demand volatility and that have a high cost (purchase) price.

Following a sensitivity analysis over the minimum volume increase assumption, a follow-up study could be to research how transport volumes can be controlled under a cross-dock scenario in order to have efficient transportation. Following from this, a second suggestion for future research is to research how a successful pilot project could be set up such that the potential cost savings become apparent even in a small-scale pilot version of scenario 5.

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## Preface

This master thesis report is the final result of the time I spent researching an interesting and relevant topic at a large Dutch food wholesaler that has been active in (e-)fulfilment for many years. It constitutes the final phase of my master studies Operations Management & Logistics at the School of Industrial Engineering at the Eindhoven University of Technology.

With the completion of this project I am looking back not only on a pleasant time working on the project, but also on five and a half great years being a student at a well-respected university and faculty in a city with international allure.

I performed this master thesis project from February to August 2015. Most of that time I spent at the supply chain department at the head quarters, but also I visited several delivery service DCs and wholesale outlets to get more insights on the studied topic. Therefore I would like to thank all the employees who guided me in this process, who taught me more about distribution and retail business, who helped me in my search for data, who proved partners in productive discussions and not to forget who made me enjoy this project as much as possible by also making some jokes along the way.

Special thanks go out to my company supervisor, drs. Nico Kuipers, for the time and effort he spent on bringing this whole project to a good end. Furthermore I would like to thank my mentor and first TU/e supervisor prof.dr. Ton de Kok for sharing his knowledge and experience and guiding me throughout the entire process of graduation. Last, I would also like to thank my second supervisor, dr. Rob Broekmeulen for sharing his expertise on the topic and providing useful feedback on my work.

This report will hopefully serve as an important source of information for the management to aid decision-making towards a great future for the delivery operation.

Bart van Eijden

Eindhoven, August 2015



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# 1. Introduction

This thesis project was conducted at a Dutch wholesaler that delivers food and food-related non-food to on average 4000 different clients per day, six days per week. Among the clients are hospitality establishments, caterers, leisure facilities and small and medium-sized enterprises in The Netherlands and Belgium. In this B2B environment, an online platform exists where customer orders are received centrally, produced over various locations and finally delivered from eight delivery service DCs located in different regions in The Netherlands. The (online) assortment includes regular dry groceries, vegetables, non-food, but also cooled and frozen food items with varying degrees of perishability. The total number of different items that a customer can order is on average 60,000, some of which are fast-moving items while others are only ordered infrequently and at low volumes.

One important feature of a supply chain in an e-fulfilment environment is that inventories are decoupled from the customer display (Agatz et al. 2008). Not only does this increase the e-tailers' flexibility in locating inventories, it also allows for example larger assortments as items in the long-tail can be pooled and thus higher inventory turns can be obtained. The main trade-off in supply chain network design for e-tailers, according to Agatz et al. (2008), therefore is between the economies of scale and risk pooling on the one hand, and delivery efficiencies on the other hand that drive inventory locations and in particular the degree of inventory centralisation.

One of the main challenges in e-fulfilment relates to how to efficiently process and deliver large volumes of small orders of low-value items (Agatz et al., 2008) in areas where there is still a low customer density (Vanelsander et al., 2013). For this, several choices can be made in the design of a fulfilment supply chain. Simchi-Levi et al. (2008) provide an overview on some of the choices that can be made. They also outline several examples of what they call the downfall of some of the highest profile Internet businesses due to issues in the logistics strategies. Successfully organised logistics processes are therefore considered critical for an e-tailer's success (De Koster, 2003).

Van der Vlist (2007) described a traditional retail supply chain as a series of interconnected stock points, in which shipments are broken up as one moves downstream in the echelon structure. Full truck load (FTL) shipping is replaced by less than truckload (LTL) shipping, and full mono pallets become client-specific mixed pallets. This process decreases the efficiency of the replenishment operation. The breaking up of shipments into smaller and more diverse carriers is referred to as handling and warehousing activities. Together with the cost of transportation they dominate the retail logistics cost structure (Van der Vlist, 2007).

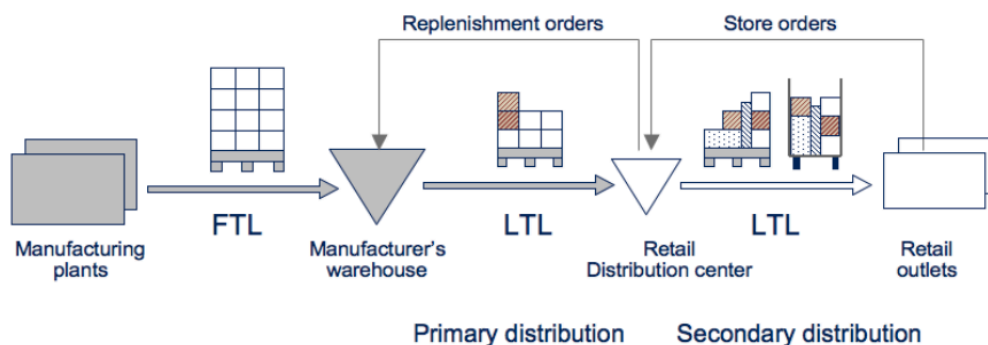


Figure 5 - Retail supply chain (Van der Vlist, 2007)

De Koster (2002) reviewed a range of distribution structures for online food retailers and found important differences between traditional food retailers, real e-tailers and intermediaries. He stated how intermediaries by the time of research were experiencing serious difficulties in running a sustainable business as it seemed rather difficult to realise the adequate service levels at competitive prices. The other two on the other hand were considered more successful and usually ran their own warehouses, either from their existing infrastructure or from special Internet warehouses. The latter as it seems, is becoming the trend even for traditional food retailers. An increase of complexity of operations (mainly meaning a large number of orders) is associated with a higher occurrence of special DCs dedicated for the fulfilment of Internet customer orders. According the De Koster (2002), only companies with full line assortments are still most likely to choose for distribution through the traditional stores.

The company under investigation in this research can be regarded as a traditional food retailer (or wholesaler) that offers a full line assortment through a mix of existing infrastructure and dedicated self-operated Internet warehouses. The current logistic footprint is the result of a gradual development of the fulfilment supply chain. The emergence of specialised delivery service DCs only occurred in the beginning of the millennium. Before, when orders were still received through a range of electronic media like fax and telephone, customer orders were picked and shipped from the existing wholesale outlets. But after several acquisitions and a continued increase in revenues, the company slowly started to set up special Internet warehouses.

Until this date, the delivery service DCs do not carry the full line assortment. Instead, a significant amount of slow-moving assortment is sourced from three existing cash-and-carry wholesale outlets, known as the services stores. These slow moving items are picked in service stores in client-specific crates only whenever a customer orders them. They are then shipped within hours towards the delivery service DCs in a cross-dock form, where they will be consolidated with all other incoming flows to finally be shipped towards the final customer the next morning. The service stores also function as a backup so that whenever an item is out of stock (OOS) at a delivery service DC, it can be supplied by the service store.

Thus, the complete fulfilment supply chain shows an overlap of different sub-supply chains. In this structure, the Internet warehouses observe a variety of product flows, ranging from cross-dock to direct deliveries. It holds a double function, namely being a transportation hub as well as a stock-keeping location.

A graphical overview of this fulfilment supply chain, including sales volume estimates, is provided in Figure 6.

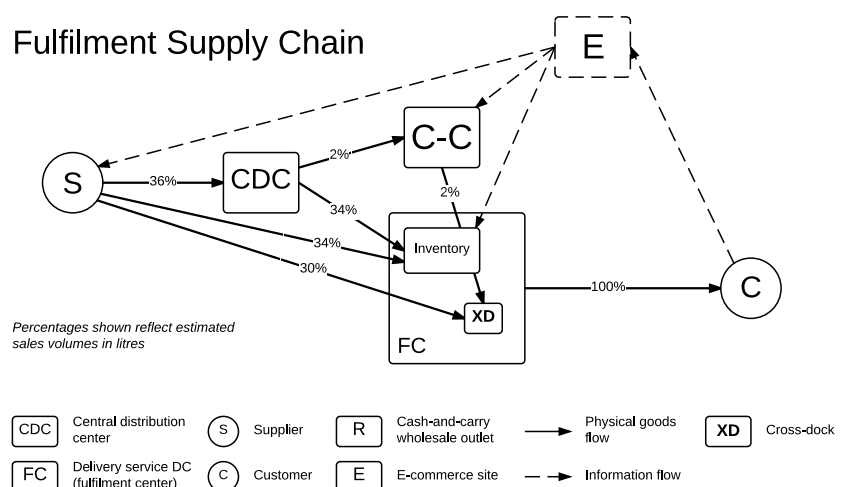


Figure 6 - Fulfilment supply chain with sales volume estimates

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## Part I – Company & Problem Description

### 2. Company Description

In this chapter an overview of the company at which the project took place is provided. The following information is extracted from the 2014 Annual Report and the corporate website.

The food wholesaler was founded almost one century ago to become what is now one of the major players in the Dutch grocery retail business (B2C, Foodretail, or ‘at home’) and Dutch wholesale business (B2B, Foodservice, or ‘out of home’) market. With a wide network of supermarkets, cash-and-carry wholesale outlets, delivery service DCs, manufacturers and supply partners in the Netherlands, the wholesaler is serving food and food-related non-food products to both Dutch and Belgian customers.

Table 2 – Financial overview for 2014

	Foodservice		Foodretail		Total	
(x € million)	2014	2013	2014	2013	2014	2013
<b>Net Sales</b>	<b>1,749</b>	<b>1,658</b>	<b>823</b>	<b>840</b>	<b>2,572</b>	<b>2,498</b>
Cost of sales					1,976	1,920
<b>Gross Margin</b>					<b>596</b>	<b>578</b>
<b>EBITDA</b>	121	114	28	29	149	143
<i>EBITDA / Net Sales</i>	<i>(6.9%)</i>	<i>(6.9%)</i>	<i>(3.4%)</i>	<i>(3.5%)</i>	<i>(5.8%)</i>	<i>(5.7%)</i>
Net Profit					69	68

The company is listed at the Euronext stock exchange in Amsterdam and over the past 25 years achieved an average compounded rate of return of 17% per year. In 2014 the company employed a workforce of over 5,800 fulltime employees with its head office located in Noord-Brabant, The Netherlands. The financial results for the previous two years are stated in Table 2.

In recent years, the food wholesaler has experienced that expenditures in the grocery retail channel for consumers have stabilised while the B2B Foodservice wholesale channel shows significant growth. According to the 2014 annual report, 41% of the revenue was generated from ‘home’ deliveries (see Figure 7) while in 2013 this was 39%. This translates into sales through the Internet channel of €1055 million in 2014 compared to €947 million in 2013. This implies that about 60% of revenue in Foodservice is generated from the Internet channel, a percentage that is expected to continue to increase over the next years.

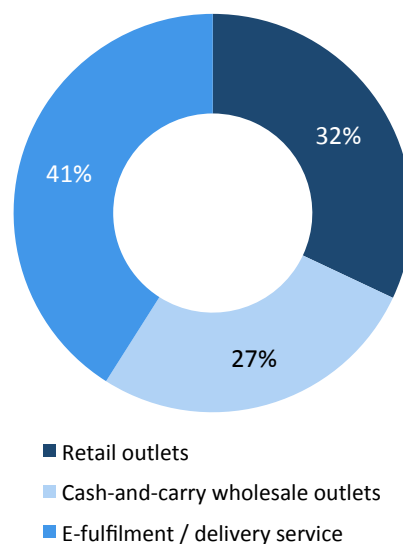


Figure 7 - Revenue distribution 2014

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## 3. Problem Definition

### 3.1 Problem Context

As set out in its annual report 2014, the Dutch food wholesaler aims to increase its market share for Foodservice from 22.9% to 30%. Most of the growth that is required to achieve this ambition will have to come from the delivery operation. For this reason, higher management recently started thinking about how the fulfilment distribution network should be developing in order to remain a competitive player by 2020. The delivery operation of recent years has been associated with returns that are declining in relative terms, and growth in sales has been accompanied by a similar rise in costs. In other words, there seem to be no economies of scale in the delivery operation taking place.

This thesis project is part of a larger effort to map what the supply chain of the food wholesaler should look like in the mid term. The current logistic footprint is mainly the result of acquisitions and so a lot of current goods flows in the network are based on legacy rather than thorough analysis. With the continued increase in revenues through the online channel in Foodservice, higher management believes that it is necessary to have a better understanding in the relevant logistics cost drivers and how these will influence design decisions related to the distribution network.

Initially this research project was set up to better understand the trade-offs that exist between the costs of handling and warehousing activities, inventory investments and transportation with respect to the goods that flow between the central distribution centre (CDC) and the delivery service DCs. Following the earlier research on multi-echelon inventory management by Van Pelt (2014), in which the sole objective was to minimise the (holding costs of) inventory, this project will include explicitly the additional costs that occur when inventory is moved between stock-keeping locations, i.e. the costs of handling, warehousing and transportation. One important reason for this choice is the work of Van der Vlist (2007), who showed how the costs of inventory are only a minor fraction of the total logistics costs in a retail supply chain. According to his study, “not the costs of inventory, but the costs of order picking, shipping and transportation are the most important elements in the retail logistics cost breakdown”. It is therefore hypothesised that the conclusions by Van Pelt might not hold if one also would consider relevant costs other than those for the holding of inventory.

The thesis project took place under the supervision of the supply chain planning and design manager and was positioned within the supply chain department. Due to the topic span of this thesis, important links were also set up with two other line functions, namely the logistics department and delivery service operations. An overview of the complete organisational structure can be found in Appendix A.

### 3.2 Problem statement

At first the aim of the project was to offer qualitative and quantitative insights into the trade-offs between the costs of handling, inventory, and transportation for the items that are being shipped between the CDC and the delivery service DCs. The underlying objective was to provide a statement, based on these trade-offs, on how the scoped supply chain should look like in order to minimise the sum of these three costs, while taking into account the product quality, customer order lead times and product availability targets.

These ideas were then translated into the following research question:

"How should the supply chain for the delivery operation of the Dutch food wholesaler look like, so that the objectives for customer order lead time, product availability and product shelf life norms are achieved with minimal costs for the sum of holding of inventory, transportation and related handling activities?"

Throughout the time-span of the project, a concrete scenario was brought up in order to provide a business case in which the trade-offs of these three costs elements would become more apparent.

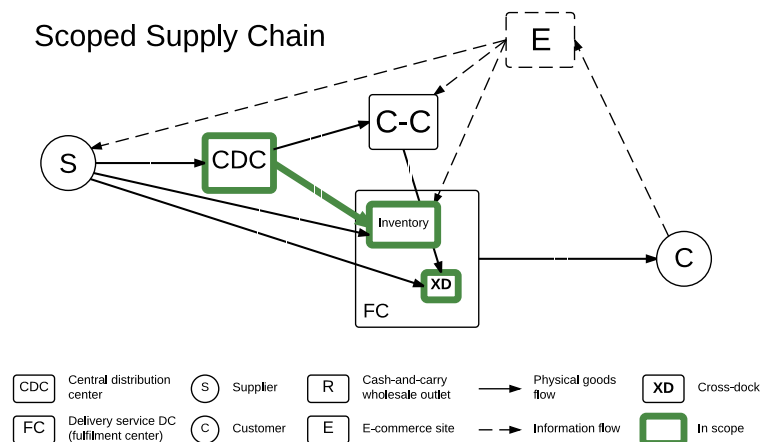
### 3.3 Scope

In several meetings with the supply chain design and planning manager it was decided that the current (geographical) locations of the delivery service DCs could be considered given and no study was to be performed on for example the optimal number of DCs. From this it followed that the research needed to concentrate on the functions of the current locations in the network, specifically by looking at where the customer orders should be produced (i.e. picked and be made ready for final delivery, which also needs to address the issue of where to locate inventories).

The result was a focus on a cross-docking scenario, assuming that customer order lead times and capacity would not be a restriction at this moment and that the last-mile delivery process would remain the same. By assuming an uncapacitated system, it would enable to first find out if there even exist any potential operational costs savings worth to consider the scenario at all.

The items in scope were only those that are currently being shipped between the CDC and delivery service DCs, i.e. those items that are pulled in from the CDC by replenishment decisions generated by the automated ordering systems (ABS) at the delivery service DCs. This means not all the items from the inventory would be in scope since the delivery service DCs also keep in stock items that are delivered directly from the manufacturers/suppliers. Moreover, not every delivery service DC has the same assortment (which is explained later in chapter 8).

Based on the above, therefore the scope was visualized as in Figure 8.



More specifically, the items that were scoped out from the research were the following:



- 
- Client-only items (i.e. 'sold' through only one delivery service DC to one specific client)
  - Items characterised by dominant seasonal sales patterns (e.g. ice cream, Christmas merchandise, etc.)
  - Tobacco products
  - Regional items (i.e. items sold to multiple customers but through only one delivery service DC)
  - Items that are at the moment not passing through the CDC but are shipped by the suppliers directly to all the delivery service DCs (in general these are from suppliers that produce high sales volume items like beer, frozen potato fries, margarine or mayonnaise)
  - Return flows (rejected products, empty crates and roll containers, etc.)

To isolate the delivery operations from the rest of the activities within the company was not straightforward. First of all the CDC holds inventory not only for the delivery service DCs, but also for its cash-and-carry wholesale outlets and regional retail DCs. Thus, knowing which activities in the CDC are relevant for this research needed extra attention. Secondly, the delivery service DCs are not uniform. For example each of them observes different final demand for different items, inventory assortments are different, warehouse layouts are optimised locally, there are minor differences between workflows, etc. The next section about research design will explain how this was taken into account by the research design.

### **3.4 Research design**

The study was set up as follows. First a research proposal was developed, aiming at better understanding the context of the assignment and crystallising the research question that was provided in section 3.2. Work on this proposal started on 2 February 2015 and was finished on 6 March. In parallel a literature research was done on strategic design and tactical planning issues for multi-channel retail supply chain networks. Combined they served as a starting point for the final thesis document.

For the main thesis several research steps were created:

#### **1. AS-IS analysis**

Following the research proposal, which served mainly to identify a suitable research topic and define a sustainable research question, more specific analyses were needed before work on a solution design could start. Specifically the relevant logistics costs in the delivery operation needed to be analysed and understood more carefully. It also led to some additional scoping to the initial research topic. The techniques to derive the costs of handling and warehousing included among other field studies, time-motion studies, interviews and data analysing. For as much as possible triangulation was used to verify the results.

#### **2. Solution design**

After better understanding the processes that take place within the delivery operation, scenarios could be created that served as a basis for the calculations and model that needed to be developed after.

##### **a. Scenario creation**

A cross-docking scenario was agreed upon as the TO-BE state, even though this would be hypothetical. Several (strong) assumptions were needed to allow for such a

scenario, however it is believed that they are not restrictive. Then, multiple scenarios were created to be compared against the cross-docking scenario so as to be able to make fair judgements on which performs best.

b. Cost parameter setting

The only way to know which scenario performs best in terms of cost was to approximate the costs of inventory and material handling the best way as possible, weighted against fair circumstances. Therefore, an important aspect of this research was to derive cost parameters that would reflect ideal circumstances without taking into account any non-optimal performance that could potentially be improved first.

c. Item selection

Due to the scope and time-span of the thesis project, calculations had to be based on a sample of the total population of items within scope. So, a large part of the research effort was to derive a representative item sample set on which conclusions could then be extrapolated, or up scaled, to the entire scope.

d. Modelling

The conceptual model was based around an Excel spread sheet in which calculations are made regarding all relevant cost of inventory, handling and transportation for the selected items. At the core of the inventory calculations, which also trigger the handling operation is the DoBr tool, an Excel based VBA tool developed by Van Donselaar and Broekmeulen (2014).

### 3. Results & Evaluation

To understand better the trade-offs between the different operational logistics costs, the reporting needed to focus on cost transparency. So, several ways of reporting were developed, including sensitivity analyses and potential improvement heuristics. Following a validation effort, the final conclusion (quantitative and qualitative) was drawn and reflected upon.

The main idea behind the thesis was to verify if a cross-docking scenario would be a viable option at all by focusing on cost savings. If so, then this research would be a good starting point for future research on how the actual cross-docking operation could be designed and implemented down to the daily operations. This study therefore can be considered more as a strategic study rather than a tactical or operational one.

All in all, the research methodology used was the regulative cycle, with some allowed iteration, based on Van Strien (1997). This framework is depicted in Figure 9.

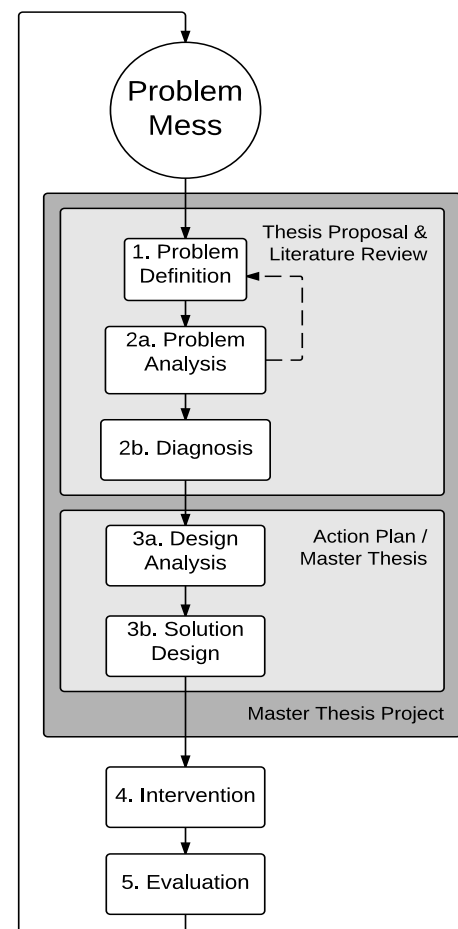


Figure 9 - Business problem solving project design

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## Part II - AS-IS Situation

### 4. Supply Chain

The fulfilment supply chain as provided in Figure 6 is only part of the larger supply chain of the entire company. To understand better the interaction between this fulfilment supply chain and the supply chain that also includes the cash-and-carry wholesale outlets and retail segment, therefore a stylised overview is provided in Figure 10.

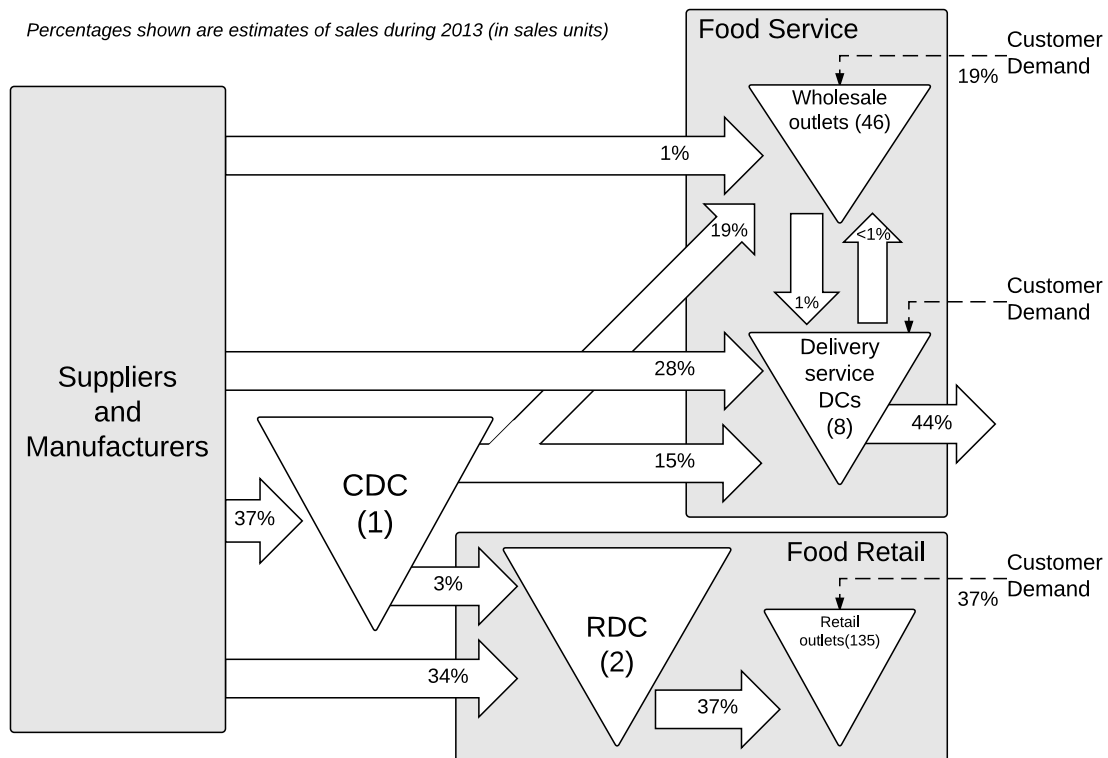


Figure 10 - Complete supply chain

Flows not shown are the transshipments between outlets and/or delivery service DCs (being routed through the CDC) and return flows. The nature of these flows however are not relevant for this research, leaving them out makes Figure 10 more readable too.

#### 4.1 Service stores

One interesting feature of the fulfilment supply chain under study is that a delivery service DC does not hold all 60,000 items that can be ordered by the final customer. Whenever an item is not ordered more than on average two sales units per week in a customer region, then the item will not be put in the assortment of the respective delivery service DC. Instead, it will be sourced from the nearest so-called service store. As Figure 10 showed, this product flow only constitutes about 2% of sales volume that passes through a delivery service DC. Services stores are three out of 46 wholesale outlets that remain open six days a week, hours after closing its doors to the regular shopping visitors. In these stores, order pickers travel through the store on electric pick carts to collect items that are not

in the assortment of a delivery service DC but are still ordered by the customer. Also, the service stores regularly serve as a transshipment location by supplying items that are out-of-stock (OOS) at the delivery service DCs.

Despite the fact that e-fulfilment enables a large freedom in where to source items from and how to allocate inventories (Agatz et al. 2008), each service store has its own set of delivery service DCs assigned to it. The main reason is that this way there is a fixed infrastructure that allows for easier planning, like having a fixed daily transportation schedule between a service store and its associated DCs. Moreover, customer order lead times do not always allow that certain service stores are allocated to delivery service DCs if they are located too far away.

Each delivery service DC receives multiple trailer shipments every day on Monday to Saturday, all of them from the beginning of the evening until a few hours after the customer order cut-off time at 23:59. It allows that the DCs will not have to carry the entire assortment, especially not the slowest moving items. These items will need to be in the stores though, because there the full assortment needs to be available to its visiting customers. Therefore the service stores have a particular value-adding role to the current setup of the distribution network, just like the CDC and delivery service DCs also each have their own role. These are summed in Table 3.

*Table 3 – Value adding roles per echelon in the current setup of the fulfilment supply chain*

CDC	Delivery service DCs	Service Stores
<ul style="list-style-type: none"> <li>• Temporarily stores large purchase orders (for example sent from overseas)</li> <li>• Pools risk over the supplier lead times</li> <li>• Benefits of achieving economies of scale in handling costs and transportation</li> <li>• Minimising inbound handling costs (large orders and/or larger quantities handled by CDC staff)</li> <li>• Minimizing supplier's costs (place larger orders at suppliers, which reduces their handling and transportation costs, which are ultimately reflected in cost price of a product)</li> </ul>	<ul style="list-style-type: none"> <li>• Decreases distance towards the customers: adds responsiveness</li> <li>• Decreases distance towards the customers: decrease last-mile transportation costs</li> <li>• Dedicated fulfilment DCs reduce otherwise cannibalisation from regular store shelves</li> <li>• Local knowledge and knowhow about the final customer</li> <li>• Enables larger volumes than when operating regular stores, or parts of stores for fulfilment; more easily scalable</li> </ul>	<ul style="list-style-type: none"> <li>• Enables customers to order up to 5.5 hours before the potential delivery moment, because some suppliers are not able to achieve this responsiveness so that inventory needs to be sourced from the inventory in a service store (like fish, vegetables, etc.)</li> <li>• Reduces OOS probability towards online customer, thus allowing higher fill rates</li> <li>• It is more cost-effective in terms of transportation costs to supply eight delivery service DCs from three service stores than from one CDC.</li> <li>• Holds assortment otherwise not found in a CDC or delivery service DC</li> <li>• Open six days a week, unlike the CDC. Therefore, it is more aligned with the activities at the delivery service DCs than a CDC</li> <li>• Handles consumer units more easily than a CDC, which makes it more suited to supply slow moving items to the delivery service DCs than the CDC</li> <li>• Lowers the total inventory investment in the fulfilment supply chain since slow-movers for eight regions are pooled into three locations</li> </ul>

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## 4.2 Demand accumulation

The customers can place orders online every day, and have the option to have it delivered already the next day (or later, but not on Sundays). Data analysis over January 2014 showed that about 50% of all orders needed to be delivered the next day, 15% two days after order placement, while the remaining 35% had longer customer lead times. Since the cut-off time is at 23:59, some orders thus need to be ready within a matter of hours because the first city-trailers commence their routes already between 04:00 and 06:00 six days a week. The majority of orders however, 80%, are received before 16:00. Also in terms of sales, 80% of sales units is roughly ordered before 16:00 each day. Appendix B shows an overview how different orders accumulated over an average day in January 2014.

## 5. Inventory Control Policies

The scoped fulfilment supply chain is a multi-echelon structure in which the inventory is controlled using a single echelon forecast-driven (installation stock) approach. This single level approach is not uncommon, since the response of many companies towards the complexity of a multi-echelon supply chain is to treat each level independently (Nahmias, 2009). Accordingly, the delivery service DCs determine their required inventory levels according to the observed demand of the final customers, while the CDC does so according to the (internal) demand it observes from the delivery service DCs. No critical demand information or information about inventory levels is shared between the two levels.

Van Pelt (2014) showed that enabling the CDC to base its decisions on point-of-sales data can potentially greatly reduce the inventory levels at the CDC while maintaining the same fill rates at the delivery service DCs. At this moment however, the current situation remains one in which inventory decisions at the CDC are solely based on the daily demand that is observed from the delivery service DCs. In other words, there is no integrated inventory management approach in the scoped supply chain.

Even though the current inventory management practices in the fulfilment supply chain were already explained by Van Pelt (2014), a quick summary is provided in the following sections.

### 5.1 Automated Ordering

#### 5.1.1 Central distribution centre

At both echelons inventories are periodically reviewed, with each one using a different inventory management system. Both of these systems are automated ordering systems, or ABS in short. At the CDC the reorder levels are (automatically) set using the P1 service level driven software program SLIM4. According to the observed demand over the previous 24 months, for each item every month SLIM4 fits a demand distribution, possibly applies a trend and seasonality pattern and then uses simple exponential smoothing ( $\alpha = 0.2$ ) to create a monthly sales forecast for the upcoming year. The size of a replenishment order is then based on the forecasted demand during the cover period (i.e. lead time + review period ( $R$ )), minimum order quantities and incremental order quantities ( $Q$ ) and an order-up-to level ( $S$ ). Whether to place an order is decided by comparing the inventory position (on hand inventory minus backorders) with the desired order-up-to level, a P1 service level target that determines the safety stock, any possible additional buffers for example to protect against the supplier reliability. The inventory control policy can thus be described as a  $(R, s, S)$  policy with  $MOQ = S -$

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$s + 1$ . But because of the many restrictions regarding the final base replenishment quantities it is better to classify it as  $(R, s, nQ)$ . To achieve the service level target as specified for the CDC, the P1 service level target as set in Slim4 regularly has to be validated against reality.

### **5.1.2 Delivery service DCs**

At the delivery service DCs a different software program is used to control the inventory levels. This program is built in-house and also assumes non-stationary demand and sets the order-up-to levels according to a demand forecast. Demand forecasts are generated per item and per day based on final customer demand from the previous six identical weekdays, excluding any days during which the item was on a promotion. It is thus a 6-week moving average forecast. Whenever the inventory position falls below the reorder level, the ordered amount is then equal to the forecasted demand during the cover period (i.e. lead time + review period), plus additional safety days and logistic days that are specified per item category. Ordered amounts are rounded up to the nearest multiple of the base replenishment quantity that is set manually by an inventory manager. As for the reorder levels, these are also set manually at a value equal to a certain number of weeks of expected average sales. These rules are rather rules of thumb and are different per item category. They vary between one and three weeks.

Because there exists no strict (internal) minimal order quantity, this system can best be described as a  $(R,S)$  policy with a fixed reorder level but with a dynamic order up to level,  $S$ . In many cases however, inventory managers have specified per item a base replenishment quantity in an attempt to either minimise the associated handling operation or to reduce the risk of damage when dealing with individual sales units instead of case packs. This is a common practice in many companies and industries (Van Donselaar & Broekmeulen, 2014), especially in retail supply chain where handling costs can dominate the overall supply chain costs (Van der Vlist, 2007). So, it can be argued that also the inventory control policy at the delivery service DCs is a  $(R,s,nQ)$  policy, but without minimal order quantities. The decision as to what the value of the base replenishment quantity should be however is not easily tractable. It is rather set on gut feeling, while also taking into account that too high values will lead to unnecessary high inventory levels, capacity issues and possibly more inventory shrinkage and outdating.

## **5.2 Review period**

Review periods are set per delivery service DC per item category with the main objective to achieve a stable workload for the order picking process at the CDC. That this strategy is quite effective is shown by Schilders (2015), who plotted the daily average workload distribution (in number of pick orders and number of picked products) per CDC area. He showed that loads are in general relatively stable between the different weekdays.

Review periods are not necessarily equal per item category across all eight delivery service DCs. Periodically there is a negotiation round between the CDC and the DCs during which the settings of the delivery and order schedule are evaluated and possibly adjusted according to local needs. The minimum order frequency for any item delivered from the CDC to a delivery service DC is once per week, with a maximum of five times per week. No orders can be placed on the Saturday (when demand is still satisfied by the delivery service DCs) because the CDC does not operate on this day. On Sunday, there are also no shipments arriving at the delivery service DCs. Delivery service DCs are

closed for about 24 hours per week, starting every Saturday at the end of the afternoon until the Sunday afternoon when the shipments for the Monday need to get prepared again.

### 5.3 Lead time

In the current situation there are two lead times assumed for the delivery service DCs. In general items will always be received two CDC-operating days later after an order is placed. But since the CDC does not operate in the weekend, there are in fact two lead times that the ABS considers. Items ordered on Monday to Wednesday are supplied somewhere during the day exactly two days later. For orders placed on Thursday or Friday, shipments will be received only after the weekend, on Monday and Tuesday the next week, respectively. Thus lead times are either 2 or 3 demand days, depending on the day of order placement. More clarification will be provided in section 6.

The CDC observes lead times that are more uncertain and depend per supplier. SLIM4 however assumes deterministic lead times, ranging between a few days to several weeks or months.

### 5.4 Base replenishment quantities

While analysing the base replenishment quantities as set at the delivery service DCs on 19 May 2015 for 3550 different cases (476 items), it was found that 49.7% of all item-location combinations had a base replenishment quantity set identical to either one case pack, a pallet layer or a full mono pallet. Out of the cases where any of these three values were not equal to one sales unit, another 4.2% of the base replenishment quantities were set equal to one sales unit. The majority of the remaining potential values were set in between any of these four values. Figure 11 provides the complete overview.

If a base replenishment quantity is set at zero, or is missing, then the ABS will automatically substitute these with the value of one sales unit. The best explanation for these missing values and quantities equal to zero can therefore only be poor data management.

When it comes to all the values set in between the values of the size of a case pack, pallet layer or full mono pallet there can be multiple logical reasons. When for example a shelf life is critical and e.g. a pallet layer is too large as a base replenishment quantity, but demand is too high to set Q equal to one case pack, then setting the Q at a multiple of case packs can be more economical. The same could apply to values between a case pack and single sales units. It is however not expected that all values are set in a logical and cost-optimal way because there is no transparency or decision-support for the ABS manager to know the real cost implications of their decisions. Moreover there can be storage capacity constraints.

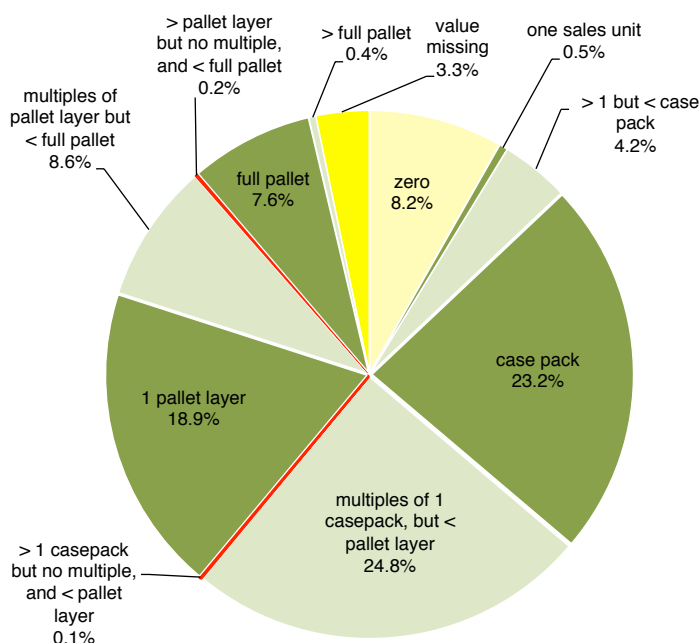


Figure 11 - Current settings for the base replenishment quantities as set in the delivery service DCs



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What is logically not desirable though, is that Qs are larger than a case pack but without it being a multiple of it. This is because it will mean that an order picker at the CDC will have to break open a case pack, which is time consuming and increases the risk of damage of the product throughout the shipping process. The same applies for Qs larger than one pallet layer, but without it being a multiple of it. The problem here is that it is much harder to put another pallet on top of the pallet layer since for this you need an equal surface. In 9 out of 3550 cases this was observed, so the occurrence is not that large (see the red portions in Figure 11).

## 5.5 Service levels & OOS situation

When a customer orders a specific item that cannot become available in time at the respective delivery service DC (so when it also not possible to source it from the service store), usually the customer is contacted personally and a substitute item will be offered. When the customer accepts this offer and receives the amount he ordered, then the service level will be recorded as 100%. Thus, the service level that is measured is equal to fraction of shipped/billed demand met routinely by a delivery service DC, i.e. a modification to the commonly known (P2) fill rate measure. With 'routinely' it means that demand can be met either directly from the shelves of a delivery service DC, or from a cross-dock flow originating from the service store. Whenever demand is not met, typically a lost sales situation is observed.

In this way, the delivery service DCs achieved a service of 98.6% during 2014 for which 98.5% is the target. But since the measured target service levels are already corrected for items that were not delivered, the obtained service levels throughout 2014 are inevitably an overestimation of the real fill rate,  $\beta$ . Thus, in reality the actual fill rate in 2014 would have been lower than 98.6%.

Also for the service that the CDC provides to the delivery service DCs there is service measure defined, which is equal to definition provided before. Also in this situation a lost sales environment is observed because a delivery service DC will just have to place a new order whenever the CDC could not fulfil a replenishment order. As Van Pelt (2014) suggests, the CDC provided a service of 96.4% towards the delivery service DCs in 2013, where the target is 96.5%.

It is difficult to tell how the measured service targets are translated into fill rates, because original demand for items that were substituted seems to not be recorded. After a consultation with certain inventory managers, it was suggested that the used service measure would not differ from a fill rate measure too much. It can be argued though, based on standard inventory management theory, that a slight deviation in a service level target can have disproportional large effects on the necessary inventory levels. It can be expected that when using fill rate targets equal to the targets used in practice, the calculated inventory levels will be an overestimation to the reality.

## 6. Order picking at the CDC

The CDC can be split up into eight different DCs, each storing different sets of item categories. They are: Food1, Food2, Food3, Non Food, Fresh Food, Frozen Food, Wine & Distilled, and Bulk. The CDC supplies almost 60,000 different items to the delivery service DCs, cash-and-carry wholesale outlets and two regional retail DCs. What concerns the case of supplying the delivery service DCs, an explanation is given next:



Whenever an order is placed at the CDC by a delivery service DC (Monday to Friday at 22:00) for a specific item, this order is then received and planned the next morning so that it can be picked at the corresponding CDC area on that day. Shipment towards the delivery service DCs will then take place the day after, mostly in the early mornings. Because the CDC does not operate on the weekends, orders placed on either Thursday or Friday are delivered later than those placed on the other three days. This is shown in Figure 12.

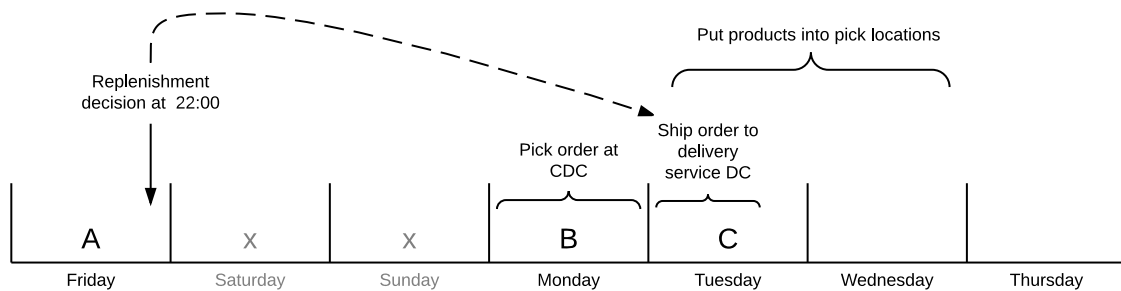


Figure 12 – The process of the delivery service DC placing orders at the CDC, and subsequent picking and replenishment

Towards the delivery service DCs there are only pallet shipments with products (often in unopened case packs) stacked either on EURO (1000x800mm) or CHEP (1000x1200mm) pallets. The type of pallet depends on the CDC area where the items are stored.

The picking process can only start after a planner first takes the replenishment orders placed by a delivery service DC and combines them to create picking orders per CDC area. For this, the largest replenishment order (in terms of volume) is taken and combined with subsequent ones until the respective pallet on which the items will need to be put by a picker is considered full. This way, each replenishment order to be picked and put on a pallet is known as an order line. For each CDC area there is a target defined that tells the planner what the available capacity of a pallet is in terms of the total litres of its content. For this, the multiplication of the length, height and width of one sales unit of an item is used. By maximising the total volume of all content on a pallet, a shipment towards as delivery service DC can be achieved using the minimum number of pallet positions in a trailer. This could for example potentially free up space so that promotion pallets (i.e. with items that will be on promotion soon) can be shipped in advance to the delivery service DCs without needing an extra ride for it. This way, achieved utilisation rates of trailers are high, in the region of 90% on average.

Once the picking orders are created, they can be picked by order pickers who travel by electric pick carts through the different CDC areas. The picking process is largely automated by a PickArt system. An explanation of several PickArt systems is found in Appendix C. Each cart can carry two pallets, hence it is possible to create batches of two pallets to minimise the total navigation time per picking order. Since the CDC does not only supply the delivery service DCs, but also the wholesale outlets and the regional retail DCs, there are multiple combinations possible for the pallets carried on a electric car. When batched, these are  $3^2 = 9$  different combinations.

In the current actual situation however, there are not always two pallets on an electric cart. In some cases there are last-minute picking orders that need to be finished in a very short time. In those cases it is preferred to send two different pickers, each with just one pallet, through the DC areas because

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this way the total picking lead time per picking order is minimized. Also, more importantly, by the end of the day when most of the picking orders have been finished already, there are leftover orders or replenishment orders that are more difficult to combine with others. Potentially they will also not fill up an entire pallet. In these cases it is possible that pick carts will have to be sent into the warehouse with just one pallet at a time.

The picking time of a batch or single pallet at the CDC can be split up into four different elements:

1. Loading time, i.e. the time needed to load empty pallets on the picking carts
2. Navigation time, i.e. the time between the confirmation that an item has been picked and subsequently confirming that the order picker is at the location of the next order line.
3. Picking time, i.e. the time between the moments that the picker confirms he is at the right location until the picker confirms he has placed the products on the pallet
4. Unloading time, i.e. the time that runs from having picked the last order line until the moment the pallets are unloaded at the right place on the expedition area.

The combination of order picking time and navigation time is called the collection time and is largely influenced by the way picking orders are created and subsequently batched. Schilders (2015) studied among others the effects of changing the algorithm in which the batches are created and found that significant savings (approx. 22%) can be achieved in the navigation time. Based on his analysis of the wine and distilled DC he found that at the moment about 41% of collection time can be attributed to navigation and 59% to picking. This way, he suggested that the potential savings of the average collection time at the wine and distilled DC can be  $1 - (0.41 * (1 - .22) + 0.59) = 9.02\%$ .

Productivity is inversely proportional to the collection time. It can be measured with different KPIs, for example the number of sales units (Dutch: colli) picked by an employee per hour or the number of order lines picked per hour. Both methods have their own benefits but also shortcomings. Consider for example the KPI sales units/hour. Whenever a pallet is planned with items that are only hand picked in case packs, like wine boxes (in general there are on average 6 sales units (Dutch: colli) in a case pack), then one could image that the KPI would be much higher than when picking for example individual 10 kg buckets of mayonnaise. Also, when an order line is large, it will take much longer to complete than it is to complete a large number of order lines that only consist of one product. In these cases it is very difficult to fairly compare picking productivity, no matter which of the two KPIs one would consider. In other words, the productivity KPIs for the picking of different item groups are to some degree incommensurable.

One way this is overcome is by the fact that there are different DCs (Food1, Food2, etc.). As these DCs combine product groups with the same characteristics it can be seen that over the long term a part of these differences in KPI performance are levelled out within each DC. Nonetheless, there still exists a large degree of contingency when it comes to picking productivity.

This can also be seen in Figure 13, where a histogram of the pick productivity in terms of order lines per hour is depicted for the Food1 DC. The data is based on 541 batches and only those batches where there are two pallets to be shipped towards a delivery service DC, picked in March 2015. Throughout this month there were no holidays and so it is considered a representative month to analyse, also because an update of the picking software had been made just before.

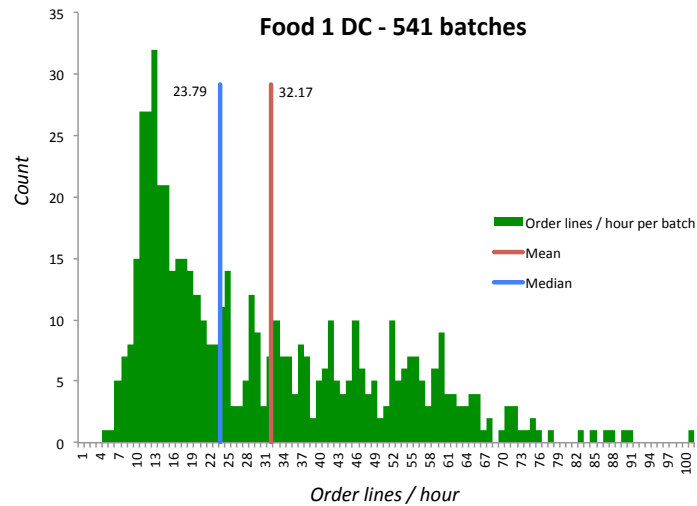


Figure 13 - Picking productivity at the Food1 DC

What can be seen is that on average 32.17 order lines are picked per hour, but that the distribution is positively skewed. This means that the majority of batches are picked at a lower productivity rate with a right-sided tail with batches with much better productivity rates. A complete overview for all CDC areas can be found in Appendix D.

An explanation for the large share of batches with a lower-than-average productivity rate could be due to the way these batches are created, for example because by the end of the day it is more difficult to create optimal batches from leftover orders. There are however more potential reasons, some of which can still be addressed by better human decision and planning. Schilders (2015) showed that at the moment, the CDC is in a non-optimal state what concerns the picking productivity. He suggested (1) to implement a new batching algorithm, (2) adjust the dock times and (3) align product groups between stores in the same dock times. With these implementations, which he argues will not affect the ordering and delivery schedule for the delivery service DCs, this translates into an increase of the productivity rate equal to at least  $\frac{1}{1-0.0902} = 0.099 = 9.9\%$ . Schilders (2015) also stated how this improvement is only the minimum improvement because for some adjustments the benefits are difficult to quantify and were thus not included in his study. Also, he states that the results can easily be extrapolated to the other CDC areas since the wine and distilled CDC area is a relatively simple one with few aisles and low number of product groups.

What was also learned from analysing the picking productivities is that orders from the delivery service DCs are picked at a lower productivity rate than those for the cash-and-carry wholesale outlets. The difference can sometimes be up to 50%. This can be explained by the fact that delivery service DCs place larger orders than the wholesale outlets because shelf capacity is less of a restriction. Moreover, for some items they might also sell much higher numbers so that the replenishment quantity is naturally larger too. Schilders (2015) showed that the picking time can best be predicted by the number of products in a batch, where a larger order line size is associated with an increase in the picking time. Another factor to take into consideration is that only orders for delivery service DCs occasionally require empty pallets to be added in between layers with each new order line. This requires some extra time for an order picker at the CDC to search for an available pallet and

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build up the pallet, hence explaining the lower picking productivity for orders placed by delivery service DCs.

The latter also explains why at the moment it is hard to quantify the difference in productivity rate between the picking of pallet layers and mixed pallets since these are all intertwined. There is no data easily available to tell whether a pick order constituted pallet layers or not. In many occasions the order picker can decide on the spot whether to add a pallet in between or not. For this reason, it cannot be guaranteed that whenever a order line is the size of exactly one pallet layer, that it will be delivered at the delivery service DC as a pallet layer. As we will see next, extra steps are needed at the delivery service DCs to create the final pallet layers.

## **7. Shelf replenishment at the delivery service DCs**

Once the pallets are delivered to the delivery service DCs, the process of replenishment will start. Upon receipt at the inbound dock, the shipment will first be organised in three different shipment categories: the mixed pallets, pallet layers and full pallets. For each, different steps are needed before eventually the goods will be available at the associated pick location. The exact process is provided in Appendix E.

Since the replenishment process is not instructed by the PickArt system but rather based on the decisions made on the spot by a replenishment employee, there is no reliable data about any replenishment activities in the delivery service DCs. Moreover, the process is quite sensitive to disturbances and so if there were any data available, it should be exercised with caution. For these reasons a study was performed by measuring in different delivery service DCs and different areas the time needed to replenish the shipments received from the CDC. In the following sections the results of these field studies will be discussed.

### **7.1 Mixed pallets**

Mixed pallets are heterogeneous pallets with multiple order lines stacked in an arbitrary way without any extra pallets in between different order lines. They are mostly created when orders were placed in quantities other than those equal to the exact quantity that fits on either one pallet layer or on a full mono pallet. Take the example when 12 sales units of an item fit on a pallet layer and the base replenishment quantity at a delivery service DCs for this item is set at 14. If an order is finally placed of size 14, then the software at the CDC does not recognise the multiple of 12 and will plan the replenishment order as a mixed pallet. This way, the 14 sales units will all be put on a mixed pallet and not for example be shipped as one pallet layer and the remaining two units on a mixed pallet.

Replenishing a mixed pallet is seen as a labour intensive activity because it involves significant travel time but also significant replenishing time as each handling unit needs to be moved by hand in a FIFO manner.

The standard replenishment process for mixed pallets, under normal conditions, can be described as three sequential steps. More detailed information is found in Appendix x:

1. Choose an item on the pallet, scan its barcode and travel to its associated pick location

2. Verify the expiry dates of the products already in the pick location and record the expiry date of the respective products on the mixed pallet as well as its quantity
3. Start the replenishment of the pick location in a FIFO manner. When needed, physically remove all the products with a shorter shelf life from the shelf and place back once the products from the mixed pallet are put in the pick location
4. Back to step 1 until no more items remain on the pallet

Time-motion studies were performed in two different areas: groceries (Dutch: DKW) and in the temperature-controlled cool zone where perishable items are stored (Dutch: Koeling). With a stopwatch hundreds of order lines on 10 different mixed pallets were measured and translated into productivity rates (order lines / hour). For each area the best and worst performing mixed pallets were not included in the calculation of the average productivity. In Figure 14 and Figure 15 these pallets are marked in grey.

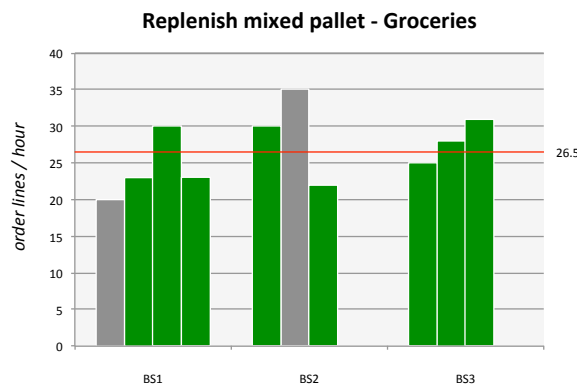


Figure 14 - Replenishment productivity for groceries on mixed pallets

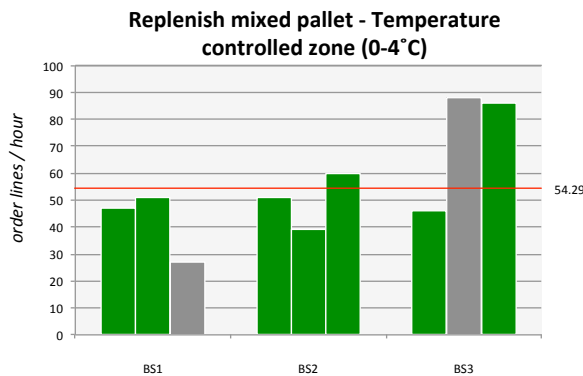


Figure 15 - Replenishment productivity for fresh food on mixed pallets

What the results show is that per mixed pallet per DC area, the productivity rates are not very different and taking the average of the KPI 'order lines per hour' seems an appropriate method.

It could be concluded that on average the replenishment of groceries on mixed pallets has a productivity rate of 26.5 order lines / hour, and for fresh food this is about 54 order lines / hour. For replenishment in the frozen food area, the productivity assumedly lays somewhere in between these two values.

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## 7.2 Pallet layers and full mono pallets

In two different warehouses the activities needed to replenish pallets and pallet layers were observed on different days. The basic process can be described as follows:

1. Create and organise pallet layers
  - a. If a pallet concerns a stack of pallet layers of different items, then first these pallet layers need to be restacked so that they are sorted roughly in per same isle in the delivery service DC. The underlying logic is that it will then involve less navigation time for the reach truck if it can bring along multiple pallets at the same time.
  - b. Whenever a pallet layer contains multiple items, empty pallets need to be added to put each item on its own pallet. The surface of each pallet must be equal so that another pallet can be placed on top.
2. Travel and put pallet in bulk location
  - a. Once the pallet layers are created and organised, they can be picked up in a batch by a reach truck and driven to the pick location of the item that lies on top. Then, if the pick location is almost empty the (contents of the) pallet can be placed in the pick location. If it however takes significant replenishment time because the pick location is not entirely empty yet, it is put away in a bulk location in proximity of the pick location.
  - b. Step 2.a is repeated until there are no more pallet layers left. After, the reach truck will go back to the inbound dock to pick up another batch.
3. Replenish pick location from bulk location
  - a. At an arbitrary moment some time later, as the pick location will eventually become empty, a truck driver will automatically receive a notification to replenish the pick location on short notice. It will thus have to search for the pallet in the bulk location with the shortest remaining shelf life and replenish the pick location with the contents of this pallet.

The steps above are also shown in the process diagram in Appendix E. The time needed to perform the steps above were measured and converted into the KPI order lines per hour. The results can be found in Appendix E too.

The time measurements proved to be very stable, so it was concluded that the productivity for replenishing an order line on a pallet layer is depending on all three steps. Summing the time needed for all three steps and converting it into a productivity rate, this turned out to be equal to 8.34 order lines per hour. For full mono pallets no creation or organisation of pallet layers (i.e. step 1) is needed, so only step 2 and 3 remain, meaning that 11.18 full mono pallets can be replenished per hour.

These KPIs are in general the same in every warehouse location because the process is exactly similar because the handling units are uniform and warehouse distances that are travelled are roughly equal for every reach truck driver because they all operate in their own warehouse area, all roughly similar sized areas.

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## 8. Assortment of a Delivery Service DC

For various reasons, each of the eight delivery service DCs has a unique assortment. Throughout 2014, without taking into account data from the two delivery service DCs that merged during 2014, the eight delivery service DCs sold a maximum of between 6,452 and 15,139 different items from their assortment during one week (incl. client-only items), the average being 10,767 items. Though this is not an exact measure of the assortment, it can still give a good indication. The difference between the assortment sizes of delivery service DCs can be explained by the following factors:

- demand patterns observed in the region
- so-called national accounts, or client-only inventory
- direct deliveries from suppliers
- available space in the warehouse

### 8.1.1 Demand patterns

Demand patterns in relation to the assortment choices made at the delivery service DC can be broken down into two elements: (1) whether there is demand for a certain item at all, (2) if there is demand, how much of it.

Some items are considered regional as they are only sold in one or two specific regions; they will not be in the assortment of most other delivery service DCs. In a similar manner there are also items perhaps not strictly regional but where demand is so occasional that not in every DC these are held in the assortment but come from the service stores whenever they are ordered by a customer. What also happens often is that suppliers occasionally discontinue some of their items (and so demand stops). These items are either scrapped completely or replaced by existing items (demand increases) or new items (demand starts).

If there is demand, the average demand in sales units dictates whether or not the item is included in the assortment of the delivery service DC. The underlying reason is that in terms of handling it is more cost-effective if items are not sourced from the service store since picking items here is typically more costly. The rule of thumb that is used across all delivery service DCs is that once demand for an item exceeds two sales units per week on average, it will be put in the assortment of the delivery service DC. There are however many exceptions to this rule. Consider the case when an item is included into the assortment. This would automatically mean that it would be taken out of the service flow (from the service store). This service store will inevitably see its inventory turnover ratio for this specific item drop significantly, which could be a problem to guarantee the freshness to its visiting customers. Especially for items with a critical shelf life this is the case, so in reality some items are still included in the service flow even though it might be more cost-effective in terms of handling if it is not.

The assortment of items in the service flows is not fixed and changes throughout the year. The transshipments from the service stores are continuously monitored so as to minimize its total volume. For this reason it can happen that when demand for a specific item increases it will be included in the assortment of the delivery service DC and removed from the service flow (but also vice versa).

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### **8.1.2 National accounts**

For some clients that are operating across The Netherlands, items are exclusive supplied from the delivery service DCs. In some cases clients even put away their entire inventory in the delivery service DCs while remaining the inventory owner and thus outsource the entire distribution operation. These national accounts can have a big influence on the assortment of a delivery service DC. If for example a large restaurant chain sources all its items from one particular delivery service DC, a large portion of the total assortment in that delivery service DC can be assigned to only that customer. This inventory is called client-only, sometimes referred to as national account.

### **8.1.3 Direct deliveries**

For some items it is undesirable if they were to be supplied by the CDC. Especially items that represent a high share of sales volume in that region are therefore directly supplied by the supplier, skipping the CDC echelon. This will take away a large burden on the transportation between the CDC and is logically more cost-effective.

For some suppliers though, the direct deliveries do not only include high volume items. It can be possible that also more slow-moving items are supplied directly to the delivery service DC because the supplier does not wish to visit both the CDC and the delivery service DC to deliver at each location different items. In other words, also the suppliers seek economies of scale and can combine their direct deliveries of high volume items with other, lower volume items. All these items will thus inevitably have to be included in the assortment of the delivery service DC .

### **8.1.4 Available space**

Delivery service DCs vary in the amount of space they have available in their warehousing operation. It could be possible for example that a delivery service DC wishes to include more items in their assortment, but due to the lack of space it is still taken from the service flow. Especially in the temperature-controlled areas this could be an issue. Generally speaking it can be argued that the more space there is available in a delivery service DC, the larger the assortment can be.



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## Part III – Solution Design

### 9. Scenarios

By comparing different scenarios, more insight can be gathered regarding the trade-offs between the costs of handling, inventory and transportation in the current fulfilment supply chain and how they hold against a cross-docking scenario. Moreover, it allows not only to model the current situation but also to optimise it for as far as possible so as to make a more fair comparison between the different options. The main idea is to find an optimal representation of the current situation and compare it with the to-be design. One underlying assumption across all scenarios is that the systems considered are uncapacitated.

In this chapter 5 scenarios are explained, with scenario 1-4 modelling the current situations under different optimisation tactics and scenario 5 being the to-be scenario.

#### 9.1 Scenario 1 – Minimal inventory levels

“Achieve minimal inventory holding costs at the CDC and delivery service DCs, given the current ABS settings except for the reorder levels”

This scenario is exactly equal to the benchmark scenario as used by Van Pelt (2014). The only difference will be that in the case of internal lead times this scenario will assume shorter and deterministic lead times. This will be explained better in section 10.2.2. In accordance with Van Pelt (2014), the objective function for scenario 1 was defined as follows:

**Objective function:**

Minimise  $\sum_d \sum_i I_i^d$

Constrained by the target fill rate, where

$I_i^d$  := Yearly inventory holding costs for item  $i$  in location  $d$   
 $d$  := all inventory holding locations,  $d \in \{1,2, \dots, 8, CDC\}$   
 $i$  := all  $n$  items under consideration,  $i \in \{1,2, \dots, n\}$

The current settings for the base replenishment quantities in all inventory-holding location for all items will be used, as well as the entire current order- and delivery schedule, with lead times corrected to reflect a state that is argued to be possible under the current schedule (this is later explained in 10.2.2). Assumed is that the inventory policy can be represented with a  $(R, s, nQ)$  inventory policy tool, and that it is functioning in an optimal way so that the reorder levels can be set cost-optimally with the service level target as a constraint. On top, the 6-week moving average forecast as used by the ABS will be incorporated in the forecast error.

Assuming an optimally functioning ABS is needed because in the actual current situation the inventory managers account for a significant amount of order advice adaptations, for example when managers modify the inventory control parameters as well as the advices themselves. It is believed

that not in all cases these adaptations are cost optimal. On top, reorder levels at the delivery service DCs are not set according to statistical analysis of the demand variability and target service levels, but rather on rules of thumb and an arbitrary validation against the reality. So, it can be argued that in the current situation there is still potential for improvement in setting better reorder levels.

## 9.2 Scenario 2 – Minimal costs for inventory and handling

“Set optimal reorder levels at the CDC using current settings, and set optimal reorder levels at the delivery service DCs using different Qs and then choose Q (i.e. EOQ) that minimises the sum of the relevant handling costs at the CDC and delivery service DCs, and inventory costs at the delivery service DCs”

Scenario 2 will function under the same assumptions of scenario 1, except that the current settings for the base replenishment quantities at the delivery service DCs will not be used anymore.

### **Objective function:**

$$\text{Minimise } \sum_i I_i^{CDC} + \sum_{d=1}^8 \sum_i I_i^d(Q) + H_i^{CDC} + H_i^{DC}(Q)$$

Constrained by the target fill rate, where

$$\begin{aligned} H_i^{CDC} &:= \text{the yearly costs of the picking of replenishment orders for item } i \text{ at} \\ &\text{the CDC} \\ H_i^{DC}(Q) &:= \text{the sum over all eight delivery service DCs of the yearly costs of} \\ &\text{replenishing item } i, \text{ which depends on } Q. \end{aligned}$$

As was stated before, the base replenishment quantities affect in a great way the handling efficiencies in a (retail) supply chain. Items are often packaged in case packs instead of individual products, and so ordering in multiples of case packs can greatly reduce the handling cost in an operation. The effort of picking up one product is equal to picking up one box or tray of multiple ones and so higher efficiency can be achieved by setting the base replenishment quantities right. The same applies to pallet layers as opposed to multiple case packs on a mixed pallet. At the moment the ABS managers at the delivery service DCs can set the base replenishment quantities arbitrarily and so it is hypothesised that current values are set non-optimal because an integrated approach is missing. In other words: ABS does not function such that the sum of costs of handling and holding of inventory are minimised.

As a way of optimising the current situation at the company, in scenario 2 therefore a more ‘synchronized’ supply chain is considered. The decision of which base replenishment quantity is optimal (i.e. EOQ) in terms of the combined costs of inventory at the delivery service DCs and relevant handling costs at both the CDC and delivery service DC is added to the calculations as performed in scenario 1. All other settings are the same as in scenario 1.

After analysing the current base replenishment quantities (see Figure 11), the following potential EOQs for the delivery service DCs were defined:

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- **A single sales unit** - included because they might apply to items with low demand and/or critical shelf life. When for a specific item a case pack is already equal to a single sales unit, then this option can be considered non-existing.
  - **A case pack** - included because as a handling unit it requires less time to handle a case pack than handling individual, single sales units (only if these two are different).
  - **Multiples of case packs** - a quarter pallet layer and half a pallet layer. These EOQs are added because in some cases it might be more cost-effective to place larger replenishment orders than single case packs.
  - **A pallet layer**
  - **Two pallet layers** – as a means to provide an option between a pallet layer and full pallet (in case a full mono pallet is not equal to two pallet layers)
  - **A full mono pallet**
  - **Two full mono pallets**

Naturally, only base replenishment quantities are considered that are feasible with respect to shelf lives. An explanation:

The exact way of telling if a base replenishment quantity can be considered, is to allow that the base replenishment quantity always sells out within the shelf life of the product. In reality this is not the entire shelf life provided by the supplier, but rather a fraction because first of all some shelf life is also inevitably taken up by inventory days at the different echelons. Second, the company uses several rules of thumb to set norms that still guarantee a certain shelf life to the final customer. This is different than for example a supermarket where items can still be sold on the day before expiry (potentially with a discount).

The norms that exist in the current scoped supply chain about shelf lives is that a maximum of one third of shelf life (as guaranteed by the supplier or manufacturer when it is delivered to the CDC) may be taken up by the inventory days at the CDC and the rest should be ‘given’ to the delivery service DCs. Thus, when you take the guaranteed (i.e. the minimum remaining) product lifetime upon entering the stock point at the CDC, two thirds of this lifetime should remain when it enters the stock point at the delivery service DCs. So, for items with a guarantee of 21 days, the delivery service DCs should always receive products with a shelf life of at least 14 days (and for any product the lower bound is 7 days).

As another rule of thumb, the delivery service DC may take up maximum half of this shelf life and the rest should be offered to its final customers. So, 7 days may be taken up by inventory days and 7 are for the customer. So, with respect to shelf life feasibility the total demand during this period should always be larger than the base replenishment quantity of that item in that location. This is an appropriate method whenever items are taken out of the stock point in a FIFO manner, which in reality is indeed the norm.

Using all the above, it should hold that:

$$\frac{Q_i^d}{\bar{x}_i^d} < shelf\ life\ norm$$

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Where  $Q_i^d$  is the base replenishment quantity for item  $i$  as set in location  $d$  and  $\bar{x}_i^d$  is equal to the sample mean of daily demand for item  $i$  as observed at location  $d$ .

The shelf life norm is defined by applying the rules of thumb from the organisation to the shelf life guarantee by the supplier or manufacturer for item  $i$ ,  $s_i$ , such that:

$$\text{shelf life norm} = \left( s_i * \frac{2}{3} \right) * \frac{1}{2} = \frac{s_i}{3}$$

Whenever none of the candidate Qs are feasible, the model will force the value for Q to be the lowest possible value, which is equal to one sales unit. All shelf life norms are naturally corrected for Sundays.

### 9.3 Scenario 3 – Synchronised supply chain

“Equal to scenario 2 but with central demand pooling at the CDC, implying that the CDC will have to operate six days a week”

This scenario comes closest to what can be considered a synchronised supply chain, though still many other improvements can be imagined. Scenario 3 uses the same logic as scenario 2, but it also applies demand pooling at the CDC. This means that instead of the CDC observing the replenishment orders as the demand from the downstream inventory locations, the CDC now observes the daily point-of-sales demand for each item per delivery service DC. When these are summed together, it becomes the new daily demand that the CDC observes. The CDC will still apply the installation stock policy but it will observe much less volatile demand and can thus significantly bring down its safety stocks. So, in terms of costs the only difference between the results of scenario 2 and 3 will be the inventory costs at the CDC.

Analysis shows that the current (not weighted) average coefficient of variation (CV) observed by the CDC is 2.01 while in the pooled scenario this is reduced to 0.98. Only in 2 out of 476 cases the CV for the pooled scenario turned out higher than the current actual situation. More information on this is explained later in section 10.8 and Appendix F and G.

Since demand pooling does imply that the CDC will have to make replenishment decisions six days per week, this will be a hypothetical scenario and only serves as reference. What can also be is that point of sales data from the Saturday will be added to the Monday, so that the CDC can still operate on five days per week. However scenario 3 is set up with the assumption that the CDC can make replenishment decisions 6 times a week, and also receive goods 6 times a week. Therefore, as far as the CDC inventory is concerned, it can be considered exactly similar to the demand pooling scenario of Van Pelt (2014).

Another crucial point that prevents scenario 3 to be the benchmark scenario for this research is that under the demand pooling scenario there is still uncertainty as to how to allocate the shipments among all eight delivery service DCs. As long as no information about inventory levels is also shared (which approaches a multi-echelon system), the demand pooling scenario still needs many answers to

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important questions. For this reason, scenario 3 will serve only as a reference purpose since the inclusion of a multi-echelon approach is out of scope for this research. Van Pelt (2014) can be considered a good reference.

#### **9.4 Scenario 4 – Synchronised supply chain & shorter lead times and review periods**

“Equal to scenario 3, but under the condition that lead times and review periods at the delivery service DCs are exactly one day”

Another scenario to take into account is when the delivery service DCs will have no restriction in the review moments and can place orders each day they operate, especially because under scenario 4 the CDC will have to operate six days a week anyway. Also, this would mean that the delivery service DCs can then also always receive them exactly two working days later, i.e. also receiving replenishments on Saturdays.

The expectation is that inventory levels will decrease because more review moments will lead to more order moments, which in turn will lead to smaller replenishment quantities per order moment and thus lower average inventory levels. But with more order moments also the handling operations will be repeated more often and thus will lead to an increase in handling costs. Also, it can be expected that there will be a negative effect on the handling efficiencies in the CDC in terms of picking because there will be more navigation and scanning time per pick order, plus there is less potential to create efficient picking batches. Last, also it can be argued that an extra trailer ride is needed on the Saturday but it can also be argued that this will not lead to increase transportation costs when it means that one of the shipments during the normal 5-day week can be saved.

Thus, if scenario 4 is more cost efficient than the first three scenarios still needs to be seen. The assumption used however, is that picking efficiencies at the CDC will be equal across all scenarios and no extra transportation costs can be expected for scenario 4. This way, if the reductions in inventory are not enough to account for the increase in the expected handling, then scenario 4 can never possibly be the best candidate to compare against the to-be scenario. So, scenario 4 can be considered a potential improvement though the extensive assumptions needed make this scenario more of a scenario for future reference, just like scenario 3.

#### **9.5 Scenario 5 – Cross-docking**

“A hypothetical central warehouse where customer orders are picked and shipped to the current delivery service DCs in a cross-dock form, using these warehouses only as a transportation hub for these items”

Scenario 5 will reflect the to-be scenario in which the items in scope are not stored at any of the delivery service DCs anymore, but will be located only at a hypothetical central warehouse, located in the same location as where the current CDC resides. In this location all customer-specific orders will be picked (for the scoped items) per warehouse area for optimal batching potential, put in customer-specific crates or on roll containers and delivered to the delivery service DCs every day (throughout

the day) in a cross-dock form, already sorted on a pallet for as much as possible per route. Once at the cross-dock platform, the crates will have to be combined with the items that have already been picked at the location itself or have come from other cross-dock flows.

Scenario 5 is depicted for two delivery service DCs in Figure 16, but only for the case of crates. For roll containers the situation will be similar, except that they are obviously not transported on pallets.

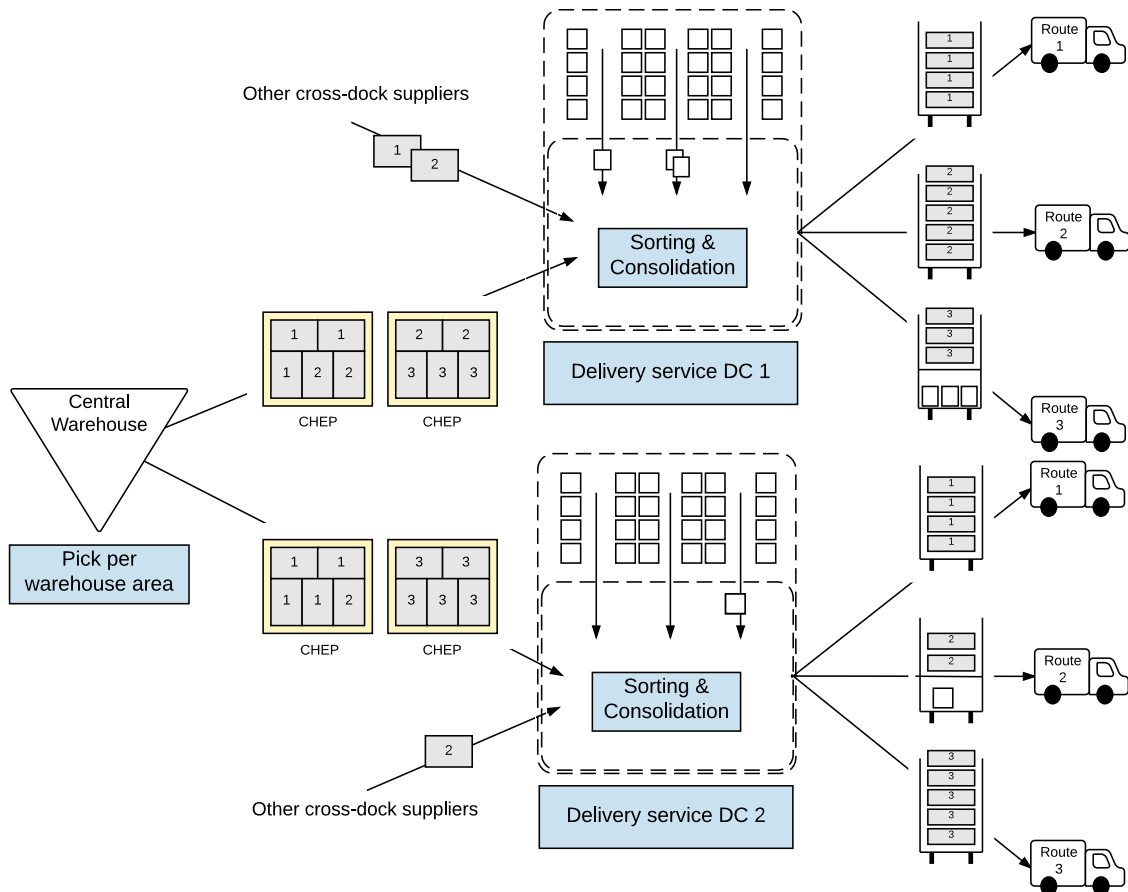


Figure 16 - Cross-dock scenario for the case of client specific customer crates

For the proposed design, crates are considered the most ideal form of transportation for low-volume items since they can be shipped towards the delivery service DCs on CHEP pallets, and thus be stacked higher than what could be achieved with roll containers, thus utilising the space in a trailer better. For high volume items roll containers might be better since they are associated with less handling activities. For the calculation purposes though, the question whether a roll container or crate is used will be derived from current practices (see section 10.3).

The main benefit of a cross-docking scenario is that one echelon will be completely removed from the equation, hence also the associated handling costs that were described in chapters 6 and 7. By keeping only one echelon, under this scenario there will be the effect of pooling. It is expected that this will decrease the supply chain wide inventory levels but also increase the volumes that need to be shipped towards the delivery service DCs. The reason is that shipments will consist of crates (with added air) stacked on pallets instead of pallets with stacked case packs, and also some client-specific roll

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containers with items that don't fit in a crate. So, inevitably the cross-dock shipments will have a larger volume. Also, since the shipments to the delivery service DCs will still need to be prepared, there will be some extra handling activities needed at the central warehouse to organise the crates and roll containers such that when they arrive at the cross-docking locations they can be efficiently distributed over the right routes with minimal time. These will be explained in section 10.6.

A few assumptions were needed to allow for the calculations in scenario 5:

1. The time at which the cross-dock shipments arrive at the delivery service DCs does not conflict with the customer order lead times and the deadline at which the routes to the final customers will need to leave the delivery service DCs. This is true as long as the last trailer leaves the central warehouse in time so as to arrive before approximately 3:30AM at the delivery service DC.
2. The central warehouse would operate under similar agreements with the suppliers as the CDC is at the moment, but for a six-day week. So the order- and delivery schedule of the CDC in the pooled demand scenario 3 and 4 could be applied to the central warehouse as well.
3. The picking efficiency of final customer orders in the hypothetical central warehouse was assumed equal to the current average picking efficiency across the eight delivery service DCs. This means that for the further calculations in the model they would become irrelevant and so were not included. This assumption was derived from the following three sub-assumptions:
  - a. The picking efficiency will decrease since the warehouse will inevitably be physically larger than any of the current delivery service DCs. Thus, on average more navigation time can be expected per picking order than under scenario 1-4.
  - b. Since more batches will be picked in one location, it allows for more effective batching of pick orders and thus a higher picking efficiency can be achieved than under scenario 1-4.
  - c. Following the two sub-assumptions above, it is assumed that these two will balance each other out so that there will be no bottom line effect.
4. It is assumed that whenever a finished pick order arrives at the cross dock platform in a delivery service DC, there is no difference in terms of further activities needed if this order arrived by a truck (in scenario 5) compared to when it arrived from a pick cart (like is the case in scenario 1-4). Thus, from the moment a truck arrives with cross-dock orders at a delivery service DC, all subsequent activities are irrelevant and so not included in the model. This assumption was based on a visit to one of the delivery service DCs where the cross-docking process was observed for one night.

The benefits of a cross-docking scenario are not only that the costs of inventory and handling will be reduced. By scrapping eight downstream inventory locations and merging them into one location, it means that the inventory turnover ratio will increase as well, and so the shelf life offered towards the customer can potentially be improved. In the current situation this is already observed at the CDC area 'Fresh Food', where certain items are also being cross-docked using a pick-to-zero methodology (see Appendix C). On top, the less handling involved for a product, the lower the potential damage that can be inflicted upon it. One could imagine that every time a product, case pack or pallet is picked up there is a chance it may fall, gets deformed, scratched, damaged, etc. Therefore the cross-docking scenario in terms of product quality is the preferred one.



There are multiple reasons why it was chosen to only model the situation where an item is taken out of all the delivery service DCs' inventories, and not for example leave two or three delivery service DCs in the current situation. First of all it would only increase the complexity of the supply chain even more. More importantly though, to allow individual decisions for all eight delivery service DCS whether or not to cross dock their items, would mean that  $2^8 = 256$  different scenarios would have to be calculated, with each of them having different pooled demand data sets. By only allowing for a complete cross-docking scenario, only one version of pooled demand needs to be created (which is already quite some work on its own). Moreover, when only for example two locations decide to cross-dock, the pooling effect would be much less then when all eight will do it. Last, as demand can always change or shift between customer regions it will not make sense to choose for 1 out 256 cross-dock scenarios because it can already be non-optimal as soon as some demand figures change.

## 9.6 Summary

For a better understanding, Table 4 provides a short overview of the differences between the scenarios.

Table 4 - Overview scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Reorder levels (CDC, central warehouse in cross dock scenario & eight delivery service DCs)	Decided by tool	Decided by tool	Decided by tool	Decided by tool	Decided by tool
Demand observed by CDC or central warehouse	Replenishment orders placed by delivery service DCs	Replenishment orders placed by delivery service DCs	Pooled daily demand from final customers	Pooled daily demand from final customers	Pooled daily demand from final customers
Base replenishment quantities (CDC)	Set by supplier (exogenous)	Set by supplier (exogenous)	Set by supplier (exogenous)	Set by supplier (exogenous)	Set by supplier (exogenous)
Base replenishment quantities (delivery service DCs)	As currently used by inventory managers	EOQ	EOQ	EOQ	-
Lead time between CDC and delivery service DCs	Derived from current ordering and delivery schedule	Derived from current ordering and delivery schedule	Derived from current ordering and delivery schedule	One day	Hours
Review periods at the delivery service DCs	Derived from current ordering and delivery schedule	Derived from current ordering and delivery schedule	Derived from current ordering and delivery schedule	One day	-
Forecast technique at the CDC and central warehouse	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)
Forecast technique at the delivery service DC	6-week moving average (ABS)	6-week moving average (ABS)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	Simple exponential smoothing, $\alpha = 0.2$ (SLIM4)	-

## 10. Conceptual Model

The model developed is an Excel based spread sheet with underlying VBA code to approach a (R,s,nQ) inventory control policy. This VBA code is also known as the DoBr tool, developed at the TU Eindhoven by Van Donselaar & Broekmeulen (2014).

The horizon considered is a one-year period, in which (only) all relevant operational costs of handling, warehousing and transportation, plus the holding costs of inventory are considered.



## 10.1 Variables and parameters

Throughout the model different variables and input parameters were used, which are summarised in Table 5.

Table 5 - Variables and input parameters

Variable / parameter	Definition
$L_i$	Average lead time for item $i$ , defined as the number of full days that elapses from the moment a replenishment order can be created until the moment the replenishment order arrives in the stock point. Only days during which demand can take place are considered. Averages are derived by taking the average of all potential review moments per item/location combination.
$R_i^d$	The review time for item $i$ at delivery service DC $d$ , i.e. the number of days between two review moments. Only days on which demand can take place are considered.
$\tau$	The review moment of an arbitrary potential delivery cycle
$Q_i^d$	Fixed base replenishment quantity for item $i$ as used in location $d$ , in sales units
$D(t_1, t_2)$	Demand during time interval $(t_1, t_2]$
$\bar{x}_i^d$	Sample mean of daily demand for item $i$ as observed in location $d$ , in sales units. It is calculated based on $n$ independent observations of daily demand $x$ in location $d$ , per item $i$ denoted by $x_1, x_2, \dots, x_n$ such that: $\bar{x}_i^d = \frac{\sum_{w=1}^n x_w}{n}$
$s_i^d$	Sample standard deviation of daily demand for item $i$ observed at location $d$ , in sales units. It is calculated based on $n$ independent observations of daily demand $x$ in location $d$ , per item $i$ denoted by $x_1, x_2, \dots, x_n$ such that: $s_i^d = \sqrt{\frac{\sum_{w=1}^n (x_w - \bar{x})^2}{n-1}}$
$\sigma_{error_i}^d$	The standard deviation of the forecast error for item $i$ in location $d$ , which depends on the forecasting technique used such that $\sigma_{error_i}^d = Y^d * s_i^d$ , where $Y$ is a constant $> 1$ that depends on the forecasting technique used in stock keeping location $d$
$s$	Reorder level, i.e. whenever the inventory position for an item falls below $s$ a replenishment order is placed
$\beta$	Fill rate, i.e. the long-term fraction of demand satisfied directly from the shelves
$c_i$	Cost price of item $i$ , i.e. the average price at which one sales unit of an item was purchased from the supplier or manufacturer
$H$	Assumed holding cost percentage, 12%, i.e. the percentage that needs to be attributed to the cost of capital and risk of holding inventory (storage cost, e.g. warehouse rental costs, are considered sunk)
$v_i$	Volume in litres of one sales unit of item $i$
$p_i$	The maximum volume in litres at which products of item $i$ can be stacked on its associated pallet type whenever it is sent from the CDC to the delivery service DCs
$w_d$	Travel distance in kilometres between the CDC and delivery service DC $d$ , one-way
$t_d$	Weighted average transportation tariff in euros per kilometre per delivery service DC $d$ , based on a historical distribution of trailer types that travelled to location $d$
$U$	The average utilisation rate of a truck, i.e. the fraction of the trailer capacity (measured in pallet places) used on an average trip towards a delivery service DC
$c_i^d$	Weighted average for the capacity (measured in pallet places for item $i$ ) of trucks that visited delivery service DC $d$ during 2014, based on a historical distribution of trailer types that travelled to location $d$
$h_i^{CDC}$	Handling tariff in euros per order line for item $i$ at the CDC, i.e. the labour costs of picking a replenishment order for item $i$ at the CDC
$h_i^{DC}(Q)$	Handling tariff in euros per order line for item $i$ at the delivery service DC, i.e. the labour costs of replenishing a replenishment order for item $i$ at the delivery service DC as a function of the base replenishment quantity
$I_i^d$	Yearly inventory cost per item $i$ in location $d$

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$H_i^{CDC}$	Yearly handling costs at the CDC (i.e. picking) in euros per item $i$
$H_i^{DC}$	Yearly handling costs (i.e. replenishment) in euros per item $i$ , summed over all delivery service DCs
$T_i^A$	Yearly transportation costs in euros for item $i$ being shipped between the CDC and the delivery service DCs under scenario 1-4
$T_i^B$	Yearly transportation costs in euros for item $i$ being shipped between the CDC and the delivery service DCs under scenario 5
$l_i$	The maximum volume in litres at which a crate or roll container at a delivery service DC is considered full, which depends per item $i$ , with $l \in \{35, 540\}$
$u_i$	The unloading time in seconds for one crate or roll container for item $i$ , with $u \in \{15, 60\}$
$i$	Item index, with $i \in \{1, 2, \dots, 476\}$
$d$	Stock-keeping location index, with $d \in \{1, 2, \dots, 8, CDC\}$ where each number represents a delivery service DC in one of the eight customer regions

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## 10.2 Inventory costs

Inventory costs were approximated per item  $i$  and location  $d$  using inventory on hand estimates. These levels depend among others on the reorder levels and base replenishment quantities and are decided by DoBr using the fill rate as a constraint. The use of DoBr has a big advantage as it evaluates the inventory policy at a P2 service measure, while many other studies fail to do so and rather use either the mathematically more simple P1 measure (Bretthauer, Mahar & Venekataramanan 2010; Nozick & Tunquist 2001; Daskin, Coullard & Shen 2002). The main reason why it is better to evaluate at a P2 measure is that it is much more meaningful in a sales environment because, unlike the P1 measure, it is a good reflection of the product availability as perceived by the customers. An example to underline this is provided by Van Donselaar & Broekmeulen (2014). The formula used to derive the costs of holding inventory:

$$\text{Yearly inventory cost per item } i \text{ per location } d, I_i^d = \frac{E_i^d[I^{OH}(\tau+L)] + E_i^d[I^{OH}(\tau+R+L)]}{2} * c_i * H$$

More specifically, the expected inventory on hand at location  $d$  at the beginning of an arbitrary potential delivery cycle just after a potential delivery is defined as  $E^d[I^{OH}(\tau + L)] = E[(IP^d(\tau) - D^d(\tau, \tau + L))^+]$ . In words: the expectation of the inventory position at an arbitrary review moment minus the demand during the lead time. If this expectation is negative then the on hand inventory level is zero. With discrete demand,  $E^d[I^{OH}(\tau + L)]$  is equal to  $\frac{1}{Q} \sum_{j=0}^{Q-1} \sum_{k=0}^{S+j-1} (s + j - k) * P(D_t^d = k)$

The expected inventory on hand at the end of an arbitrary potential delivery cycle just before a potential delivery is defined as  $E^d[I^{OH}(\tau + R + L)]$ . The expressions can be derived in a similar fashion as for  $E^d[I^{OH}(\tau + L)]$ .

Since the conceptual model assumes stationary demand and works with daily demand averages, taking the average of the begin and end inventory levels of a potential delivery cycle is only a linear approximation. Especially for low service levels (like at the intermediate nodes in a multi-echelon system) this can be an inaccurate method for periodic review models. Van der Heijden and De Kok

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(1998) showed that taking the averages of these two KPIs usually underestimates the mean physical inventory levels for periodic review models. They argued that the inventory process between replenishments shows a concave behaviour, which gets stronger as variability in demand increases and the fill rate decreases. For a (R,S) policy they suggested using a trapezoidal rule, which is a piecewise linear approximation over  $n$  sections. But what they also mentioned is that when fill rates are high, taking the average of the begin and end inventory levels of a potential replenishment cycle gives better approximations than with low fill rates. Van Donselaar & Broekmeulen (2014) confirm this and suggest that this method can give ‘very good results’. Because the target fill rates in the model will be set fairly high (see 10.2.3), therefore there should be no major concerns in using this linear approximation. An advantage is also that the built-in formulas of the DoBr tool can be used directly.

### 10.2.1 Demand parameters

#### Mean and standard deviation

The sample means  $\bar{x}$  and sample standard deviations  $s'$  of daily demand were specified per item-location combination and were derived from data series from a 52-week long period in 2014 (see section 10.8 and Appendix F).

Because demand in the model is assumed to be stationary, the DoBr is likely to underestimate the inventory levels because in reality demand patterns can be time-varying, which manifests itself e.g. in a trend, seasonality and/or products life cycles. In accordance with Van Donselaar & Broekmeulen (2014) therefore a heuristic approach is used. Instead of letting DoBr determine a single reorder level on the sample mean and sample standard deviation of the demand data series for the cover period of length  $L + R$ , it is suggested to rather derive a new reorder level on every review moment, based on the forecasted demand for the next  $L + R$  periods and the standard deviation of the *forecast error*,  $\sigma_{error}$  for these  $L + R$  periods.

While deriving a new forecast in the current setup is still done by assuming stationary demand (so that it will just be based on the sample mean once again), to derive the standard deviation of the forecast error, two situations existed. As SLIM4 uses simple exponential smoothing with  $\alpha = 0.2$  for its one-year ahead forecasts, an equation quoted by Strijbosch, Moors & De Kok (1997) could be applied such that:

$$\sigma_{error}^2 = \frac{2}{2-\alpha} s'^2 \quad (1)$$

For the delivery service DCs, which use the ABS system and applies a N-week moving average forecast with  $N = 6$ , Silver, Pyke & Peterson (1998) provide that  $\alpha = \frac{2}{N+1}$ . Substituting  $\alpha$  with  $N$  in equation (1) gives:

$$\sigma_{error}^2 = \frac{2}{2-\frac{2}{N+1}} s'^2 = \frac{N+1}{N} s'^2 \quad (2)$$

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This way, the standard deviations of the forecast errors used by DoBr are  $\sigma_{error} = \sqrt{\frac{2}{2-0.2}} * s' = 1.0541 * s'$  for SLIM4 and  $\sigma_{error} = \sqrt{\frac{6+1}{6}} * s' = 1.08 * s'$  for ABS. This is similar to the values used by Van Pelt (2014) and shows that the forecast method as set up in SLIM4 provides more accurate estimates than that in ABS since  $1.0541 < 1.08$ . For this reason, scenario 3 and 4 will assume the use of SLIM4 also for the forecasting at the delivery service DCs.

### **Demand distribution**

Because demand in reality is discrete, the DoBr tool was set up so that it tries to fit a discrete probability distribution function of demand for any item  $i$  from the parameters  $\bar{x}_i^d$  and  $\sigma_{error_i}^d$ . While using the full empirical distribution would give exact results, the fitting procedure is an approximation but is more practical to use since now only the two moments of the demand distribution need to be known. Moreover, a full empirical distribution is not available; only a 52-week set of historical data was used.

The choices that the DoBr tool could make for discrete demand distribution were the binomial, Poisson, negative binomial and geometric distribution and the selection is a function of the mean and the variance-to-mean ratio. The exact fitting procedure of the DoBr tool is based on work of Adan et al. (1995).

Due to some limitations of the tool, whenever the fitting of a discrete demand distribution was not supported, a Gamma distribution was assumed (see Van Donselaar & Broekmeulen, 2014). These settings are similar to Van Pelt (2014).

### **Out of stock situation**

For orders placed by final customers at the delivery service DCs a lost-sales situation was applied in the DoBr tool because in general no backordering takes place at the delivery service DCs. For orders placed by the delivery service DCs at the CDC also no backorders are administered; orders are just placed again when they are not received at the first attempt. Hence for the orders placed by the delivery service DCs also a lost sales situation can be assumed. No record is however kept of the original demand of the delivery service DCs, only actual shipment quantities are available. For this reason, the DoBr was set up to apply a backordering situation for the orders placed at the CDC. This is equal to the earlier choices made by Van Pelt (2014).

### **10.2.2 Lead time & Review period**

To be able to make a fair comparison between the existing situation and the new scenario, it was assumed that all lead times are deterministic and so that there would have to be no safety stocks installed to protect against lead time uncertainty. This is a deviation to the earlier work by Van Pelt (2014), who modelled more closely the actual situation but which can be considered modelling a non-optimal state.

Lead times were eventually derived for each item per delivery service DC from the order- and delivery schedule that was operational in May 2015. Each item in a certain delivery service DC has its own review moments, which could be on any of the 5 weekdays (Monday to Friday). Some items may be reviewed five times a week while others are only once a week. The day on which an order may be

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placed has an effect on the lead time because of the weekends, during which no deliveries by the CDC towards the delivery service DCs take place. This way, for each item-location combination the review periods and lead times were corrected for the weekends and averages were calculated. These averages served as the input for the model.

One important assumption in terms of lead time is that whenever a shipment arrives somewhere on an arbitrary day at the delivery service DC, it will be available at the pick location before the end of that same day; that is before the picking of final customer orders has been completed. This way in fact only one day on which demand can take place needs to be covered (unless there is a Saturday involved, then it would be 2). In the actual current situation this is not assumed and so the ABS works with longer lead times, which are either 2 or 3 days (corrected for the Sunday). Perhaps these are more realistic, but during several visits to different delivery service DCs it was observed that it could be possible to replenish the shipments within a day. Since this would be an ideal case, it was chosen to model this scenario to give the current situation a more fair chance in comparison with the cross-dock scenario. Therefore, the lead times were considered only to be either 1 or 2 days and not 2 or 3. This is another deviation compared to Van Pelt (2014), the review periods are derived equally though.

### **10.2.3 Service target**

Since Van Pelt (2014) in his base scenario set the external fill rate target at 98.5% and internal fill rate target at 96.5%, to be able to validate the findings of this thesis report against the findings by Van Pelt it is therefore chosen to at least make calculations with these exact same target service levels.

However, for reasons explained in section 5.5, also lower fill rates will need to be examined as it will possibly reflect the current situation more precisely. Another reason is that the inventory levels will not necessarily have to be set according to the service level target to reflect the reality because the service stores also contribute to higher service levels of the delivery service DCs. This way the delivery service DCs can achieve the same service levels with lower inventory levels. For research purposes this should however not be taken into account because in an ideal situation these transshipments should not be necessary for items that are also in the inventory of a delivery service DC, mainly because these transshipments are also associated with higher costs.

Since any exact measures were impossible to derive the actual fill rates as obtained in 2014, the decision was made to arbitrarily set an external target fill rate at 96% instead of 98.5%, and an internal service target of 94% as opposed to 96.5%. The expectation is that inventory levels will be significantly lower, and so potential cost savings for a cross-docking scenario will be lower too.

### **10.2.4 Shelf life**

In order to also incorporate the shelf life of items, an option of the DoBr tool was used that modifies the inventory position so as to reflect the expected outdating of items as well. The option enables that the number of products expected to expire during the next  $L + R - 1$  periods is subtracted from the inventory position at the moment of a review,  $IP(\tau)$ . The tool works for shelf lives between 1 and 30 periods (i.e. days), for values larger than 30 the shelf life is ignored and products are considered non-perishable. Considering the item set that was used, which is explained in section 10.8, the effects of using this option are only limited.

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### **10.2.5 Base replenishment quantities**

The model for scenario 2-4 was set up in such a way that the considered base replenish quantities were always feasible in terms of shelf life and expected demand. This was done in two ways. The first is explained in Appendix F, stating that already some items were excluded from research when demand was too low to offer the target shelf lives to the final customer even when orders by the delivery service DCs of size equal to one sales unit were placed. These items under no circumstances could be feasible in terms of shelf life so most likely they had been sourced from the service store anyway.

The second way is that when optimising the base replenishment quantities (under scenario 2-4), the calculations were not performed at all when it proved that shelf life would be an issue. An exact explanation was given in section 9.2. So, in the model under scenario 2-4 only base replenishment quantities are considered where the expected demand of the item is such that it is high enough to sell all the products without expected perishing taking place. In scenario 1 however, where the current base replenishment quantities were used, there were some infeasibilities with respect to shelf life but it was chosen to leave these in as the scenario would not be the benchmark scenario.

### **10.2.6 Holding costs**

In accordance with the supply chain design and planning manager the holding costs were set at 12% to include both capital and non-capital related costs. For a validation some estimates were obtained about the shrinkage of inventory throughout 2014, which could roughly be translated into a holding costs charge of 5%. On top, the company uses a 7% weighted average costs of capital (WACC), which then adds up to 12%. It was decided not to count the rental or ownership costs of the inventory locations since they were argued to be sunk because in none of the scenarios there will be fewer or more inventory locations considered, except for the hypothetical central warehouse. The costs for this warehouse are not included in the calculations though and estimates on the allowed investment may follow from, among others, any potential costs savings obtained in the cross-dock scenario. A holding costs percentage of 12% is equal to the measure used by Van Pelt (2014).

### **10.2.7 Pipeline inventory**

Pipeline inventory between the CDC and delivery service DCs was not considered since it is only a fraction of the entire inventory. Items do not necessarily have to be in the pipeline every day of the year because review periods for those items may be longer than a day and not every review moment will result in a replenishment order being placed. Also, in the scenarios considered, only an ideal state is considered where the lead time is only one or two days. What concerns the pipeline towards the CDC, the supplier or manufacturer is normally not paid for until receipt so that also here the lead time is not relevant.

## **10.3 Transportation costs**

Transportation costs under scenario 1-4 were based on total sales volumes using a calculation that takes into account the size of an item in term of litres, and how many sales units fit on a EURO or CHEP pallet when it is shipped to the delivery service DCs. With the pallet capacity known of the two types of trailers available (a standard trailer and eco-trailer), and the historical distribution of trailer types towards each of the delivery service DCs and the overall average utilisation rate of trailers  $U$ ,

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the transportation costs could be calculated once also the kilometre tariff in euros per kilometre,  $t_d$ , and total demand were known.

Assumed was that the costs of transport are linear to the distance covered to allow for more straightforward calculations. Because overall utilisation rates in reality were rather high, it is argued that this assumption is sufficient for this research purpose.

Yearly transportation costs per item in scenario 1 to 4,  $T_i^A$  were derived as follows:

$$T_i^A = 2 * 306 * \frac{1}{U} * P_2 * \frac{v_i}{p_i} * \sum_{d=1}^8 \mu_i^d * w_d * t_d * \frac{1}{c_i^d}$$

As can be seen, the transport volumes were not based on the actual shipped amounts (the data which is used to derive daily demand per item for the CDC, see Appendix F), but on actual demand as observed by the delivery service DCs, corrected for the service level target. This is a more fair approach because this will scope out any amounts that would else be missing because they were sourced from the service stores (which is a non-optimal state). From the other side, also any damaged or perished products that were shipped but not sold are scoped out this way. Using actual demand figures is therefore a more precise and fair input.

For scenario 5 the following formula for the yearly transportation costs per item,  $T_i^B$ , was used:

$$T_i^B = 2 * 306 * \frac{1}{U} * P_2 * \frac{v_i}{p_i} * e_i * \sum_{d=1}^8 \mu_i^d * w_d * t_d * \frac{1}{c_i^d}$$

The difference with the earlier equation is that there is a minimum volume increase factor,  $e_i$ , which depends on the item. For items picked to customer order in crates there is a minimum of 45% increase in volume (accounted for by 'adding' air) while for items picked on roll containers this value is 28%. These values are derived from current practices of how pick orders at the delivery service DCs are planned. An empty crate with a content of 55 litres is planned with products until a maximum of 35 litres product volume is reached, or a maximum weight of 20 kilograms. Only one type of crate is currently being used in the delivery operation. Therefore, the *minimum* amount of air 'produced' during the picking process is 45%. Similarly, roll containers are planned at a maximum of 540 litres (or 320 kilograms) while the theoretical content of a roll container is 750 litres, this translates into the minimum volume increase of 28%.

Data about the minimum volume increase per item was obtained by looking for each item across all delivery service DCs in which DC area the item was located in the delivery service DC. From this data it could be derived whether the item is picked in a crate or on a roll container. Because almost every item had different locations among the different delivery service DCs, it was chosen to pick the area observed most commonly, i.e. the mode. Based on the mode the choice for a crate or roll container was derived.



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## 10.4 Handling costs scenario 1

Handling costs are triggered from the behaviour of the inventory ordering system, which periodically reviews the inventory positions of each item and subsequently may place replenishment orders at the CDC upstream. The handling costs considered are only the cost of operations as performed by manual labour. For every scenario, all costs are derived from the time estimates from section 6 and 7 and multiplied by an assumed hourly wage of a logistics employee of €21.50 per hour.

The KPI used to derive the handling costs in the scoped supply chain is the probability a replenishment order is generated during a review period,  $E[OL] = P(IP(\tau) - D(\tau, \tau + R) < s) = \frac{1}{Q} \sum_{i=0}^{Q-1} \{1 - \sum_{d=0}^i P(D_R = d)\}$ . This probability is calculated in DoBr using the DoBr\_EOL function and is then used to calculate the expected number of orders placed in a one-year period. Because in 2014 there were 304 days with recorded sales, i.e. days on which the delivery service DCs were operational, the number of orders placed per delivery service DC per item during 2014 follows from:

Number of orders placed by delivery service DC  $d$  during 2014 for item  $i = \frac{304}{R_i^d} * E[OL]_i^d$

Whenever an order is placed, it leads to these orders needing to be picked at the CDC and subsequently replenished upon receipt at the delivery service DC. Thus, the cost driver in this perspective is chosen to be the number of orders (per item) placed.

As can be read in sections 6 and 7, the current picking and replenishing times were analysed carefully. The results obtained were then corrected for any further efficiency gains that were proposed by Schilders (2015) and then used as a basis in the calculation to derive the approximated costs of the handling operations in the scoped supply chain. For that, for each item information was obtained about the location in the CDC so that the right cost parameter could be linked. For frozen-food items a replenishment productivity was assumed as the average of productivities measured in the dry groceries and fresh food DC areas.

Yearly handling costs (i.e. picking) at the CDC per item,  $H_i^{CDC}$ :

$$H_i^{CDC} = \sum_{d=1}^8 \frac{304}{R_i^d} * E[OL]_i^d * h_i^{CDC}$$

Yearly handling costs (i.e. replenishment) at the delivery service DCs per item,  $H_i^{DC}$ :

$$H_i^{DC}(Q) = \sum_{d=1}^8 \frac{304}{R_i^d} * E[OL]_i^d * h_i^d(Q)$$

where  $Q \in \{(multiple\ of)\ pallet\ layer, full\ pallet, any\ value\ other\ than\ a\ (multiple)\ of\ a\ pallet\ (layer)\}$

A quick explanation for the different replenishment tariffs at the delivery service DCs depending on Q is that mixed pallets are replenished at different productivity rates than pallet layers and full mono pallets. Thus, the appropriate costs depend on the Q that was set by the ABS managers.



## 10.5 Handling costs scenario 2-4

There is an important difference between the first scenario and scenario 2-4. In scenario 1 the base replenishment quantities were used as they were set by the ABS managers on May 2015 (see Figure 11). In scenario 2-4 however, the economic order quantity was used so that the choice for  $Q$  per item  $i$  per location  $d$  is such that  $H_i^{CDC} + H_i^d(Q) + I_i^d(Q)$  are minimised. This way, the total cost for handling and inventory at the delivery service DCs is minimised so that lower total costs compared to scenario 1 can be expected. This makes it possible to make a more fair comparison with scenario 5. The way to find the optimum  $Q$  was to just calculated all possible combinations that were feasible in terms of shelf life, based on the same formulas of the handling costs in scenario 1.

## 10.6 Handling costs scenario 5

In the cross-docking scenario it was argued that there is one extra handling step. These were calculated by first knowing per item and per delivery service DC if the item in the current situation is picked in crates or on roll containers. Because this was found not to be uniform across the different locations, the mode was chosen for further calculations.

For each item the total sales volume was calculated and divided by the amount of litres at which a crate or roll container is considered full. This amount is represented by  $l_i \in \{35,540\}$  and thus is item specific because it needs to be known if it will be picked in a crate or roll container. Therefore it holds that:

$$\text{Number of full crates, or roll containers per item in 2014} = \frac{1}{l_i} * 304 * \beta * \sum_{d=1}^8 \mu_i^d * v_i$$

When assuming that each customer visited on a route requires *at least* 1 crate (which is highly realistic), then about 4013 crates can be expected per day (derived from data over 2014, see Figure 17), or a total of 1,227,978 crates in 2014. When validating this with the sum that was obtained over the sample set, and up scaling it, the numbers were very close as it would equal 1,641,070, or about 1.33 crates per customer. This seems reasonably realistic so the method can be considered accurate enough.

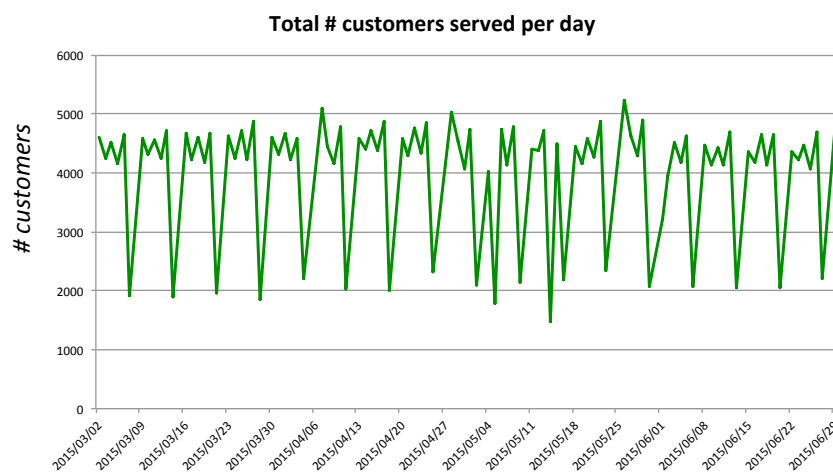


Figure 17 - Number of customers visited per day

With these numbers it was then calculated what the extra handling costs were. For the unloading time of a crate pick cart with 60 crates 15 minutes was used, while for one roll container this was 1 minute. Thus the unloading time in seconds for one crate or roll container for item  $i$  is  $u_i \in \{\frac{900}{60}, 60\}$ . Then, the extra handling costs of the cross-dock scenario were calculated per item as follows:

$$H_i^{XD} = \frac{u_i}{3600} * 21.5 * \frac{1}{l_i} * 304 * \beta * \sum_{d=1}^8 \mu_i^d * v_i$$

## 10.7 Potential cost savings

Potential cost savings were eventually derived for each item by taking scenario 2 as it reflected the most fair benchmark scenario, and compare these results with the to-be scenario number 5. By summing all relevant costs per item, the potential relevant operational cost savings were calculated as follows:

Potential relevant operational cost savings per item  $i$  =

$$\left( 1 - \left( \left( I_i^{CDC} + \sum_{d=1}^8 I_i^d + H_i^{CDC} + H_i^{DC} + T_i^A \right) - (I_i^{Pooled} + H_i^{XD} + T_i^B) \right) \right) * 100\%$$

## 10.8 Item selection

In order to be able to make calculations, a subset of items was created. The objective was to create a representative selection of items that reflects well the average assortment of a delivery service DC so that any conclusions from this research can be generalised and up scaled to the entire delivery operation. It was very important to select the right items and calculate the right daily demand averages and standard deviations, because based on these parameters the tool would calculate the ordering pattern and thus also trigger the entire handling operation.

There are several reasons why it was chosen not to work with the entire item selection. First of all there exists no single assortment that is carried across all eight delivery service DCs. If there were any, then this assortment would also just be a fraction of the total number of items shipped from the CDC to any of the delivery service DCs. As was explained in section 8, the assortment of a delivery service DC is the result of several factors and therefore can never be the same across all locations. Secondly, for some items it was not possible to retrieve all necessary data due to missing records or data errors. Thirdly, to make calculations that reflect with enough detail the current situation, a lot of careful data processing is needed. There exists a trade-off where the benefits of adding more items to the set do not add any more insights or power to the model, especially considering the large amount of work that goes into pre-processing the data. It is argued that whenever the subset reflects the population well, the insights gathered are sufficient for this research purpose.

A comprehensive overview of the exact process to derive the item set can be found in Appendix C. The complete characteristics of the final item set can be found in Appendix D.

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## Part IV - Results & Evaluation

### 11. Results & Discussion

In this part the results will first be provided and discussed. When not mentioned, the results are evaluated for an external fill rate target of 98.5% and an internal fill rate target of 96.5%. Also, potential cost savings for the cross-dock scenario 5 are always evaluated against scenario 2, unless stated otherwise. For the results on external and internal fill rates of 96% and 94%, respectively, please refer to Appendix H.

#### 11.1 Total relevant operational costs

It can be seen from Figure 18 that the cross-docking scenario yields the lowest total relevant costs. Compared to scenario 2 the total potential cost savings are 29.8%. Breaking down the numbers further, it can be seen that specifically on inventory holding costs 70% can be saved, and on handling operations 76%. Transportation costs on the other hand are associated with an increase of 30%.

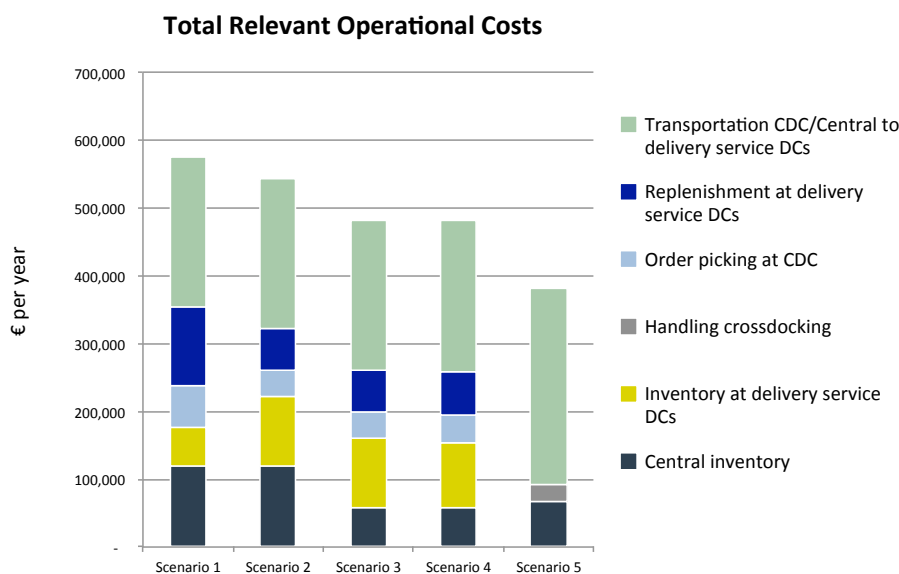


Figure 18 - Total relevant operational costs for the five studied scenarios

When comparing scenario 5 with the pooled demand scenario 3, total potential cost savings are 21%, with the difference caused by the difference in inventory levels at the CDC. Total potential savings on inventory costs will be 58%.

What can also be seen immediately is that scenario 4 does not improve significantly on scenario 3, even not while assuming equal picking productivity at the CDC, so it can be discarded right away.

#### 11.2 Base Replenishment Quantities

One of the sub-objectives was to apply economical order quantities to scenario one in order to derive lower costs for the sum of the costs of handling in the CDC, costs of handling in the delivery service DCs, and the costs of inventory in the delivery service DCs.

The results for scenario 2 show that for 67.4% of the item-location combinations the EOQ was found to be higher than the currently used base replenishment quantities (as of May 2015). In 16.9% of the cases they were equal while 15.7% of the EOQs turned out to be lower than the current setting. So, in the majority of cases the inventory managers have set their base replenishment quantities lower than what is considered supply chain wide cost optimal. This is an important finding because it tells that there is potentially still a lot of room for improvement on this aspect. The complete overview of the optimal settings is provided in Figure 19.

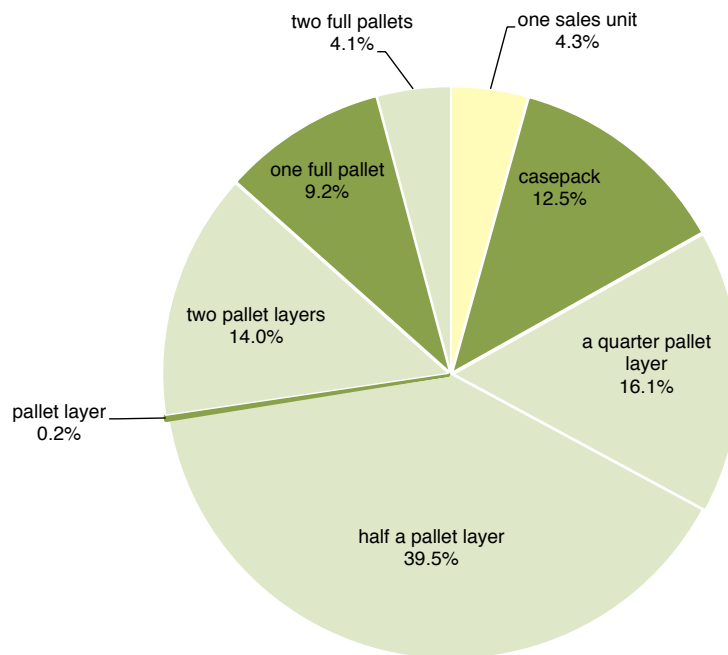


Figure 19 - Economic base replenishment quantities under scenario 2

A potential explanation for the currently used settings is that the inventory managers in the delivery service DCs put more focus on obtaining low inventory levels in their warehouses than to optimise the total sum of relevant order costs. Placing larger replenishment orders for them is not attractive since it will bring up the average inventory level as opposed to when they place smaller (but more) replenishment orders. This is understandable because inventory managers are not only evaluated on the provided service levels towards the final customers (for which they would favour larger orders), but also the costs of inventory shrinkage. On top they also have to deal with any possible storage capacity constraints, which can differ among different item categories but also different delivery service DCs. Nevertheless, the balancing game they have to play each day between service and shrinkage does not consider the implications that their replenishment orders have on the handling costs that follow from it. If it would, then scenario 2 would reflect best the current setup of the supply chain in a cost-optimal state under the assumption that capacity is no restriction.

### 11.3 Inventory levels

When it comes to the inventory capital investment (i.e. without applying the holding costs to the inventory levels), it can be seen that between scenario 1 and 2 indeed scenario 1 provides the lowest inventory in the delivery service DCs at a value of €469,532 against €857,354 (see Figure 20). Under scenario 1, the downstream locations hold about 32% of the total inventory in the scoped supply

chain. Under scenario 2, this is increased significantly to 46%. This is also an important finding because it means that when the objective is not only to minimise the costs of inventory (Van Pelt 2014) but also taking into account the other related costs (towards a more integrated approach), relative more inventory needs to be held downstream.

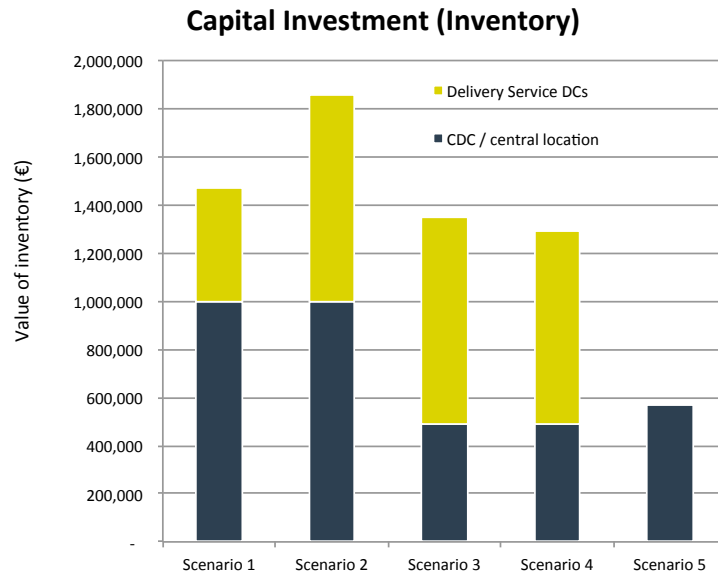


Figure 20 - Capital investment under the different scenarios

What is also important to note is the results of scenario 3 compared to scenario 2. When the CDC is able to observe the pooled daily demand at the delivery service DCs, instead of the replenishment orders that they place, then a significant reduction in inventory at the CDC can be achieved, potentially 51%. These results are in line with what Van Pelt (2014) found earlier, albeit with a slightly different item set and different demand figures.

The main difference with Van Pelt (2014) though, is that under scenario 3 the inventory levels at the delivery service DCs are the result of applying the EOQ. For this reason, the downstream inventory levels are relatively even higher in scenario 3 than in the earlier study by Van Pelt (2014). He found that under demand pooling the distribution of inventory between the two echelons was 50/50 while in Figure 20 this is rather 36/64. So, when considering EOQs relatively more inventories are needed in the lower echelon, which then also shifts the relative distribution. This is an important finding and signifies the crucial difference between this study so far, and that of Van Pelt (2014).

Further reduction of downstream inventories can still be achieved when the delivery service DCs are able to order each item each day, given that the CDC will operate six days per week (i.e. scenario 4). But as we already saw in Figure 18, this does not lead to significant lower total relevant costs because the costs of handling will increase due to the increased number of orders placed. This already holds even when no efficiency losses in picking at the CDC are assumed, or increased transportation costs.

## 11.4 Item analysis

When taking scenario 2 as the base scenario, each item in the sample can be evaluated in terms of total relevant costs for scenario 5. The potential cost savings that scenario 5 offers against scenario 2

can be grouped into different classes to get a better understanding of how the cost structure for handling, inventory and transportation costs is made up.

Table 6 - Potential cost savings classes

Potential savings	Count	% of # items	Sales volume (L)	% of sales volume	# Suppliers (cum)
More expensive	18	4%	11,551,457	47%	15
Between 0-10%	6	1%	1,480,302	6%	21
Between 10-20%	13	3%	3,168,653	13%	29
Between 20-30%	17	4%	1,642,401	7%	38
Between 30-40%	57	12%	2,253,433	9%	77
Between 40-50%	76	16%	2,163,248	9%	117
Between 50-60%	101	21%	1,360,742	6%	155
Between 60-70%	96	20%	647,312	3%	180
Between 70-80%	61	13%	312,086	1%	192
Between 80-90%	22	5%	33,049	0%	202
Between 90-100%	9	2%	12,283	0%	205
<b>Total</b>	<b>476</b>	<b>100%</b>	<b>24,624,967</b>	<b>100%</b>	<b>205</b>

The numbers in Table 6 show that for 18 out of 476 items in the set (i.e. 4%) the cross-docking scenario is more expensive than scenario 2. Together they make up for 47% of the total sales volume in the set, supplied from 15 different suppliers. They are however not the top 18 of items with most sales volume, so it already suggests that also criteria other than sales volume are important to consider. Appendix I shows the sales volume top 25 of the used sample set and includes an indication what the potential cost savings are on the relevant operational costs.

Table 6 also shows that for the majority of the items in the sample set significant cost savings can be obtained, with most of the savings roughly in the 50-70% region. Further analysis is provided in the graphs in Figure 21, which shows how the costs of handling, inventory and transportation are distributed among different cost savings classes.

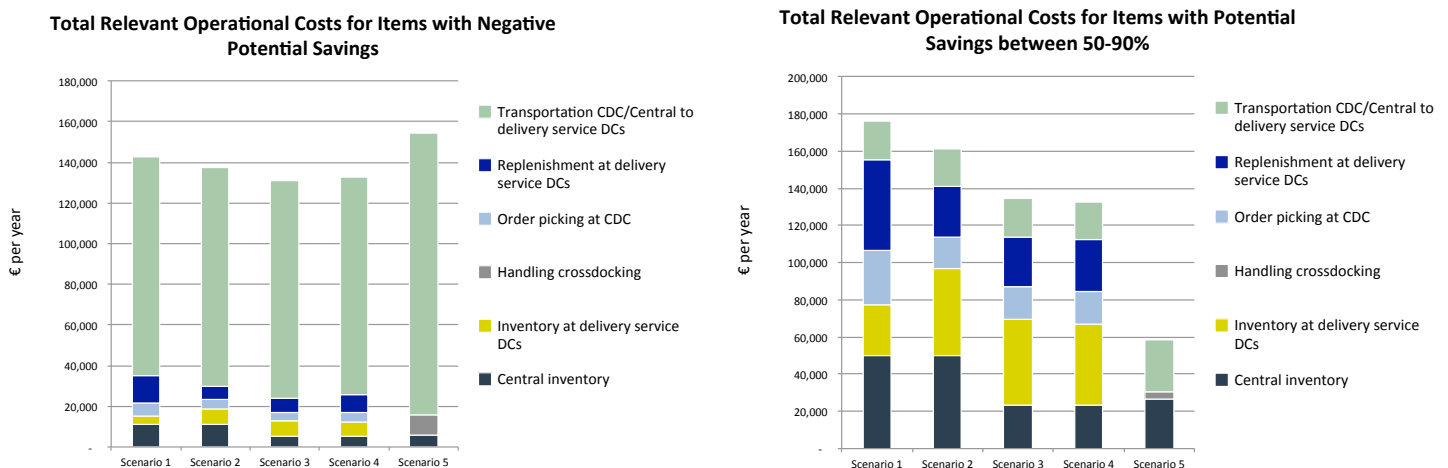


Figure 21 - Cost structures among different cost savings classes

It is easy to see that for some items the transportation costs are a dominant cost factor while for other items the costs of handling and inventory are relatively much higher. In general, it was found that for items with a large physical size (above 30 litres per sales unit), and items with high sales (above 80.000 units per year), cross docking would only yield minor potential cost savings, if not negative.

## 11.5 Predicting potential cost savings

To have a better understanding as to which factors influence the degree of potential costs savings for a particular item, SPSS was used to run several linear regressions.

The result is that even though it seems like total sales volume per item is the most important predictor, in fact there are other significant ones. As a start, a total of eight potential predictors were evaluated:

- Cost price per item for one sales unit (euros)
- The volume per item for one sales unit (litres)
- The review period per item as a non-weighted average over all delivery service DCs (in days)
- The total yearly sales per item (units)
- The total yearly sales volume per item (litres), i.e. interaction variable of volume per item \* total yearly sales in units per item
- Value density per item, i.e. interaction variable of cost price per item \* volume per item
- The standard deviation to mean ratio for final customer demand per item-location combination, weighted over the sales (in units) over all delivery service DCs. So, a weighted average CV per item.
- The EOQ per item-location combination (in scenario 2) divided by its associated mean daily demand, and then weighted over the sales (in units) over all delivery service DCs. So, a weighted average of the  $\frac{EOQ}{\mu}$  per item.

By using the stepwise method, and also iteratively using the enter method, eventually a linear regression model was developed with a predicting power of  $R^2 adj = 0.620$  and six highly significant predictor variables.

The predictor ‘total sales volume per item’ turned out insignificant, most likely because already total sales in units and volume per sales unit were included in the model as significant and the most important predictors. A brief overview of the model is provided in Table 7 below, more model statistics are found in Appendix J. The histogram and normal P-P plot of the standardised residuals show convincing evidence that they are normally distributed and so the linear regression model seems valid. Also there is no issue with multi-collinearity as the VIFs are maximum 1.803, which is well below 10.

Table 7 – Final regression model from SPSS for predicting potential cost savings

		Coefficients <sup>a</sup>					Collinearity Statistics	
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Tolerance	VIF
		B	Std. Error	Beta				
1	(Constant)	.430	.022		19.159	.000		
	CostPrice	.007	.001	.180	4.790	.000	.565	1.771
	WeightedAvgCV	.068	.008	.288	8.119	.000	.634	1.578
	VolumePerSalesUnit	-.011	.001	-.482	-12.694	.000	.554	1.803
	ValueDensityPerSalesUnit	.019	.003	.231	6.840	.000	.703	1.423
	TotalSalesUnitsPerItem	-5.277E-6	.000	-.339	-10.685	.000	.794	1.260
	QdividedbyMUWeightedAverage	-.001	.000	-.147	-4.159	.000	.641	1.559

a. Dependent Variable: CostSavingsPercentage

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By applying the unstandardised coefficients from Table 7 the potential cost savings in terms of percentage over scenario 2 can be calculated as follows:

$$\begin{aligned} & \text{potential cost savings \%} \\ & = 0.430 + 0.007 * \text{cost price} + 0.068 * \text{weighted average CV} - 0.011 * \text{volume per sales unit} + 0.019 \\ & * \text{value density per sales unit} - 5.277 * 10^{-6} * \text{total yearly sales in units} - 0.001 \\ & * \text{weighted average of EOQ}/\mu \end{aligned}$$

So, it could be concluded that potential costs savings were positively correlated with cost price, CV and value density per item. This is not surprising, because these are all naturally associated with higher inventory costs in scenario 2. An explanation: the benefits of the risk pooling in scenario 5 are highest for items with high demand volatility (in the forecast) and those items that are most valuable in terms of cost price. Also, when value density is high it means that it is associated with higher potential cost savings because these items are typically small volume items. Therefore the volume factor will not be dominant and so the transportation costs are less likely to offset the potential savings of inventory and handling under scenario 5.

On the other hand, yearly sales (measured in sales units) and the physical size of a sales unit (in litres) were associated with an increase in costs for scenario 5 compared to scenario 2. This is also not surprising because together these two predictors translate into sales volume. Sales volume is positively correlated with the increase in transportation costs in scenario 5, something that could already have been hypothesised from Table 6. It also shows from the standardised beta coefficient that these two variables are the most dominant ones in predicting the potential savings since their absolute values are highest of all predictor variables.

Last, high values for the weighted average  $\frac{EOQ}{\mu}$  were also associated with higher costs for the cross-docking scenario. This can be explained directly by the fact that high values for  $\frac{EOQ}{\mu}$  are negatively correlated with yearly sales volume (correlation tests showed a significant correlation of -0.21). The underlying reason however is that high sales items can be ordered in much larger quantities at a time because shelf life will most likely not be an issue. Also, when order quantities are high compared to the average daily demand it means that safety stocks play a less important role since cycle stock levels will be significant. In fact, for certain items safety stocks turned out to be negative. Therefore, for items with a high  $\frac{EOQ}{\mu}$  ratio the benefits of risk pooling are less than for items with smaller ratios because the reductions in safety stocks will be less. This translates to the inventory costs savings in the cross-docking scenario being relatively low and thus scenario 5 can more easily be associated with higher costs.

## 11.6 Sensitivity analysis - transportation volume

One key assumption in the previous analyses was that the minimum volume increase during the customer order picking process is either 45% for items transported in crates, and 28% for those transported on roll containers. These are however lower bounds, so it would be interesting to provide a sensitivity analysis to see what happens when these factors are increased. It can for example be argued that not every crate or roll container is filled to its maximum planned capacity due to specific customer requirements. What is often the case in reality for example, is that customers require their



order to be split up over different roll containers or crates. Also, customer orders are not always large enough to fill an entire carrier.

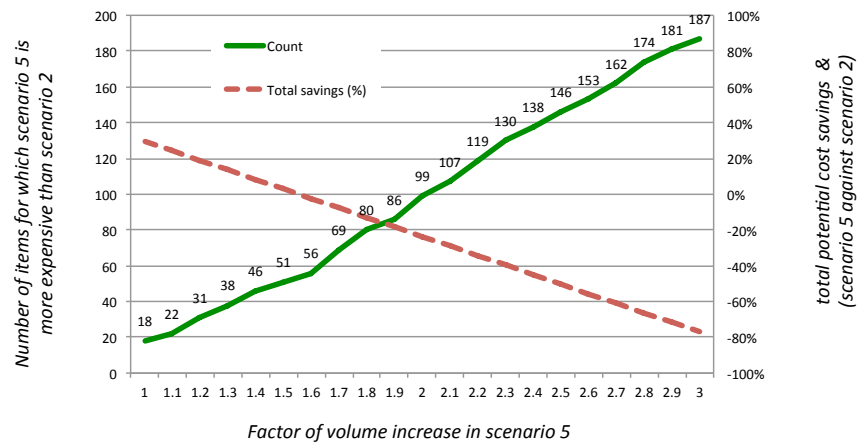


Figure 22 - Sensitivity analysis transportation cost increase

For the reasons above, a sensitivity analysis is provided in Figure 22, where the number of items for which scenario 5 would be more expensive than scenario 2 is plotted against the factor at which the transport volumes are multiplied compared to scenario 5. On the secondary axis total potential cost savings are plotted.

What can be learned from Figure 22 is that once the volume increases by only a factor 1.5 compared to scenario 5, the net benefits of switching to a cross-docking scenario completely disappear because of the high total costs for transportation. So, it can be seen that the cross-docking scenario is not very convincing yet since the assumption on which it is based is a very sensitive one.

### 11.7 Improvement heuristic

It could be argued that if calculations proof that even for under the minimum volume increase assumption (on which scenario 5 is based) some items already show that it will be more expensive to cross-dock, then it could be interesting to exclude these items from the analysis and continue the analysis with the others. This way, the cross-docking scenario for the remaining items becomes more profitable.

The outcome of this heuristic is shown in Figure 23 and Figure 24. They are based on the exact same calculations as the earlier ones, but with the 18 items excluded for which the cross-docking scenario proved not to yield any cost savings.

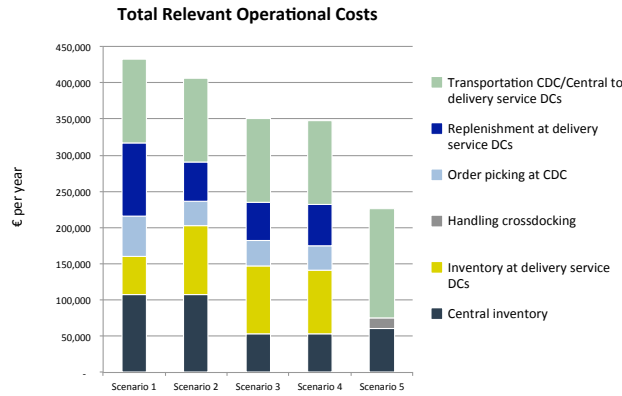


Figure 23 - Total relevant operational costs for the five studied scenarios, but with 18 items removed

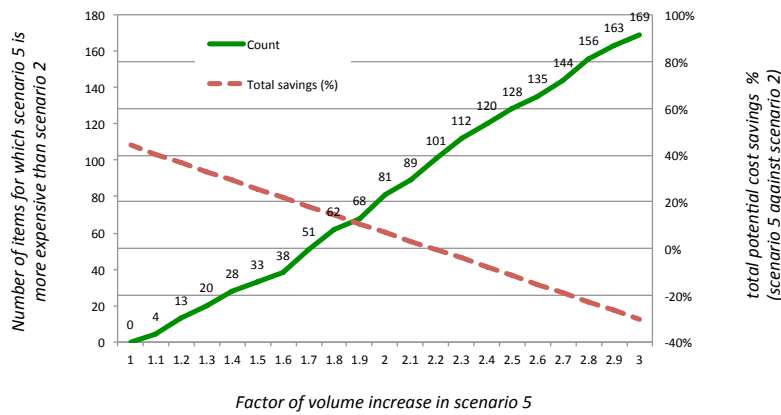


Figure 24 - Sensitivity analysis transportation cost increase, but with 18 items removed

First, what can be observed is that the total potential cost savings compared to scenario 2 are now 44.21% instead of the earlier 29.8%. Thus, it shows that the heuristic is an effective one. Breaking down the numbers further, it can be seen that specifically on inventory 70% can be saved, and on handling 84%. Transportation costs on the other hand are associated with an increase of 31%.

Then, Figure 24 shows that the allowed increase of volume has increased to a factor 2.2 before the total cost savings for the whole set become negative. This is a significant allowance compared to the earlier value of 1.5 from Figure 22.

One can imagine that this process of excluding items can be repeated indefinitely and always yield similar results. Therefore it is only performed for those items that are more expensive in scenario 5, which takes into account the minimum volume increase for cross-dock shipments. How to decide the threshold of which products to exclude or not is something that will depend on many other factors.

Several options exist on how to exclude items, like shipping them directly from the manufacturer/suppliers, or to continue the current method of shipping these items on replenishment pallets from the CDC towards the delivery service DCs. What remains though, is that even with an extreme transportation volume explosion factor the majority of items are a good candidate for a cross-docking scenario whenever trucks can be utilised properly.

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## 12. Validation

Since the sample set was tailored to exactly match the sales volume Pareto curve of the entire population, it is relatively easy to try and extrapolate the results obtained so far and validate them against the actual current situation. The conversion factor used was therefore the percentage of sales volume that the item set represents, which is 6.7% as Appendix D shows.

### 12.1 Inventory investment

When up scaling the inventory investment under scenario 1 for the delivery service DCs, the total value would be €21,899,461. A quick comparison with the study of Van Pelt (2014), where almost the exact same parameters were used, shows that this is about 2.7% higher than what he found. The difference is most likely explained not only by the use of different sample sets, but also by different years of analysis because in 2014 the revenues in the delivery operation grew with about 11% compared to 2013. Thus, it is evident that inventories based on demand figures over 2014 will give higher inventory levels.

As for the inventory in the delivery service DCs only, up scaling the earlier results translate into a inventory capital investment of €7,007,935 under scenario 1. Compared to Van Pelt (2014) this is 5.5% less (€7,418,664). The main explanation is that no uncertainty in lead time between the CDC and the delivery service DCs was assumed, while Van Pelt (2014) did. His study also applied slightly longer lead times.

Compared to the actual inventory levels in the real situation, it is more difficult to validate the results found. No reports are available of inventory levels against cost price, neither is a historical record kept of daily inventory levels at the delivery service DCs; only an indication of levels on the Sunday evening is available. These levels are however valued against wholesale outlet sales price, and not cost price due to confidentiality reasons. Also, to scope out the items not considered in this study is challenging. Significant parts of the inventory in a delivery service DC can be designated as client-only, and also large volumes of items in these DCs are shipped directly to the delivery service DCs. The reports do not make a distinction between these items. For all these reasons, the standard reports available are not sufficient to derive a good estimate.

One way to verify the inventory levels is by using the available reports and correcting them based on some strong assumptions. One report for example shows an average inventory in all 8 delivery service DCs equal to the value against wholesale outlet price of €37,924,785, measured on 52 Sunday evenings in 2014. From the annual report it is seen that the average gross margin on the revenue (i.e. revenues minus purchase price) is 23.17% (see also Table 2). On top, by analysing figures over one delivery service DC for 2013 an assumption was made that 50% of the value of the total inventory in a delivery service DC is supplied directly by the manufacturers and suppliers. Then, since client-only sales were known to be a minimum of 22% of total revenues in 2014, it is assumed that half of this revenue is generated from the inventory items in a delivery service DC (and the rest from cross-dock flows). This leaves a total inventory value of about €11.7 million. But because the levels were recorded on the Sunday, which should theoretically be the lower bound of the inventory levels on any given moment during a week, this €11.7 million will most likely still be an underestimation.

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One other source of information is provided once again by the work of Van Pelt (2014). In this study it is argued that the relevant inventory levels in the delivery service DCs are €14,153,248. The methodology behind this study suggests that there should be no major concerns in how these numbers were derived. Therefore it can be considered a good estimate, and it also does not conflict with the simplified estimate made in the previous paragraph.

It leads to the conclusion that in scenario 1 the inventory levels are significantly lower than in reality. There can be multiple reasons:

- **Sales promotions** – no promotions were considered in the calculations because demand data for these periods was omitted. Therefore the inventory levels by DoBr will be an underestimation of the real levels.
- **Order advice adaptation** - inventory managers adapt on average around 16% of their ABS order advices. It is not known if they correct by increasing or decreasing the amount, but it does have a disturbing effect on the functioning of the system.
- **MOQ** - the DoBr does not take into account MOQs, while for all items in the sample set MOQs at the CDC were larger than the incremental order quantities. Thus, DoBr will provide inventory levels that in reality inevitably will be higher. This only applies for inventory at the CDC though, since the delivery service DCs do not have to take into account any MOQs.
- **Control parameters** - Perhaps the current inventory control parameters are set incorrectly, which can likely be because the complexity of inventory management systems is not easily grasped. Also, the fact that all parameters can be changed without immediate consequence could indicate not all settings are set optimally.
- **Lead time** - The lead times used as input for the DoBr tool were lower than what is currently used by the ABS. Typically ABS adds an extra day compared to the calculation in this report. The reasons for using a shorter lead time were explained earlier in section 10.2.2.
- **Cover period** - The cover period considered in the ABS can be considerably longer than what DoBr uses. The latter uses the review period plus lead time, while ABS adds extra safety days and logistic days. The main reason that ABS uses these extra days is to cope with uncertainty, because in the current setup the demand volatility is not taken into account in setting the reorder levels and service targets.
  - A quick sample was evaluated to see the effect of increasing the lead times in the calculations so that the cover period for DoBr (i.e. L+R) would more than match the conditions of the ABS, but it did not explain the whole difference.
- **Reorder levels** - Current ABS practice is to set reorder levels manually according to some guidelines. For example for frozen food the reorder level should preferably be set to three weeks of expected sales, for products with shorter shelf lives this can be as low as one week. A ‘quick and dirty’ verification with the model showed that on average these guidelines lead to higher reorder levels than what the DoBr tool suggests.

To conclude, the differences between inventory levels calculated by DoBr compared to the estimated levels in reality are significant but for reasons that do not suggest that the DoBr tool was used inaccurately. Moreover, whenever the inventory calculations seriously underestimate the inventory levels, it will only mean that the potential cost savings for the cross-docking scenario are even higher than they are portrayed in this report. Thus, it is argued that the potential cost savings are correct, but conservative compared to the current situation.

## 12.2 Transportation costs

By up scaling the model's yearly transportation costs for scenario 1-4 (which are all equal), a total of €3,317,671 was obtained. To validate this against the actual situation, the actual total costs for transportation movements starting at the CDC were requested for 2014. These movements also included shipments to the cash-and-carry wholesale outlets and RDCs for the retail outlets, so several steps were needed to isolate only the relevant movements towards the delivery service DCs. This process is described next:

First, the total shipment volumes were considered that were shipped to any of the three location types, based on Figure 10 by assuming that sales in units roughly also reflects the sales volume in litres. From this, it would be possible to copy this distribution and apply it to the total transportation costs. However also the distances from the CDC needed to be taken into account. By looking at the locations of the wholesale outlets, RDCs and delivery service DCs it can already be seen that the average distance towards a wholesale outlet must be higher than towards a delivery service DC. The reason is because the latter are more concentrated in the geographical centre of the eight different customer regions in The Netherlands, while a significant portion of wholesale outlets is located in the border regions of these regions (and country in general).

Indeed it turned out that the average distance towards a delivery service DCs (weighted against the relative sales volume among the eight of them) was 98 kilometres for a single trip. The wholesale stores however, under the assumption that sales volumes are equally distributed among them, have an average distance of 114 kilometres from the CDC. By also making the same calculations for the RDCs, in the end the total transportation costs for the shipments between the CDC and delivery service DCs were derived. The results are shown in the far-right column in Table 8 below:

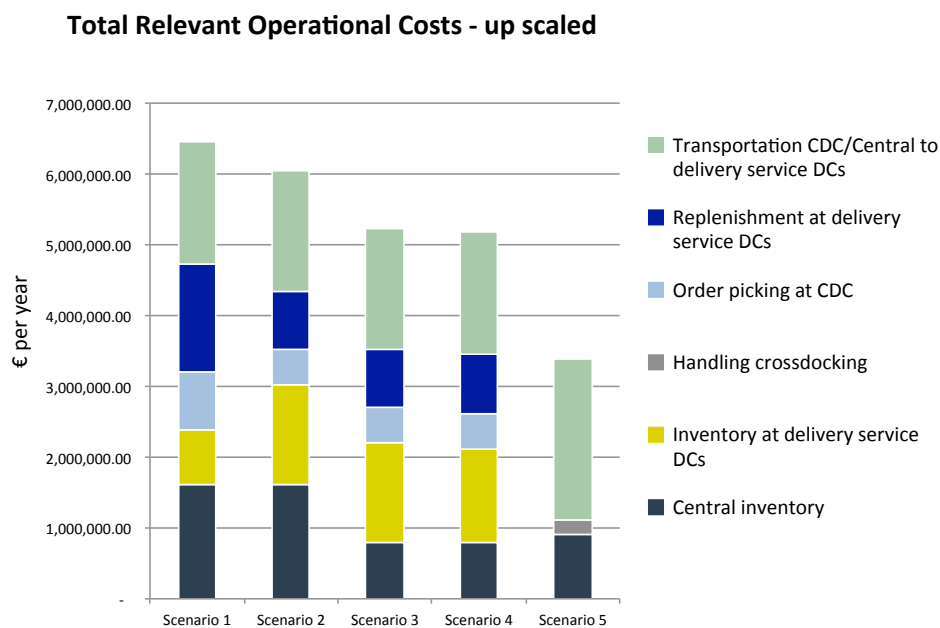
*Table 8 - Derivation of actual transportation costs*

	Weighted average distance (kilometres)	Shipment volume distribution (A)	Average distance distribution (B)	A x B	A * B normalised	Transportation cost allocation
Average trip to a wholesale outlet	113.38	51%	33%	17%	54%	5,589,099
Weighted average trip to delivery service DC	98.27	41%	29%	12%	37%	3,824,574
Average trip to a RDC	128	8%	38%	3%	10%	996,328
Sum		100%	100%	32%	100%	10,410,000

It shows that the numbers are very close, the difference being that the model gives 13% lower transportation costs. This difference can best be explained by the promotions that were scoped out (though that is mostly compensated with a higher utilisation rate than 90%), and the underutilisation of pallets in reality. In the model the calculations were based on the targets at which the pallets were planned at the CDC (in terms of volume), but it can be imagined that in reality not every pallet was stacked to its full capacity. Therefore there seems to be no reason to assume that the transportation costs in the model are inaccurate, instead they seem to reflect an optimal state of the current setup.

## 12.3 Conclusion

Because through validation it was found that there is no reason to assume that the calculations are inaccurate or wrong, now all results can be up scaled to the entire scope. Doing this, it turns out that whenever cross-docking is applied only to those items for which it is profitable under the minimum volume increase assumption, that total potential savings on operational cost will be around €2.68 million per year. This number is derived from the difference between the extrapolated results for scenario 5 and scenario 2. So in reality the potential costs savings can possibly be even higher because scenario 2 is already reflecting a cost optimal representation of the current situation, for example in the inventory levels, the picking productivity at the CDC, the functioning of the ABS and the implementation of EOQs. On the other hand, the cross-dock scenario is also reflecting a somewhat optimal state since it uses the minimum volume increase assumption that in reality most likely cannot be achieved.



*Figure 25 - Total relevant costs for five up scaled scenarios*

The results above should be exercised with caution because costs savings still need to be weighted against the investments needed in for example setting up the central warehouse. On top, cost savings are not the only factor that should be taken into account for the cross-docking scenario. The control on transport efficiencies and the introduction of additional risks are some of the other factors that need to be taken into account. They will be discussed in the next section.

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## 13. Managerial Insights & Thoughts

### 13.1 Logistic cost breakdown structure

Simply stating that in retail the costs of handling and transportation dominate the logistic costs breakdown structure only holds for the overall situation. When zooming in on different items, large deviations can be seen. The key lesson is therefore to treat each item individually, for example by looking at the sales figures, physical size of an item, cost price value or demand volatility. This way, a choice for the distribution network design can be justified better by allowing for multiple options like direct deliveries, cross-docking or the multi-echelon structure with a single-echelon installation stock approach. A multi-echelon approach was out of scope for this study.

When it comes to the cross-docking scenario, the main insight should be that for a small fraction of the item assortment it might not be a good idea to make the switch. What characterises these items is that while they are only 4% of the assortment, they make up for 47% sales volume. The dominant cost for these items is therefore in transportation, which was also reflected in the regression analysis.

### 13.2 Base replenishment quantities

What the calculations made clear is that when base replenishment quantities are set at cost-optimal values, a significant reduction in the costs of handling and inventory combined can be achieved (scenario 2 versus scenario 1). The savings on handling can be 44%, while costs for inventory (and inventory levels) will increase by 83%; the overall savings are then still 14%. So, compared to the current values that are set by the ABS managers at the delivery service DCs there is still a lot of potential for improvement.

There can be three reasons why current values are non-optimal. The first is that there is no decision-support to decide on the optimal values. Second, the consequences of setting non-optimal values are not directly attributed to the performance of an ABS manager. They are only focusing on providing adequate service levels using minimal inventory levels, which is also reflected in the fact that 67.4% of current base-replenishment quantities are set too low to be considered cost-optimal. A third option, which is of a whole other category, is that perhaps there are storage capacity constraints in the delivery service DCs that prevent the ABS managers to place larger orders.

### 13.3 Inventory allocation

One of the main difficulties in a study of this type is to accurately model the inventory levels. Using the DoBr tool this was however possible and gave an important insight compared to the earlier work by Van Pelt (2014). What concerns the inventory allocation between the upper and lower echelon, one lesson is that relatively *even more* inventory should be located downstream. This is because when considering total costs of handling and inventory, it is more cost-effective to place larger replenishment orders than in the current situation so that the costs of handling are reduced. It turned out that the rise in costs of inventory did not outweigh the reduction in handling costs. This could hold because the cost price value of items considered in the scoped Foodservice supply chain is relatively low. The overall cost reductions from scenario 1 to 2 applied to the majority of items in the sampled set (105 out of 476 cases).

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## 13.4 Transportation

In the current situation there is a lot of control (and flexibility) on the shipments that take place between the CDC and the delivery service DCs. Work loads at the CDC are relatively smooth because of the implementation of an order- and delivery schedule (see Schilders, 2015) and also because pallets can be stacked relatively efficiently with case packs and pallet layers. When switching to a cross-dock scenario this control is largely lost because the orders placed by the customers cannot be coordinated or directed/influenced. Whenever a customer only orders one item of all the scoped items, it will still have to be moved to the delivery service DC in a separate crate. The transport efficiency is therefore largely decided by the order patterns of customers.

As Figure 24 showed, the allowed increase of volume over the calculations that were made in scenario 5 is a factor 2.2 before the cross-docking scenario does not lead to any costs savings anymore. This is already under the assumption that 18 items are not being cross-docked anyway. Another assumption though, is that there is only one crate type, namely of size 55 litres. This was derived from current practices. To reduce the volume explosion for shipments in the cross-docking scenario, management could therefore still consider using multiple crate sizes.

## 13.5 Suppliers

Because of the complete removal of one echelon in the cross-docking scenario, now a good inventory management of the central warehouse becomes even more important. The reason is that in the current two-echelon design of the fulfilment supply chain, there are more buffer stocks in the system and replenishment orders placed by the delivery service DCs are supplied within a matter of a few days. When centralising inventory these buffers disappear while the lead times from the suppliers are considerably longer than that of the CDC towards the delivery service DCs. It is also one of the reasons why the total inventory value in the centralized location is still higher than in all delivery DCs combined (scenario 5 compared to scenario 1), even with the effects of risk pooling already taking place.

Also the imposed Qs by the suppliers are naturally larger, even though it is not sure on which basis the current values were derived. What is important to realise though, is that the current base replenishment quantities (and MOQs) set by the suppliers are probably based on the fact that the CDC also supplies the wholesale outlets and retail RDCs and thus more inventory is turned. It could be interesting to see if it would be possible to reduce the MOQs and/or Qs.

Another effect of the cross-docking scenario is that the inventory turnover ratio for some items for the CDC will drop significantly if it is chosen to build a separate supply chain for the delivery operation. Inevitably the conditions about MOQs with the suppliers would then also have to be re-discussed to prevent excessively large inventories or problems with shelf life at the CDC.

## 13.6 Human resources

What is already observed in the current design of the supply chain is that finding enough employees willing to work in the nightly hours during which the cross-docking process takes place is a challenge. This challenge can become even bigger when most of the picking is moved to another location and subsequently cross-docked, thus increasing the total workload for the cross-docking teams. The task of finding enough people, and securing them for a while on the job, should not be underestimated.



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Also, since most picking will be centralised in a cross-docking scenario also there should be enough employees available to work in this central warehouse. It can be expected that the majority of the current picking employees in the delivery service DCs cannot be relocated like the items since the daily commutes can be well over 100 kilometres.

### **13.7 Catastrophes**

When it is chosen to switch as much as possible to a cross-docking scenario for the scoped items, it means that all demand for these items would have to be met from one specific location. This brings extra risks when it comes to for example power shortages, fire and natural disaster. The current situation with eight different delivery service DCs spreads this risk over many more locations so that the losses will be much smaller when one region suffers from a catastrophe. One way to solve this is to build two warehouses, located centrally but also distributed so that they are separated enough. An extra benefit is also a shorter average distance to the delivery service DCs, but the investments will also be larger. Having two warehouses however would need much more research before any conclusion can be drawn. The conclusions in this report cannot be directly applied to a two-warehouse scenario since first an allocation should be decided upon, followed by re-calculation of all transport distances as well as the subsequent pooling effects and possible effects of allowing transshipments between the two warehouses.

### **13.8 Shipping frozen food**

In the current situation, frozen food is usually shipped separately to the delivery service DCs in special trailers that can cool well below zero degrees Celsius. Because these shipments are largely pallet layers and full mono pallets, this can be done in an efficient way. In a cross-docking scenario though, this will become more problematic since then the frozen food shipments will have to be either transported separately or in special compartments of the trailer. This will add not only extra costs, but also add extra handling time and more flexibility in fleet management. The question is how to organise the transportation in such a way that it does not add too much time and extra activities to the cross-docking process, while also taking into account food safety.

### **13.9 Service flows**

Whenever a cross-dock scenario seems a favourable option for certain items, then it could also be considered if the service flows can be decreased as well, by relocating the sourcing of these items also to the hypothetical central warehouse. To decrease a service flow will however mean that the inventory turnover ratio can become an issue in the service stores. Through interviews it was learned that at the moment already some items are put on display using more facings than allowed for by current consumption in the store due to marketing reasons. Internet sales therefore allow for certain items to be put on display in higher numbers than would else be possible.

Nonetheless, the benefits can be large since picking from the service stores is more costly than picking from a delivery service DC, let alone the total cost in a cross-dock scenario. Thus, savings that were obtained in this thesis report can easily be applied to the service flow as well.

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## 14. Conclusions & Recommendations

This research aimed at better understanding the logistic costs that occur within the scoped supply chain of items that are currently being shipped from the CDC inventory towards the inventory of the delivery service DCs. By gaining a better understanding, the objective was to be able to make a statement about the current design of the distribution network and see how it should look like in the future, given that the delivery operation is expected to keep growing. The research question defined was:

*"How should the supply chain for the delivery operation of the Dutch food wholesaler look like, so that the objectives for customer order lead time, product availability and product shelf life norms are achieved with minimal costs for the sum of holding of inventory, transportation and related handling activities?"*

By creating several uncapacitated scenarios, with each of them having different degrees of optimisation of the current situation, the costs of a cross-docking scenario were compared to the most fair scenario, i.e. that reflects best a cost-optimal state of the current situation. This scenario turned out to be scenario 2, while other scenarios only served for reference purposes.

One main conclusion with respect to the research question is that the design should be different for different items given that the logistic cost breakdown structure is not uniform across items. What concerns the cross-dock scenario design specifically, it turned out that compared to scenario 2, for some items (characterised mostly by high sales volumes) cross-docking was not a profitable switch. For the majority of items however significant potential savings were identified. The calculations show that by up scaling the results found with a representative sample set, the total savings on operational costs can be in the range of €2.68 million per year when those items for which it is never profitable are excluded. This figure could serve as an indication of what a possible investment in building a new central warehouse may be. On top there can be positive effects expected for product quality since the inventory turnover ratio in a centralised warehouse will be higher than at eight decentralised inventory locations.

This report is not conclusive though. The focus so far had been mostly on costs, based on certain assumptions that should be exercised with caution. One of them was the minimum volume increase assumption. The cross-docking scenario is associated with a certain loss of control on transport efficiency, which could not be modelled exactly apart from the sensitivity analysis. Since there is no control on the order patterns of customers, organising and planning the transportation in a cost-effective way for the cross-dock shipments can be more challenging since a high utilisation of trailers is much more difficult to obtain. On top, there is a tight timeframe during which any extra handling may take place to reduce transport volumes. This could need more research because the sensitivity analysis proved that whenever transportation volumes are not managed correctly, the potential savings for cross-docking decrease rapidly. There is some allowance though, up to a factor 2.2 compared to the number used in scenario 5.

Recommendations with relation to this study and the current design of the fulfilment supply chain are the following:

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Validate the current choice to ship large sales volume items from the CDC to the delivery service DCs. Since the moving of these items between the CDC and delivery service DCs is not necessarily a value-adding activity, a hypothesis can be that direct shipment is a better option. This depends also however on the fact if it will lead to less shipments being needed towards the delivery service DCs, and not for example only lead to lower trailer utilisation rates.

Any other recommendation that can be given at this moment is to use the indication of potential costs cost savings as input for the continuation of the distribution network design debate. What has become clear at least for now, is that the central warehouse could never possibly carry the entire assortment but will have to move more into the direction of a slow-moving DC. This as long as sufficient efficiency in transportation can be obtained. The next step could therefore be to start a (simulation) study on transportation efficiencies in a cross-dock scenario, which will be explained in the next chapter. Possibly also the location of the new warehouse can be a subject of topic.

## **15. Limitations & Future Research**

### **15.1 Limitations**

This research is characterised by a few limitations.

The first one is that the current actual dynamics of demand patterns are perhaps not fully captured by the DoBr tool. First of all an assumption was needed that demand is stationary, which might not necessarily be true. In that perspective, the ABSes used in the inventory keeping locations are more accurate since they make decision based among others on regularly updated forecasts. On top, the DoBr tool is not (yet) ready to incorporate minimal order quantities. These two limitations were identified as potential reasons why validation showed that actual inventory levels in the fulfilment supply chain are higher than in the model. There is however no other tool known to the author that can model accurately inventory in the retail environment as observed in this research.

Another limitation is that one assumption was that in the cross-dock scenario the production lead time is short enough to not conflict with the customer order lead time. While analysis showed that indeed 80% of the orders arrive before 16:00, as long as customers can still place a second order until 23:59 the feasibility is determined by the last placed order since the city trailers can only leave when all orders are loaded. Moreover, the minimum volume increase assumption was based on crates and roll container planned at full capacity. To create full carriers though, for example by combining two half-empty crates into a full one takes extra time that was not taken into account in the calculations. It is not known if time in the cross-docking scenario allows for such significant handling activities. The sensitivity analysis did show though that there is still some allowance on the volume increase before potential savings diminish completely.

A third limitation is the assumption of linear transportation costs per kilometre. In reality these costs are incremental since hiring a truck comes with a fixed costs, followed by the variable costs of fuel per distance covered. The assumption was used because utilisation rates at the moment are high, but with the loss of control over transportation efficiency high utilisation rates in the cross-dock scenario are not self evident and also depend on the exact implementation of the to-be scenario.

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Fourth, no uncertainty of supplier lead times was assumed. In reality this might be an important factor to decide on the safety stocks at the CDC because lead times here are sometimes considerably long. This will be important not only in scenario 1-4, but also in scenario 5 since the hypothetical central warehouse will also be directly supplied by the suppliers and manufacturers and no more buffers exist in the cross-docking supply chain.

Last, it was assumed that the picking of final customer orders could take place with the same efficiency as the average picking efficiency in the current situation. For this reason it was considered a non-relevant cost in this study. This assumption could however use more research, but due to the highly hypothetical nature of the cross-docking scenario it was chosen to just go ahead with this assumption. In reality though, the picking efficiency depends on a lot of factors like warehouse layout, order batching potential, the degree of automated and mechanised picking, the expected amount of congestion, etc. All these aspects were intentionally left out of scope for this study.

## **15.2 Future Research**

Since this study mostly focused on potential cost savings, follow-up studies would naturally have to focus more on the implementation of a cross-dock scenario. One study therefore could be to research how transport efficiencies can be controlled under a cross-dock scenario because the sensitivity analysis in this report showed that volume is a critical cost factor. Also the implications of optimising transport efficiency in relation to customer order lead times are an important topic. Physical activities to improve the density of shipments take time, and it can be interesting to know how much optimisation is allowed to not conflict with the strict deadlines each night. One approach could be to build a simulation model and study different cross-docking designs.

It can also be interesting to research how a pilot cross-docking project could be set up, and from which location. The main difficulty in implementing the full scenario 5 from this thesis project is that it is an all-or-nothing switch, which comes with a huge investment and a ton of risk like failure to meet customer lead times. On the other hand, setting up a small pilot project might not grasp the true potential of the cross-docking scenario as it needs a certain scale to be able to utilise trucks, see the effects of risk pooling and enable a direct reduction of FTE for handling activities. Also, since the activities at the CDC highly depend on the delivery service DCs also here the consequences of a pilot project should be managed carefully. So, how to set up a successful pilot project would certainly need thorough thinking.

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# Appendix A – Organisational Structure

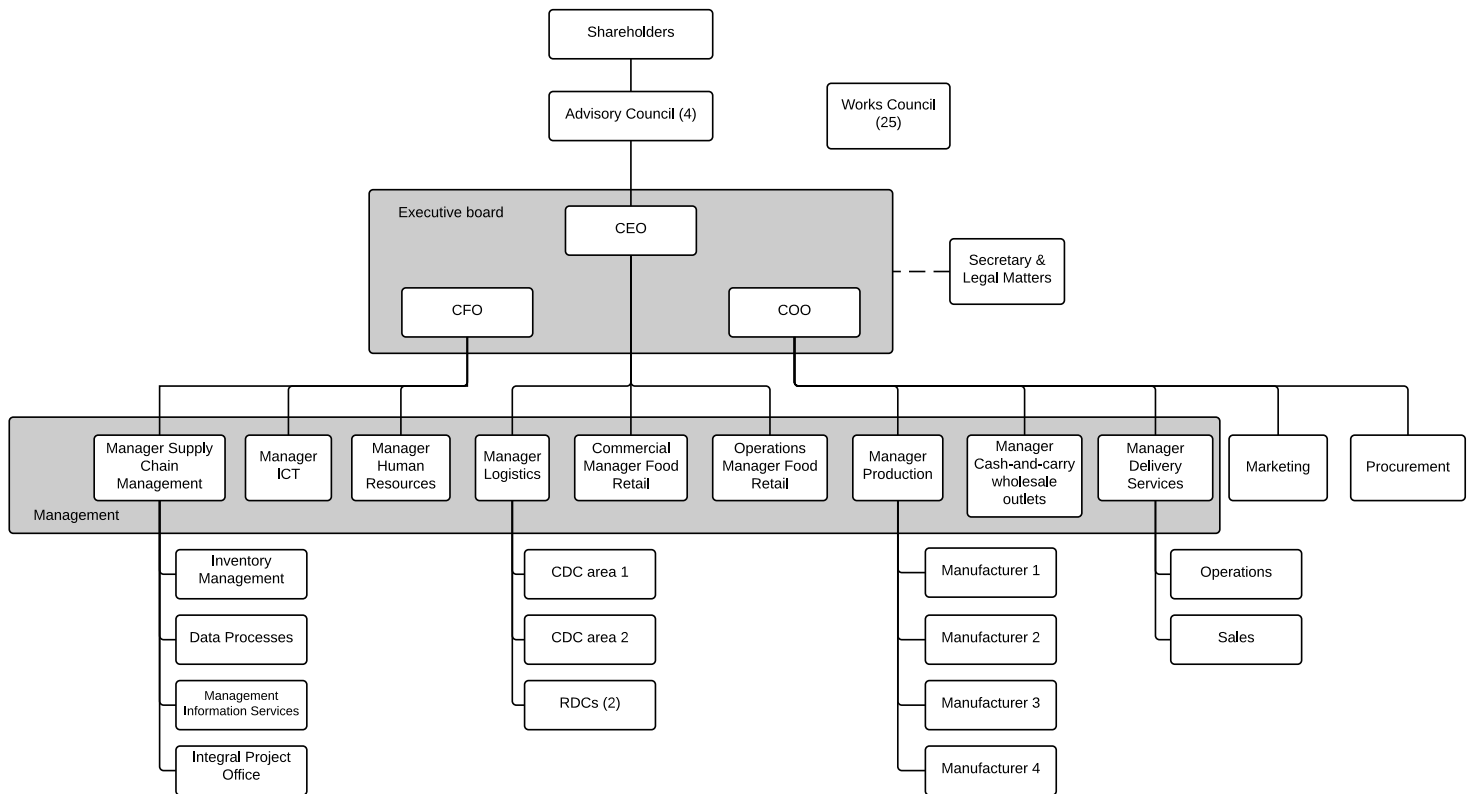


Figure 26 - Organisation structure of the Dutch food wholesaler

# Appendix B - Accumulation of online demand

Received orders at a delivery service DC with next day delivery



Figure 27 - The accumulation of (pick) orders at a delivery service DC

All received orders



Figure 28 – The accumulation of customer orders through the online ordering platform



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## Appendix C – PickArt

### PickArt: Paperless Batch Order Picking

PickArt is a system developed by the Belgium-based company ABM. It is a paperless order picking system that enables batching of multiple picking orders while navigating through a warehouse according to an optimized route. The system is designed to decrease the total seek and travel time per picking order. Orders are received through pick-to-graphic displays that instruct an operator with the next step each time after a barcode has been scanned.

To start the route, first several picking orders are batched by a planner and downloaded to the PickArt cart. Then, the operator is asked to link the carriers on the cart to individual picking orders. With all orders in the batch connected, the system then directs the cart to the start of the route to a specific item location. After validating the location with a scan, the system instructs the operator to start picking the required number of units of this item. For this, above each crate that requires one or more units of this item a light will illuminate. The lights are dimmed again after scanning or pressing the respective display module, which should be done once the item is picked. This way, picking orders can be completed with minimal errors in a way that is arguably more efficient than when using paper-based systems.

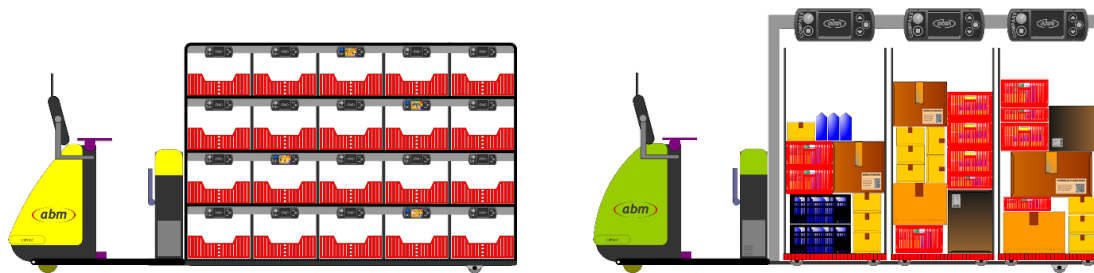


Figure 29 - Electric pick carts (left: 60 crates in a batch, right: 3 roll containers per batch)

At the Dutch food wholesaler, PickArt is incorporated several forms. There are for example carts that can carry up to 60 crates at the same time, enabling the batching of maximum 60 picking orders. Above each crate there is a pick-to-graphic display attached to instruct the operator. The cart itself is installed on an electric pick truck and can thus be moved across a warehouse according to the optimized route as determined by the system. Other versions used are electric pick trucks that can carry either three (delivery service DC) or four (Retail DC) trolley containers, two CHEP pallets (1200x1000mm) or two EURO pallets (1200x800mm). The latter two are found predominantly at the CDC.

### Pick-to-light

A ‘pick-to-light’ (PTL) or light directed system is a static system that consists of lights that are put above racks or bins from where an employee will be picking items. Whenever an operator downloads a picking order to the system, the lights above the relevant bins will illuminate with a quantity to pick. The operator can then grab an empty carrier and fill it up with the required items as he/she moves through the picking aisle of illuminated bins. To confirm a pick, the operator needs to press the indicator, retrieve the required units of the item from the bin and put them away in the carrier.

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In the case of the food wholesaler, the pick-to-light systems have a live roller conveyor that runs parallel to the front of a static set of flow racks filled with item-carrying bins. This way an employee can easily push his carrier through the aisle, saving him/her the lifting of heavy crates. On top it is also a more time-efficient form than for example pushing along a cart.

PTL systems are typically used to increase the picking productivity of an employee, specifically for small items that can be put away in a standard bin like a crate. Due to the short distance between these bins, which are often also positioned in multiple rows above each other (see Figure 30), combined with the fact that an employee does not actively have to search for the location of a bin and look up the required pick quantity on a paper, the time needed per order line is typically much shorter compared to paper based systems or even PickArt systems using traversing routes.



*Figure 30 - Pick to light in the non-food DC*

The large amount of hardware (and software) needed to install a PTL system makes the investment typically higher than systems without such requirements. Also more resources are needed to make sure the racks or bins are always sufficiently filled since it requires extra time for items to be stripped from the packaging before they are put away in a bin.

### **RF (pallets only)**

A third method of picking orders is by pick trucks that are designed only to lift and move around pallets. This system works through a radio frequency (RF) network that instructs the operator through a display where to pick up a pallet. Due to the limited applicability of this system, it is only used for large bulk orders. Bulk orders are orders that involve only full pallets, i.e. pallets that only need to be picked up as a whole and for which no manual labour like restacking or activities of others sorts are involved.

### **Pick-to-zero**

Pick-to-zero is a picking methodology that can be considered the opposite of PickArt. Instead of visiting for each picking order exactly the location of the item, pick-to-zero dictates that for each item you visit the locations that ordered. So instead of grabbing an item from one location (PickArt), pick-to-light is distributing one item over multiple locations (each representing a ‘customer’). Because the total number of units of a particular item being distributed is exactly the total amount ordered by the customers, it will lead that at the end of the distribution process no units will remain, hence the name pick-to-zero.

Pick-to-zero is used at the CDC for items with a critical shelf life. It is an effective methodology because doing so leads to that at the end of each day no inventory remains in the CDC, which adds extra shelf life to the inventory at the delivery service DCs, and thus potentially also to the final customer. The system does require that a customer (in this case a delivery service DC or a wholesale outlet) can only place an order exactly on the day before the supplier visits the CDC. Also, the

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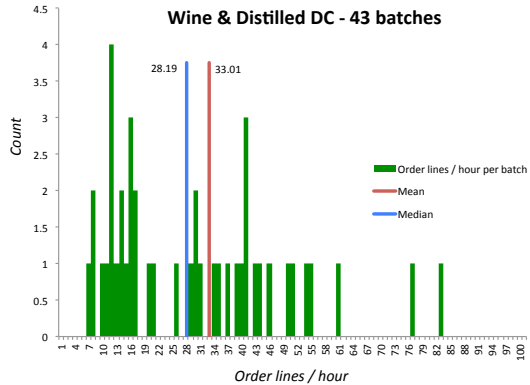
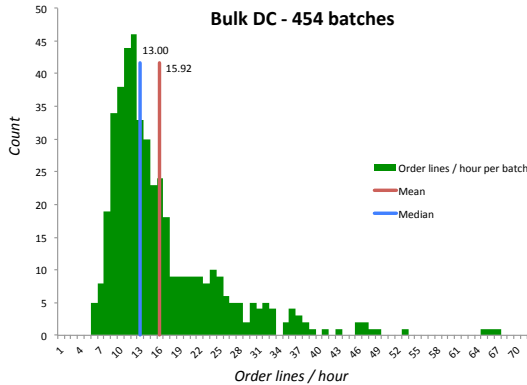
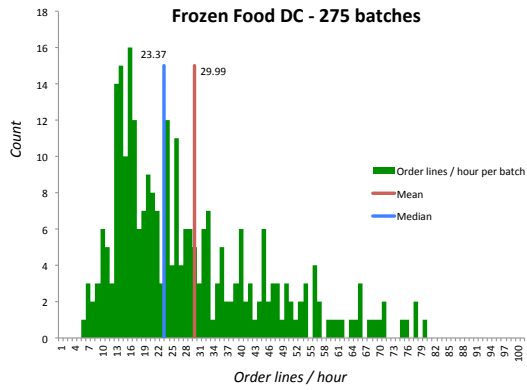
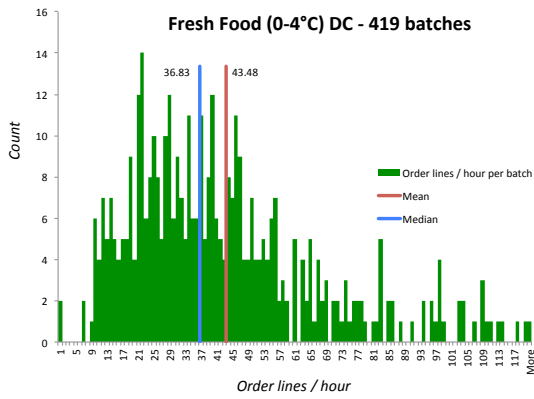
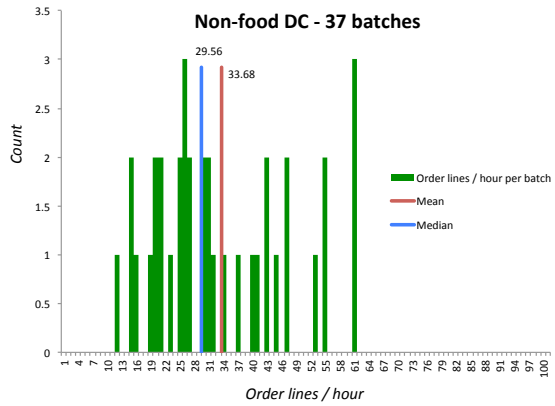
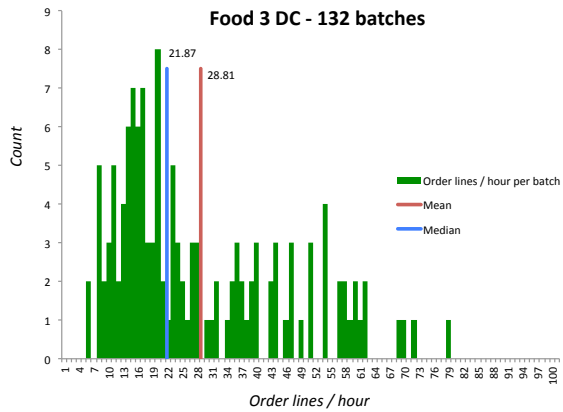
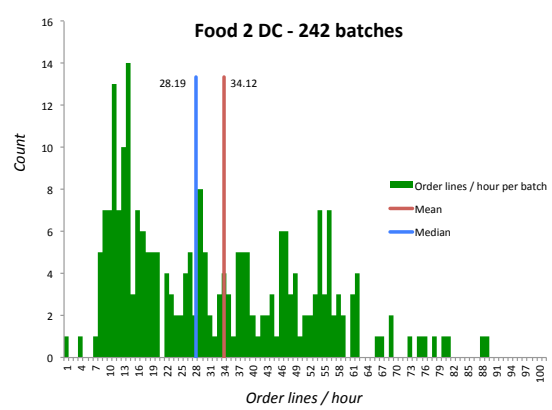
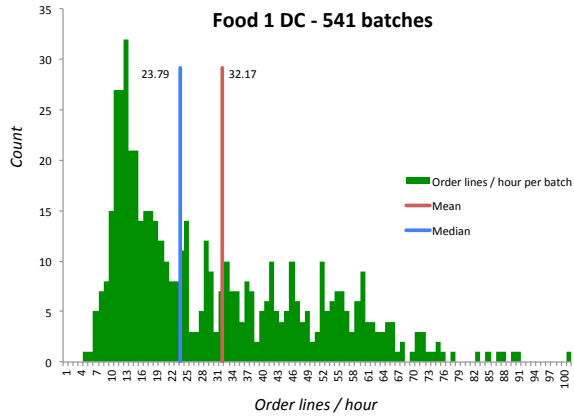
supplier then needs to supply the exact amounts that were ordered in total. It thus requires some flexibility from the side of the supplier, for which it often charges a higher cost price. While a pick-to-zero is technically possible with the aid of a PickArt system, at the moment paper is still used to guide the process as the methodology is still in a start-up phase.

Pick-to-zero requires that the supplier supplies directly to the location where the pick-to-zero process takes places. For this reason it is not viable for most items in a delivery service DC since it will require a supplier to then visit all eight of them instead of just visiting one central location like the CDC. For low volume items this will inevitably lead to higher costs charged by the supplier. On top, a pick-to-zero methodology is highly unlikely to work in the context of final customer orders because there will be simply too many different customers per day and there is not enough space in the delivery service DCs for the layout of such a system. Moreover the customers over which to distribute the products will be different each day.

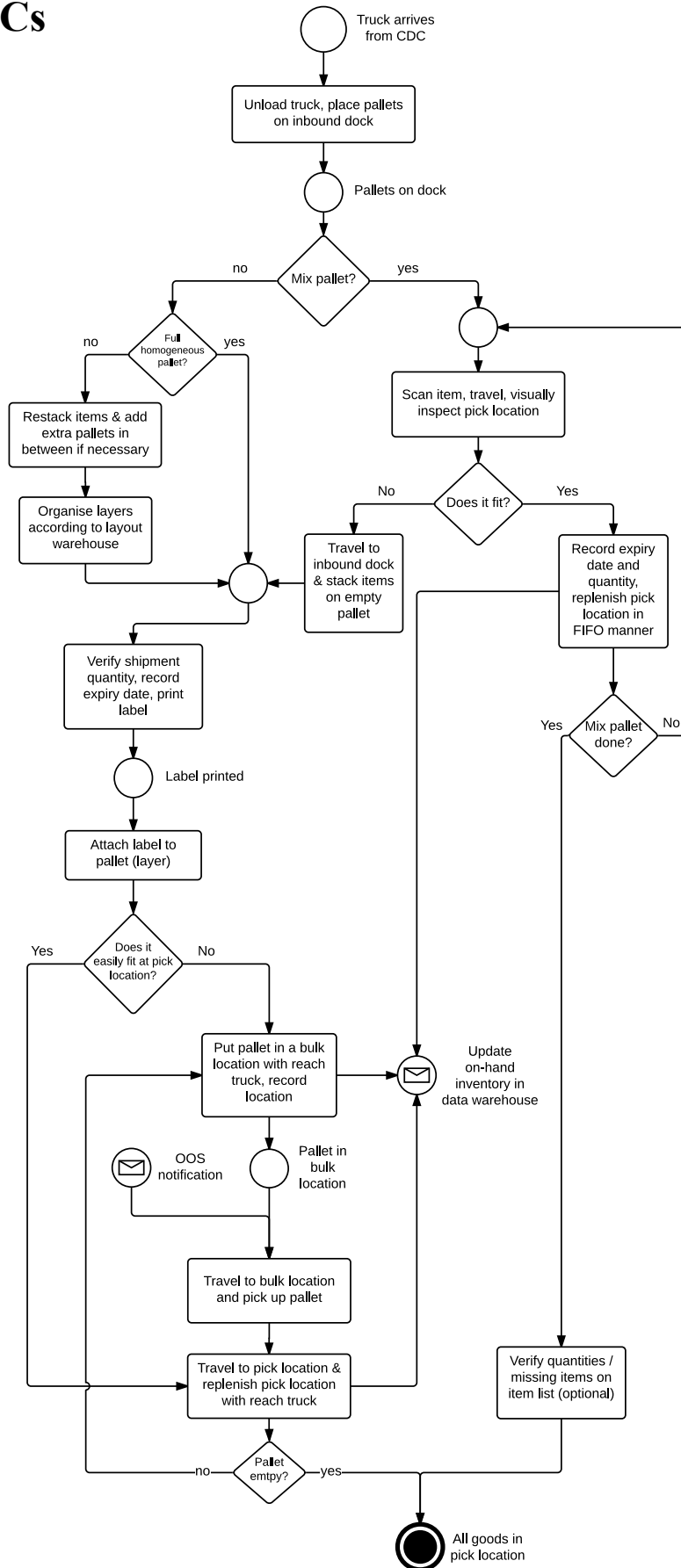
**Put-to-light (Dutch: ‘verdeelplein’ or ‘folderplein’)**

Put-to-light is a methodology used in the CDC for items that will be on promotion because it is an efficient way to handle large volumes. The main idea is that there is a designated area with locations that represent customers (i.e. the whole sale stores and delivery service DCs, similar to pick-to-zero) and pallets of goods are moved in front of these locations and then distributed accordingly. The main difference with the pick-to-zero is the large volumes and the automation in the form of the assistance of illuminating lights and displays that dictate the amount to distribute.

# Appendix D - Current Picking Productivity at the CDC



# Appendix E - (Mixed) Pallet replenishment at the delivery service DCs



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## Mixed pallets

Time-motion studies were performed to analyse the time it takes to replenish mixed pallets in a delivery service DC in the two (out of three) different DC areas, namely the temperature-controlled zone with perishable items (0-4°C also known as ‘Koeling’), and the DC area where regular groceries and non-food items are stored (also known as ‘DKW’).

The measurements were done in three delivery service DCs, the combination of them being considered a representative sample of all eight delivery service DCs. In each location the measurements took place during at least one full day, where in the morning multiple mixed pallets were analysed in the temperature-controlled areas and in the afternoon several mixed pallets in the grocery section. The employees undertaking the replenishment operation during those measurements sessions were chosen by their group managers for being representative employees that can perform according to the desired performance level.

The time-motion study was set up as follows. Each mixed pallet consists of multiple articles in varying quantities, each making up an order line. Mixed pallets typically are made up of 10+ order lines. Per order line the replenishment operation consists of several activities that can be considered either fixed or variable per article quantity (i.e. size of an order line). An overview:

1. Choose an item at easy reach on the mixed pallet, scan its barcode and retrieve the location information on a handheld electronic device that is connected to a database.
2. Travel to the location of the item in the warehouse, identify the exact pick location and inspect if the location can fit the products on the mixed pallet.
3. If so, check the expiry dates on the products in the pick location and compare them with the date of the products received. Record them into the system, as well as the shipped quantity.
4. Start the replenishment of the pick location in a FIFO manner. When needed, physically remove all the items with a shorter shelf life from the shelf and place back once the items from the mixed pallet are put in the pick location.
5. Back to step 1.

During the time motion studies, sheets were filled in where for each order line the time in seconds for three steps were measured with a stopwatch. These steps were: travel (step 1 & 2), scan and record (step 3), replenish (step 4). The reason to use these three steps is because they can most often be identified easily during the observations. An example of the sheets used during the observations:

Pallet description:	Mixed pallet DKW		Location:	....
Begin time:	08:00 AM			
Finish time:	08:37 AM			
Article number	Travel	Scan & Record	Replenish	Total
12345	44	23	5	
67890	0	12	40	
...	...	...	...	...
Clean up pallet	-	-	-	100

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Even though some slight deviations in work procedures were observed during the observations across the different locations, it proved that the measurement method was sufficient to be performed in all locations and DC areas. Sometimes though, the administrative steps of scanning and recording were intertwined with the other three steps and even with other article numbers, depending on the employee and area. For this reason, there was also an extra column created for the total time needed per order line in case the distinction between the three steps was difficult to observe. Especially with observations made in the cooling area, information about the individual steps sometimes could often not be retrieved. When for example crates contained four different items, the employee at some point needed to gather extra empty crates and put each item in a separate crate. This sorting activity was easy to observe and time, but it was not possible to divide the time fairly over the article numbers, especially at the speed at which these activities occurred one after the other. In those cases, only the total time for an order line was observed (i.e. time for individual steps is omitted) and the time for this sorting activity was added to the total time needed for the first replenished item of those four items.

To verify the sum of the total time measurements per order line, also the begin and finish time of each pallet was recorded, as well as overhead like the time needed to clean up the mixed pallet after replenishment was done. It was found that measuring individual order lines can be a good indicator for the time distribution between fixed and variable time aspects, but that they always underestimate the exact time needed per order line. The main reason is perhaps that when each time measurement has a few seconds of error, it quickly adds up.

Another conclusion is that the time per individual step is highly fluctuating since it for example really depends on whether an employee needs to travel to another isle in the warehouse. This is mostly depending on the way the pallets are stacked at the CDC compared to the way the delivery service DC is organised (i.e. 'slotting'). An experienced employee with knowledge about the location of items can have some kind of control over it by selecting the next item on the pallet in a wise way, but in general it can be considered an exogenous factor whether or not the next item on your pallet is near the current location or not. It was observed that for many items there was substantial travel time, while for others there was none. Also what distorted the measurements were items for which the pick location was already full, or where the items did not have a pick location at all. For these order lines a lot of extra steps were needed (see the process diagram earlier), each of them adding up to the total time.

So, in the end it was decided that the most stable, fair and reliable way to measure the replenishment productivity in the delivery service DCs was to divide the total time for a mixed pallet by its number of order lines.

## Pallet layers and full mono pallets

The replenishment of pallet layers and full mono pallets were studied using the same methodology. The results can be found in section 7.2 and show that productivity is about three times lower in terms of order lines per hour. But whenever orders being placed with these base replenishment quantities also lead to orders being placed three times less often than when ordering items that will be supplied on mix pallets, savings on handling can be obtained.

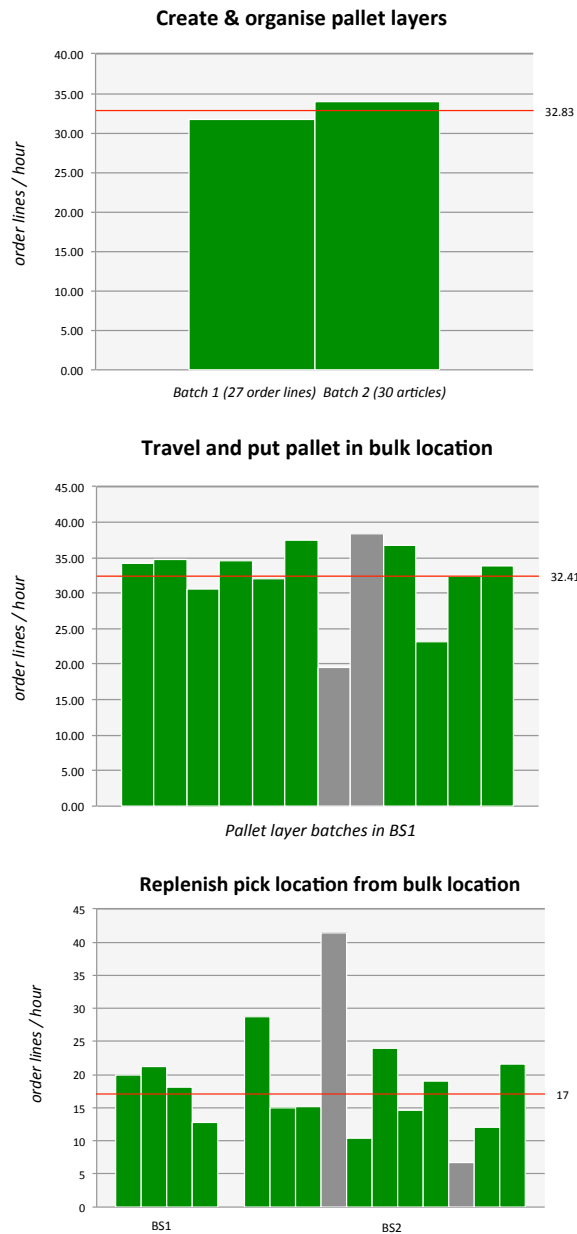


Figure 31 – Productivity for various steps in the replenishment process for pallets and pallet layers



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## Appendix F - Demand Data Preparation / Processing Steps

On average there are over 10.000 different items kept in both the inventory of a delivery service DC and the CDC (the exact number is hard to tell because every delivery service DC has a different assortment). To be able to make calculations within the specified scope and time of this research, a selection out of these items needed to be made. The starting point was a set of items that were shipped between the CDC and delivery service DCs in 2013, provided by Van Pelt (2014). This selection, 1403 unique items, already excluded any items with obvious seasonal patterns during 2013 and items that were being phased in or out during 2013. Also these items were verified to see if they were not cross-dock items or items that were not completely sourced from the CDC but also from other locations. Only 'regular' items were considered, that is: any item that is under normal conditions transported from the CDC inventory to the delivery service DC inventory and from there sold on towards the final customers throughout the entire year.

### PHASE ONE:

#### **1. Daily demand per item per delivery service DC**

For this research it was chosen to retrieve the demand data over 2014 by requesting for each item from the initial selection, and per delivery service DC a time series of total daily requested quantities for each operational day during week 1 until week 52 in 2014. Due to a merge of two delivery service DCs into a new one during 2014, the data from these three locations is also merged into one location because all sales of the two locations were relocated to the new location. During the transition period no phantom sales were found in the set. To conclude, in the data set only eight delivery service DCs exist, even though in the beginning of 2014 there were nine.

An example of what constitutes demand for an item: say that online a customer in region A orders on January 1<sup>st</sup> 20 units of item A. This order is received centrally and redirected automatically to the appropriate delivery service DC (based on the customer's postal code) in region A. When it turns out that the item is not available a substitute item will be offered, item B. Let's say that the customer agrees upon the delivery of item B and says that he wants his order to be delivered on January 9<sup>th</sup>. The requested quantity of item A is then discarded and not recorded into a database anymore. But for item B 20 units will then be assigned to January 9<sup>th</sup> as being the demand from that customer for that item in that region on that day. If and only if no other customers in the same region ordered item B to be delivered on January 9<sup>th</sup>, then it will also be equal to the total demand for that day for item B in region A. Even if only 5 items were delivered in the end, the demand would still be 20 since that quantity was originally requested. The service measure for that event will then be equal to 25%.

The days in the time series that are no operational days for the delivery service DCs (like some holidays and most Sundays) were omitted since no deliveries can take place and so no demand can be assigned to that day. Operational days without demand for a particular item are given a demand equal to zero.

#### **Omitting data points**

Once the daily demand data were obtained, first all negative demand was omitted. These negative demand quantities can be return flows so it is chosen to simply omit these data points. Then, any sales

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for items that were at that time in the promotion folder were also omitted because they bias the demand averages and standard deviations. Sales of promotion items are typically higher than sales during regular weeks and, in general, cannot be considered representative. Any sudden peaks or surges in demand for an item due to large promotions will also increase the standard deviation, and this will lead to the DoBr tool installing too many safety stocks during regular periods. Due to the way promotions are recorded in the data warehouse, it was not possible to omit a demand data point on a particular day if the item was indeed on promotion but without it having any recorded sales in any of the delivery service DCs. In these cases, the data points are left in the sample and thus carry a demand of zero.

After omitting the promotional and negative requested quantities, the leftover demand points were scanned as a way of verifying that the process of omitting data was performed correctly and completely. During this activity two data points were found with exceptionally high requested quantities, being more than 100 times larger than any other data point in the respective daily demand series. These points were also omitted from the time series since they probably represent special orders or are perhaps even data errors.

### **Mean, standard deviation and CV**

Then, for each series the sample mean, sample standard deviation and coefficient of variation were calculated. For each item-location combination, the average daily demand  $\bar{x}$  during 2014 was obtained by summing the values of all its demand data points  $x_i$  and dividing it by the number of observations,  $n$ :

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

The sample standard deviation of the series,  $s$ , was obtained by:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}}$$

The coefficient of variation for an item,  $CV$ , is then equal to:

$$CV = \frac{s}{\bar{x}}$$

### **CV outliers**

Also a count was done of the total occurrence where daily demand data points were higher than zero. This operation yielded several observations (item-location combinations) where the demand during 2014 only occurred on one day (154 observations) or not even at all (28 observations). For those cases where no demand was recorded at all, these items have most likely been replaced or phased out over the course of 2013 and 2014. Therefore the respective series were removed completely from the data set. For the series with demand on only one day, it proved that the coefficient of variation was extremely high, between 14.9-19, and so it was decided to also remove these time series completely. These data points can be considered either exceptional demand probably not met from the shelves of a delivery service DC, and most likely they are just items that have been phased out during 2014. Further analysis indeed confirmed that in the last 6 weeks (and some even in the last 5 months) there had been no more recorded sales in any of the delivery service DCs for these items. On top, for these

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items there was also no information available anymore in May 2015 about the review period for the CDC, signalling they had been phased out.

A second round of analysis was made by checking all data series again, this time to see where demand only occurred on two days during 2014. A total of 130 series were identified. Also here it proved that coefficients of variation were very high and so also these series were omitted from the data under the same reasons as those described in the previous paragraph.

Then, the data set was arranged in descending order of coefficients of variation to look for any other anomalies. Most data series on top of this list proved once again to be items with very few demand days during 2014, between 3 and 9. There were however several occasions where CVs were high, even though the number of days where demand occurred was  $>10$ . For these series, extreme demand data points were suspected. Closer inspection identified several extreme values compared to the average demand. It was decided arbitrarily to scan for outliers in those series where  $CV > 9$  but the number of demand days  $> 10$ . Whenever an obvious outlier was identified (typically 10 times the second largest value in the series), it would be omitted unless it did not improve the CV significantly. A total of 22 extreme values were omitted in the end. It showed that actually for any other items in the list, for example with CV around 7 no more outliers could be identified. These items just had a rather volatile demand pattern, mostly due to low sales frequency (i.e. slow movers) and thus these data were not modified.

When finally checking again how many different items were left in the original sample of size 1403, it turned out 12 items were not represented in any of the time series anymore. So, the total item selection at this point had a size of 1391 items.

### **Delivery schedule information**

Then, to improve the item selection even more the list of items was validated by comparing it with the delivery schedule for the CDC in relation to its direct suppliers. A data file was obtained with 30,514 items marked as active in the month of May 2015. For another 123 items in the sample it turned out there was no information (anymore), signalling that these items had been phased out. Therefore, at this stage  $1391 - 123 = 1268$  items were left in scope. Then, also the items that were sold in only 1 delivery service DC throughout 2014 were omitted since they are either regional items, perhaps even for national accounts or just phased in or out as well. This was the case for another 9 items, making the grand total of in scope items 1259 out of the initial starting selection of 1403 items.

More steps will be explained next to describe how this selection needed to be narrowed down even more.

## **2. Daily, pooled demand per item**

A second, similar time series was retrieved from the data warehouse with the same data, but merged over all delivery service DCs. This way the country-wide, pooled demand for each item could be obtained. Also for this data set all the sales during promotions were omitted, as well as negative quantities. On top the 22 exceptional high values that were found earlier in the data series per delivery service DC were also corrected for in this set. Finally, the mean, standard deviation and CV were obtained.

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A quick check to verify the results showed that the average CV of all items in this data set was significantly lower (1.20) than that of the average CV of the time series of the previous item-location combinations (2.53). It confirmed the risk-pooling effect taking place. Further analysis (after some additional scoping) is provided in Appendix D.

### **3. Daily demand per item at the CDC**

To obtain the demand that the CDC observes from the delivery service DCs, a time series was retrieved of the *actual* shipments per day per item to all delivery service DCs combined, during 2014. Unfortunately no data about the *requested* shipment quantities is kept in the warehouse, only the actual shipment quantities are available. This is however not a big issue since these are internal shipments and so any missed units will simply be ordered next time. Thus, over the long term the shipment quantities between the CDC and delivery service DCs should be equal to the requested quantities (corrected with the fill rate target and with some anticipated damage, outdating or obsolescence of stock). Only when there exists a structural problem in the supply of goods the numbers will not line up, but these items are not considered during this research.

#### **Omitting data points**

To enhance the quality of the data, also on this set some activities were performed. First any negative shipments were omitted. Then, since the promotional sales were omitted in the previous two data sets, also this data needed to be corrected for promotions.

Due to the way promotions are recorded, it was not possible to exactly identify which fractions of the shipments were due to promotions, and which due to regular sales. The method developed therefore was to omit per item the data of the shipments between the CDC and the delivery service DC on the days of promotion, but shifted by three days due to the average delivery lead time between the CDC and delivery service DCs. So, if an item was on promotion on Friday, then the shipments taking place on the Tuesday before, were omitted. If an item was on promotion on Monday, then the shipments on the Thursday before were omitted. The only shortcoming of this method, due to technical reasons, is that promotions on Wednesday suggest that shipments on Saturday should be omitted but there usually are none because the CDC usually does not operate during weekends. Therefore, a slight overestimation of the shipments was expected because not all promotions could be omitted. However, there is no other exact way to tell when the shipments for a promotion are sent to a delivery service DC because this also involves many other factors. For example, when trailers with regular shipments are sent to a delivery service DC, the remaining space is often utilised by shipping ahead the future promotional items. A DC manager can make the decisions on the spot to ship promotions ahead of time, depending on the available capacity in the trucks.

Also, 9 more items were identified that did have sales in the delivery service DC but that had not been shipped between the CDC and delivery service DC (unless they were originally in the data set before the promotions were omitted). These 9 items were also left out of scope for the data set. The final size of the item sample, for all three of the data sets, is thus a selection of 1250 items.

#### **Verification**

A quick check was performed to compare the total volumes in the data sets to see if omitting the promotions had caused any major differences between them. The total size of the actual CDC shipments was 7,785,973 units (for the 1250 scoped items), compared to 7,600,139 units for the total

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requested quantities from the individual delivery service DCs (for the 1250 scoped items). If corrected for the average service level that was provided by the delivery service DCs in 2014, namely 98.7%, then it means that the volume of inventory in the delivery service DCs seemed to have increased with about 3.8%. But by also taking into account some inevitable damage, outdating or obsolescence of stock at the delivery service DCs, this statistic is expected to reduce slightly. What is also likely is that because the promotions are sometimes sent more than three days in advance when there is some available truck capacity, not all promotions could have been filtered out exactly. There is no record available to see when promotions were shipped from the CDC to the delivery service DCs.

To conclude, it still could be possible that inventory levels did increase slightly throughout 2014, also because revenues grew with about 11%. So, there is a good indication that the removal of promotions in the shipment data was effective. When the promotions in this data set would not have been corrected, the inventory increase would have been >15%, which seems much less realistic.

### **PHASE TWO – SHELF LIFE:**

Each item is given a shelf life that the manufacturer or external supplier guarantees as a minimum towards the CDC (while in reality, shelf lives at the inbound dock are recorded most often at higher values since the guarantee is only a minimum).

From the data selection process in round one, 1250 items were found to be in scope and so the shelf lives of these items were retrieved. It was then observed that there were certain item-location combinations where the average daily demand was not enough to even order a single unit of an item without having infeasibilities with shelf life. An example:

Item A has a shelf life guarantee of 21 days. As an accepted rule of thumb, a maximum of one third of this shelf life may be taken up by the inventory days at the CDC and the rest should be ‘given’ to the delivery service DCs. So, the delivery service DC will receive the item with a shelf life of at least 14 days. As another rule of thumb, the delivery service DC may take up maximum half of this shelf life and the rest should be offered to its final customers. So, 7 days may be taken up by inventory days and 7 are for the customer. So, the total demand during those 7 days should always be larger than at least one unit, or  $\frac{1}{7} = 0.14$  units per day else there is definitely an infeasibility with shelf life (while not even considering the safety stocks). If demand is lower than 0.14 units per day, it means that whenever the delivery service DC orders the minimum of one unit of the item at the CDC, it is expected to be already expired by the time the unit has been sold, even when there is no safety stock already present at all. So, whenever the following equation holds then it was decided to leave the item out of scope:

$$\frac{s_i}{3} < \frac{1}{\bar{x}_i^d}$$

where:

$s_i$  := shelf life for item  $i$  (in calendar days) as guaranteed by supplier or manufacturer to the CDC

$\bar{x}_i^d$  := mean daily demand for item  $i$  in location  $d$

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Because of this shelf life restriction, some items in the item selection (size: 1250) showed to have infeasible shelf lives with respect to their daily demand: at the CDC (where minimum order quantities are defined by the supplier or manufacturer and always  $> 1$ ), there were 146 items with infeasibilities<sup>1</sup>. At the delivery service DCs there were 106 cases, representing 86 unique items. Combined it was found that an extra 214 items needed to be removed from the selection, resulting in an item selection of  $1250 - 214 = 1036$  items in scope.

**PHASE THREE – SALES VOLUME CURVE:**

With the 1036 scoped items, plots were drafted of the cumulative sales figures over 2014 (in units and litres), which were then compared to the sales of the entire population (20514 items). In order to have a representative data set, it was chosen to match the curves of the cumulative sales volume. For this, several items needed to be manually removed in an iterative process. The result is a set of 476 items. Some statistics of this dataset are provided in the next appendix, Appendix D.

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<sup>1</sup> While for this research purpose there is a shelf life infeasibility, in reality it might not be the case because the CDC also supplies the wholesale outlets and retail RDCs. Demand for an item in reality is therefore inevitably higher, and so there might not be a shelf life infeasibility in reality. However since this research isolates the delivery service operation, it is more accurate to leave these items out of any calculations.

## Appendix G – Final Item Set Statistics

Table 9 - Item set statistics

CDC Area	Total count in set	Percentage of total assortment shipped from the CDC in 2014	Percentage of total sales volume in 2014	Percentage that is picked in crates (as opposed to roll containers)	Percentage sold in either 7 or 8 delivery service DCs
Food 1	114	2.5%	5.8%	79%	93%
Food 2	100	3.5%	6.0%	78%	91%
Food 3	45	2.0%	6.5%	89%	93%
Non-food	28	1.2%	4.8%	86%	86%
Fresh Food	50	2.1%	5.7%	84%	86%
Frozen Food	91	2.3%	5.9%	0%	79%
Wine & Distilled	10	1.7%	3.1%	60%	100%
Bulk	38	2.3%	9.4%	5%	95%
<b>Total</b>	<b>476</b>	<b>2.3%</b>	<b>6.7%</b>	<b>59%</b>	<b>89%</b>

The item set was tailored as to include as many items as were initially in the sampled set, but under the condition that the combination of them follows the same Pareto curve as the cumulative sales volume curve from the population. Also, it was taken into account that sales volumes in the set should be equally spread across DC areas. The result can be found in Table 9.

When looking at the final item selection, (Figure 33 and Figure 32), we can see that 50% of the sales volume (in litres) constitutes the sales of 2.8% of the items in the set. Further, 80% of sales are generated by about 12% of the items while the remaining 20% is from sales of 88% of the items.

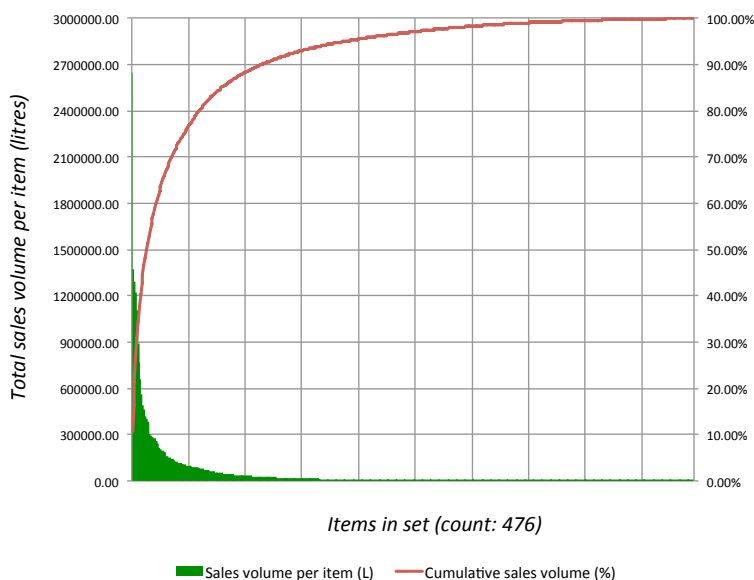


Figure 32 - Yearly sales volume distribution of all selected items

When plotting the total sales volumes of all items that were shipped between the CDC and the delivery service DCs (see Figure 33), we can see almost exactly the same statistics. The only difference is that this curve is derived from data from 20,514 different items. Thus, it can be

concluded from the two graphs that the item set can be considered representative for the sales volumes observed in the scoped supply chain.

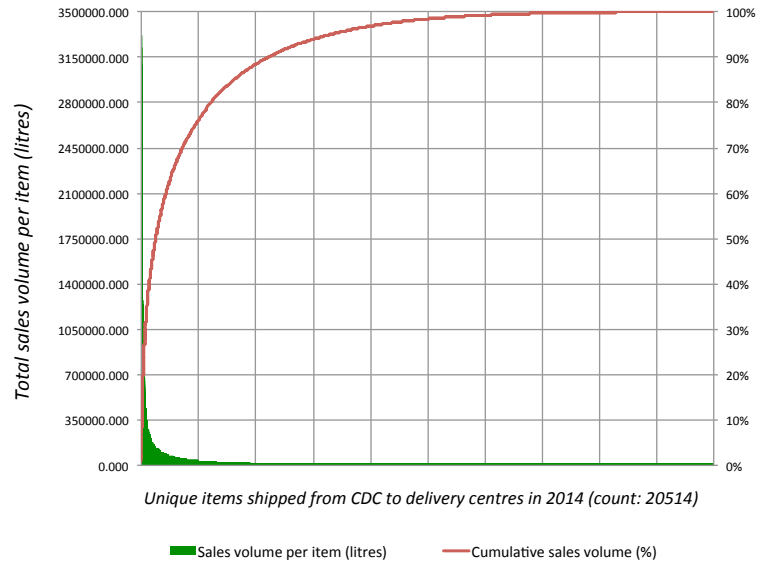


Figure 33 - Yearly sales volume distribution of all items shipped between CDC and delivery service DCs

What concerns the sales in terms of units, the curves deviate slightly, as can be seen in Figure 34 and Figure 35. It proved very difficult to match the item set over two different dimensions. But since one hypothesis is that sales volumes drive more costs in this research project than sales units, it was chosen to tailor the item set such to reflect the sales volume distribution most closely.

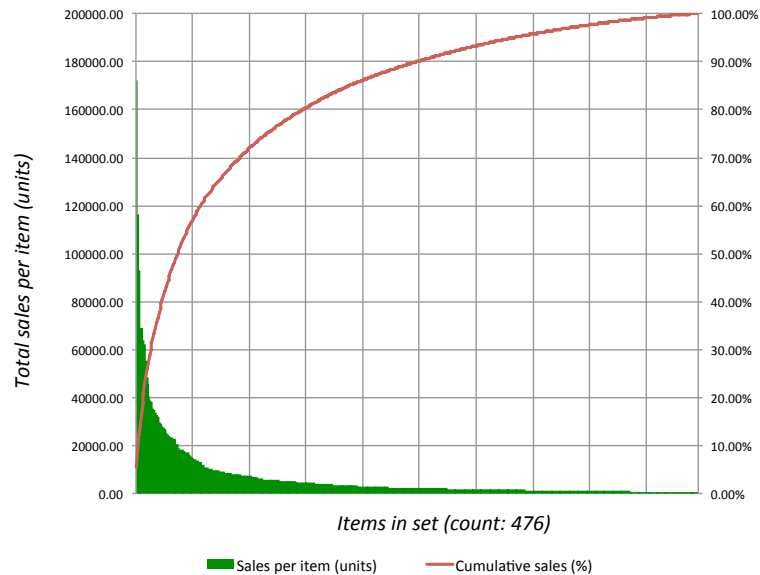


Figure 34 - Yearly sales (in units) of all selected items



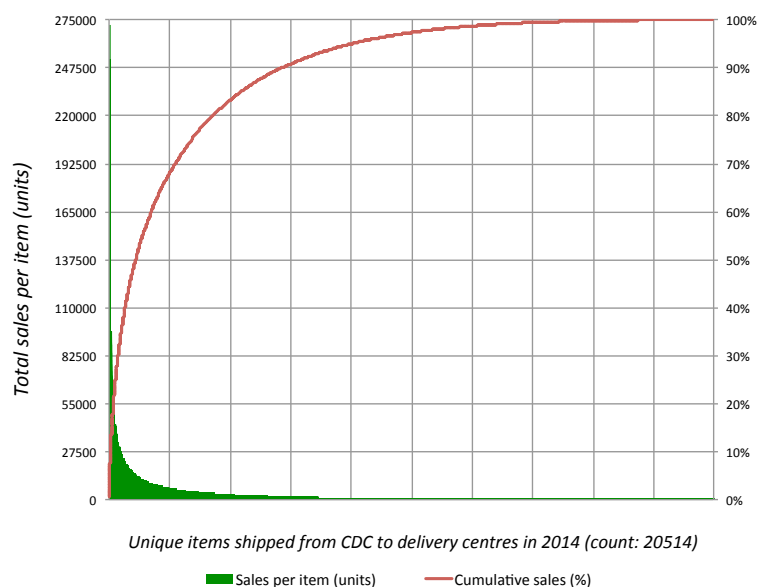


Figure 35 - Yearly sales (in units) of all items shipped between CDC and delivery service DCs

Other statistics from the item set are given in the next tables and figures:

Table 10 - Item set cross-section (highest and lowest values)

Statistic	Lowest	Highest	Comments about highest values
Sales per year (units)	194	172,275	±2393 mono CHEP pallets, 92 standard trailers
Sales volume per year (litres)	81	2,642,694	±2393 mono CHEP pallets, 92 standard trailers
Cost price (€)	0.29	56.28	
Volume per sales unit (litres)	0.03	81.91	
Guaranteed shelf life by supplier (days)	17	999	Some items don't have a best-before date, missing values are substituted with 999 days
Coefficient of variation (not pooled)	0.34	14.81	
Coefficient of variation (pooled)	0.26	4.44	

Most items are of relative low value, with most items having a cost price between €2 and €3 per sales unit, as can be seen in Figure 36.

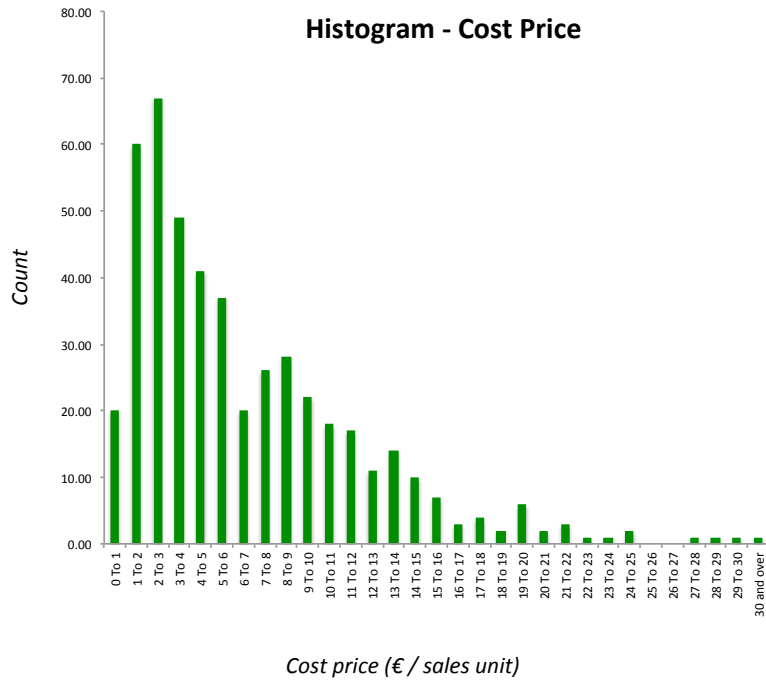


Figure 36 - Cost price histogram

What concerns the shelf life, most items in the set are guaranteed a shelf life of one year or more upon receipt at the CDC. There is however a wide variety of other shelf lives found in the set, as can be seen below (Figure 37).

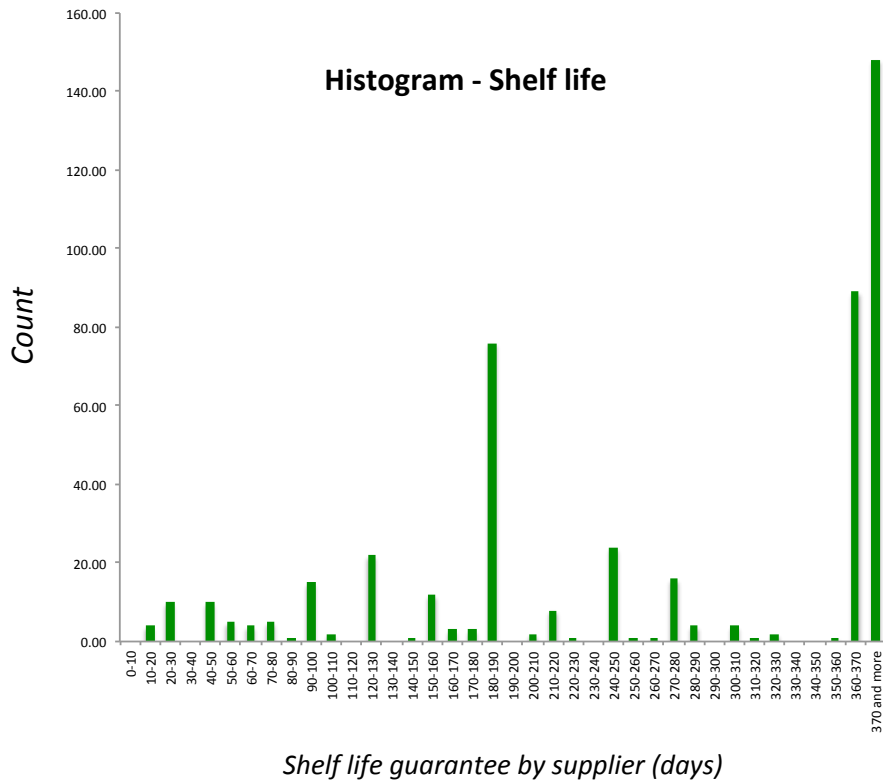


Figure 37 - Shelf life histogram

When looking more closely at the coefficients of variation, based on the sample mean and sample standard deviation, it can be seen that for all item-location combinations the most common CV is between 1.2 and 1.6. In the pooled scenario overall CVs decrease significantly (compare Figure 38 and Figure 39).

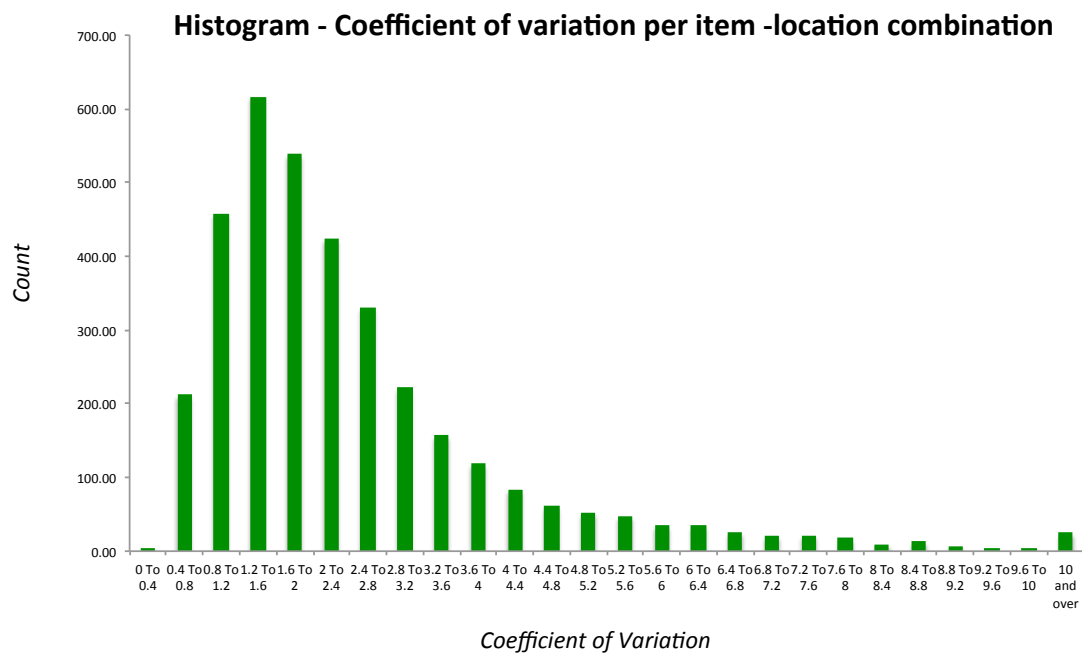


Figure 38 - CV per item-location combination

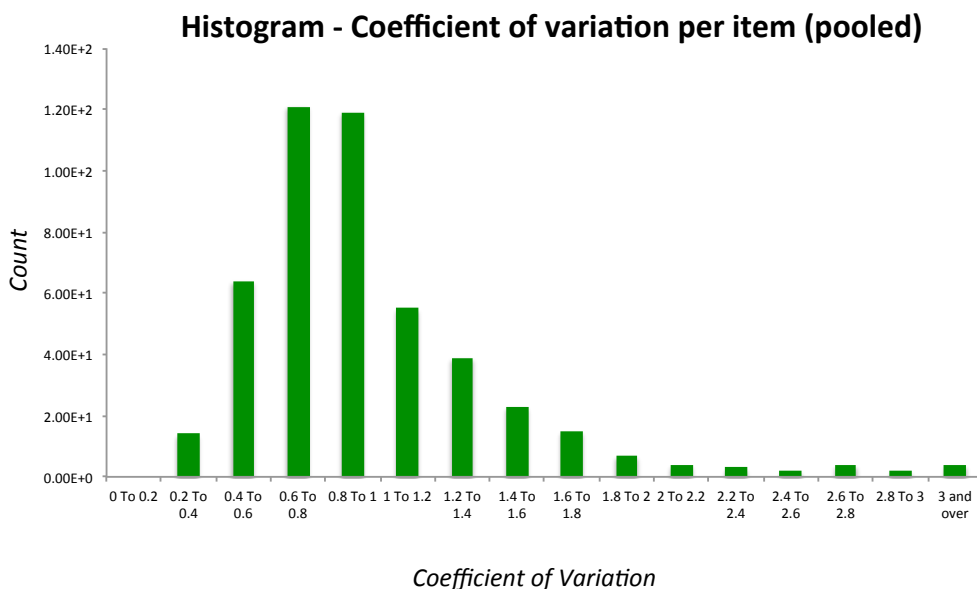
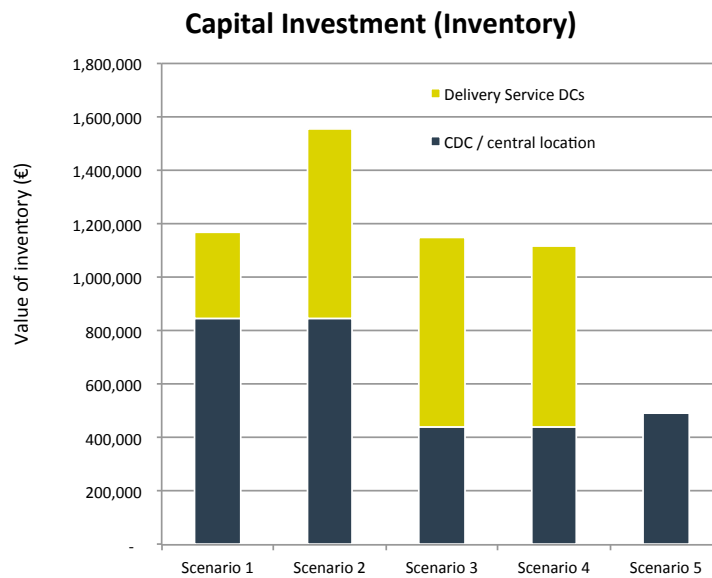


Figure 39 - CV per item (when locations are pooled)

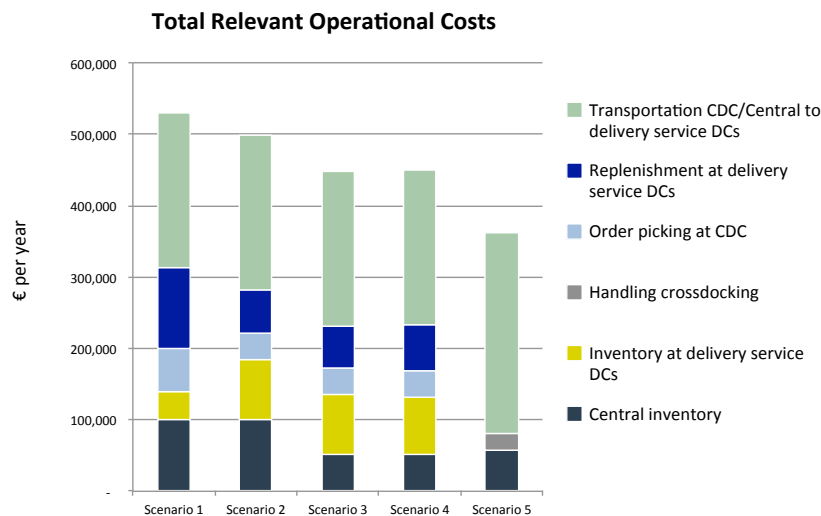
## Appendix H – Results under lower fill rate targets

The following results are based on the exact same calculation as those mentioned in chapter 11, yet under lower fill rate targets. The fill rate target to the final customer is set at 96%, and the internal fill rate at 94%.

With those setting, the capital investment under scenario 2 for the sampled set turned out at about €1,541,625, or 17% lower than what was calculated in chapter 11.

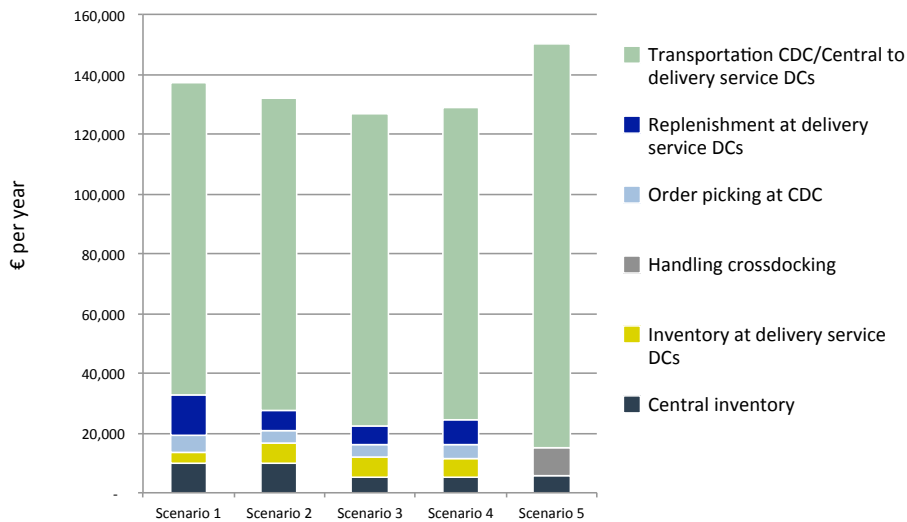


Whenever all items are cross-docked, the results show a total potential savings on operational costs of 27.19%, which is 2.6% lower than the 29.8% savings under the higher fill rate target. Thus, when fill rates are lower then potential savings will also be. The relation is however not so sensitive to changes in different fill rate targets. The graphs below show more detailed results.

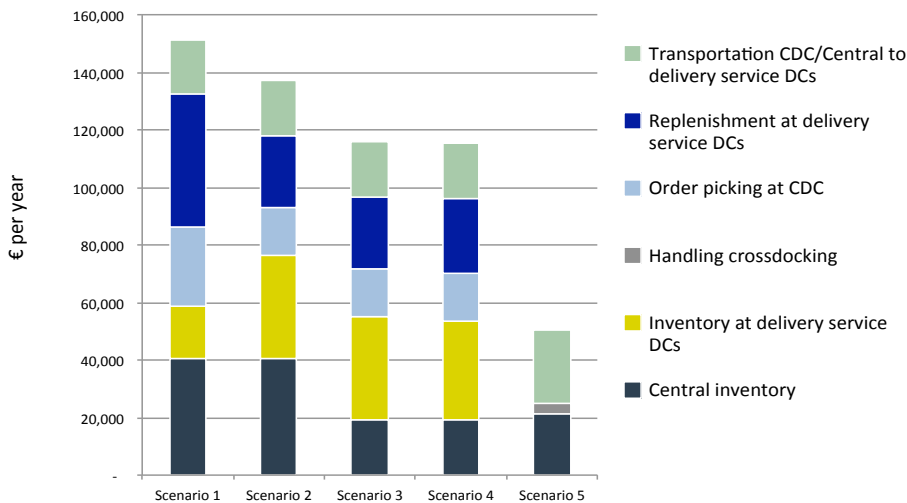


Potential savings	Count	% of # items	Sales volume (L)	% of sales volume	# Suppliers (cum)
More expensive	18	4%	11,258,273	47%	15
Between 0-10%	8	2%	1,735,701	7%	23
Between 10-20%	15	3%	3,230,759	13%	31
Between 20-30%	23	5%	1,779,064	7%	45
Between 30-40%	60	13%	2,101,274	9%	85
Between 40-50%	75	16%	1,726,187	7%	121
Between 50-60%	100	21%	1,305,507	5%	158
Between 60-70%	84	18%	558,757	2%	180
Between 70-80%	56	12%	248,742	1%	189
Between 80-90%	28	6%	43,734	0%	202
Between 90-100%	9	2%	11,971	0%	205
<b>Total</b>	<b>476</b>	<b>100%</b>	<b>23,999,968</b>	<b>100%</b>	<b>205</b>

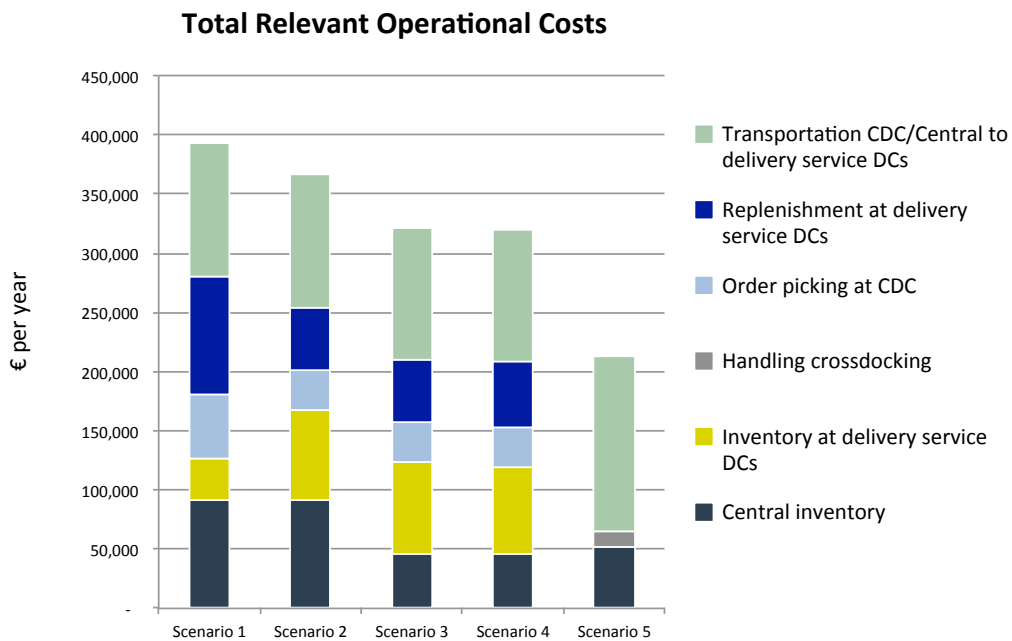
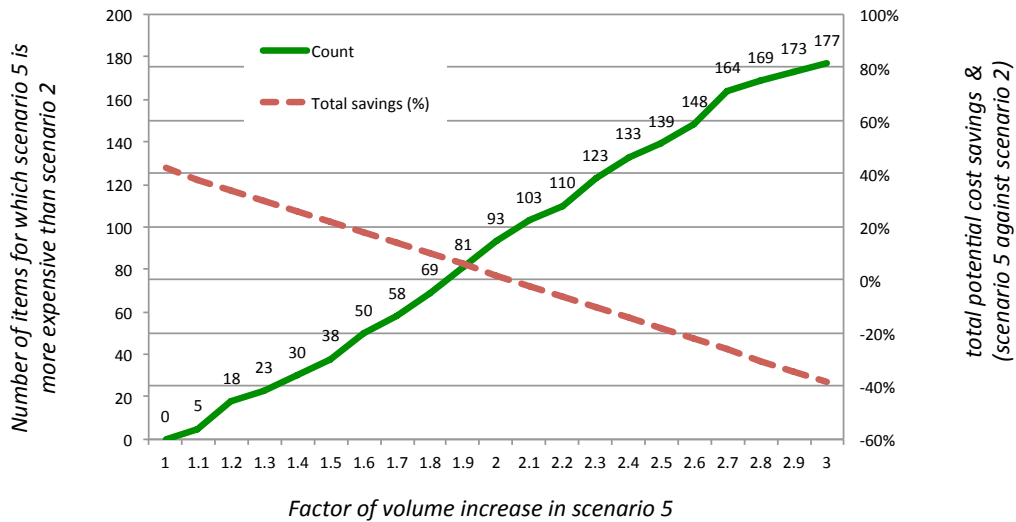
### Total Relevant Operational Costs for Items with Negative Potential Savings



### Total Relevant Operational Costs for Items with Potential Savings between 50-90%



With 18 items removed under the minimum volume increase assumption, the remaining items will account for a total savings of 42%, compared to the 44.21% mentioned in chapter 11.7. Further charts are shown below:



Up scaled to the entire population the total potential savings on operational costs are about €2.30 million per year (not shown in a graph here), which is about 14% lower than when fill rates are 98.5% and 96.5%.

## Appendix I – Sales volume top 25 items

Table 11- Sales volume top 25 with description and potential cost savings

Potential Cost Savings						Sales Volume	Weighted
Inventory	Handling	Transportation	Overall	Description of one sales unit		(litres)	average CV
51%	7%	-28%	-15%	12	PK LANDHOF VOLLE MELK 1L	2642694	0.58
59%	31%	-28%	-5%	12	PK FR.VL.LL.OPSCHUIMMELK 1L	1373934	0.53
42%	8%	-28%	-22%	1	DS TR.BONNE KAISERBROOD 100X55G	1289829	0.69
77%	25%	-28%	-1%	1	EM KERN MAYONAISE 10L	1217409	0.52
68%	27%	-28%	15%	24	FL AA DRINK HIGH ENERGY 33CL	1102813	1.18
67%	7%	-28%	-20%	50	PK TR.BONNE ITALIAANSE BOL 120G	890436	0.64
51%	41%	-28%	-17%	1	DS DRH SCHARRELEI S 90ST	770781	0.65
73%	-4%	-28%	4%	1	DS T.D.D-BEKER 3000X180CC	663891	1.62
78%	50%	-28%	14%	12	FL LIPT.ICETEA GR.CLEAR 50CL	563130	0.76
80%	10%	-28%	-13%	1	DS TR.BONNE HAMB.BR+SESAM 24X55G	489714	0.90
59%	35%	-28%	-11%	1	DS VDM BESCHUIT MONO 125X7,7G	461793	0.95
64%	55%	-28%	-3%	1	DS MOLCO CIABATTA JUNIOR 70X90G	419190	1.30
71%	-103%	-45%	-18%	1	ST KK GESN.J.BEL 50X20G	405476	0.52
69%	52%	-28%	-10%	1	DS KAM.KADET WIT SES.GESN. 32X50G	385399	0.90
71%	66%	-28%	23%	1	DS KERN FRIKANDEL EXTRA 40X85G	371567	0.75
76%	72%	-28%	44%	24	BL CHOCOMEL 250ML	307667	1.27
53%	65%	-28%	13%	6	PK FR.VL.HALVAMEL 930ML	296060	0.94
79%	17%	-28%	-11%	20	ST TR.BONNE CIABATTA 250G	285346	0.97
79%	50%	-28%	6%	1	ZK MCCAIN STEAKFRITES 2,5KG	279993	1.30
72%	31%	-28%	-11%	6	FS SPA REINE BLAUW GLAS 1L	278438	1.70
67%	80%	-28%	21%	16	ST DE LEKK.RB GEV.KOEK 100G	260459	0.90
77%	53%	-28%	10%	1	DS AM KOFFIEKOEKJES 200ST	245907	0.77
68%	42%	-28%	15%	1	KR BAVARIA PILS 24X30CL	244961	1.81
82%	77%	-28%	43%	1	CN OLITAL.OLIJFOLIE SANSA 5L	215538	0.61

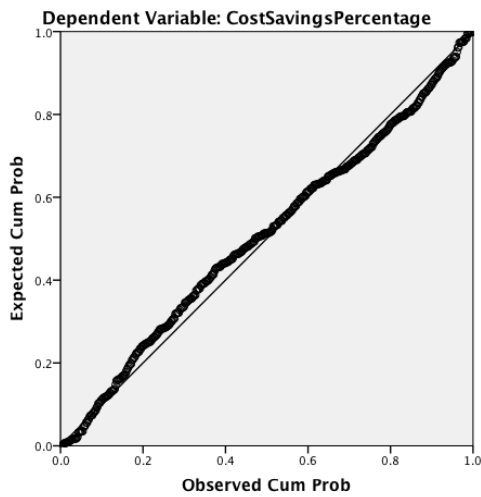
# Appendix J – Output SPSS

**Coefficients<sup>a</sup>**

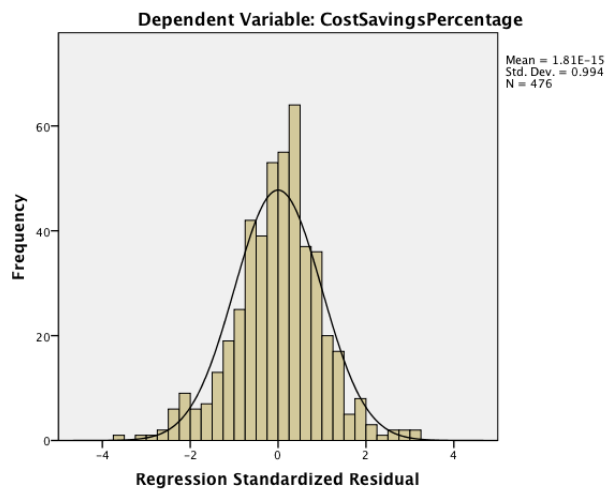
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	.430	.022		19.159	.000		
CostPrice	.007	.001	.180	4.790	.000	.565	1.771
WeightedAvgCV	.068	.008	.288	8.119	.000	.634	1.578
VolumePerSalesUnit	-.011	.001	-.482	-12.694	.000	.554	1.803
ValueDensityPerSalesUnit	.019	.003	.231	6.840	.000	.703	1.423
TotalSalesUnitsPerItem	-5.277E-6	.000	-.339	-10.685	.000	.794	1.260
QdividedbyMUWeightedAverage	-.001	.000	-.147	-4.159	.000	.641	1.559

a. Dependent Variable: CostSavingsPercentage

**Normal P-P Plot of Regression Standardized Residual**



**Histogram**



**Model Summary<sup>b</sup>**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.790 <sup>a</sup>	.625	.620	.13461

a. Predictors: (Constant), QdividedbyMUWeightedAverage, ValueDensityPerSalesUnit, TotalSalesUnitsPerItem, CostPrice, WeightedAvgCV, VolumePerSalesUnit

b. Dependent Variable: CostSavingsPercentage

**ANOVA<sup>a</sup>**

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.152	6	2.359	130.177	.000 <sup>b</sup>
	Residual	8.498	469	.018		
	Total	22.650	475			

a. Dependent Variable: CostSavingsPercentage

b. Predictors: (Constant), QdividedbyMUWeightedAverage, ValueDensityPerSalesUnit, TotalSalesUnitsPerItem, CostPrice, WeightedAvgCV, VolumePerSalesUnit