MASTER

# The inventory deployment decision in the retail supply chain

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# The inventory deployment decision in the retail supply chain

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# Abstract

This report describes the development of a quantitative ILP-model in order to solve the so-called inventory deployment decision for ambient products in a retail supply chain with central and regional distribution centers (DC) with internal consolidation. The inventory deployment decision is the problem at which distribution stage and in which storage pick type products should be stored. The model includes handling, inter-DC, and inbound transportation costs and allocates each product to the optimal distribution stage and storage pick type, such that overall costs are lowest, while taking into account capacity and service constraints. Results show that the most important product characteristic in the inventory deployment decision is the volume sold per week. In addition, the optimal allocation of products to DCs is also for a big part determined by the potential volume delivered by the supplier to a DC, as economies of scale could be realized when a supplier is allocated to only one distribution stage. It can be concluded that deciding both on the product- and supplier-level is beneficial.

## Management summary

The company at which the Master thesis project is carried out, is Jumbo Supermarkten. This is a grocery retailer with a distribution network consisting of national distribution centers (NDC) and regional distribution centers (RDC) with internal consolidation.

### Problem situation

Jumbo Supermarkten wants a more cost efficient logistics network to take the next step towards perfection of every day low costs and as a result every day low prices for the customers. In this context, the problem Jumbo Supermarkten faces is how to decide whether an article should be stored in a NDC or RDC, such that costs are lowest. This is called the inventory deployment decision. Besides this, Jumbo Supermarkten wants to know how to decide which storage pick type should be assigned to the product in the specific DC, such that costs are lowest. In the RDCs (Beilen, Breda, Veghel and Woerden) products could be assigned to double 2m high, 2m high or 1m high pallet pick locations, while in the NDC (Elst) products could be assigned to 2m high, 1m high pallet, flow- or shelf rack pick locations. A specific product allocated to the RDC, could be stored in different storage types in each of the RDC sites. The focus of the Master thesis is on ambient products.
The following main research question is formulated for my Master thesis:

*How should ambient articles be allocated to distribution stages, concerning central and regional distribution centers with internal consolidation in the retail supply chain, and storage types such that overall costs are lowest, while taking into account capacity and service constraints?*

### Conceptualization phase

In the conceptualization phase, first the resulting costs of the current allocation of ambient articles to the distribution stages and storage types are analyzed to determine which costs are relevant in the inventory deployment decision at Jumbo Supermarkten. An estimation of the cost break-down structure of the distribution network of Jumbo Supermarkten for ambient articles is shown in Figure I. The inbound transportation costs are not known at Jumbo Supermarkten and therefore not included in the figure. The costs at the suppliers (handling) and costs at the stores (handling, inventory, waste) are not included, as these are out of scope. As shown in Figure I, the majority of the costs of the distribution network for ambient articles at Jumbo Supermarkten are handling costs and outbound transportation costs. However, the outbound transportation costs are independent of the inventory deployment decision, as the demand of the retail stores is fixed and as a result the number of trucks transported from the RDCs to the stores is fixed. The fixed facility costs also have a substantial part in the cost break-down structure, however these are also independent of the inventory deployment decision. The costs due to inventory and waste are considered as negligible in the inventory deployment decision (considering only ambient articles), as these costs have a limited effect on the total costs, while they are time-consuming to model. A minor part of the total costs consist of inter-DC transportation costs, however these could influence the inventory deployment decision as for products stored in the NDC the inter-DC transportation costs are substantial (on average approximately 12%). Finally, based on the literature study, it can be assumed that inbound transportation costs are relevant in the inventory deployment decision. As a conclusion, the handling, inbound and inter-DC transportation costs are the costs that are relevant in modeling the inventory deployment decision at Jumbo Supermarkten.

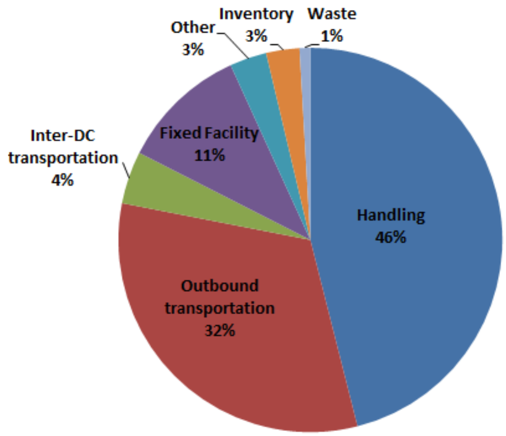


**Figure I: Cost break-down structure of the supply chain of Jumbo Supermarkten.**

Finally, it is also determined which product characteristics could affect the inventory deployment decision. According to a literature study, the demand rate, the volume of the product, the supplier of the product (and supplier characteristics like the distances to the DCs), supplier agreements and safety regulations could affect the inventory deployment decision.

## Modeling phase

In the modeling phase, two different ILP-models are developed. The difference between the two alternative models is the cost function used for calculating the inbound transport costs. The relevant costs are incorporated in the quantitative models making use of Time-Driven Activity Based Costing (ABC). In ABC costs are assigned to activities and the costs for a product are based on the activities performed on the product in the supply chain. In Time-Driven ABC duration drivers are used, which estimate the time required to perform the activity. The relevant product characteristics are incorporated in the models as input and influence the costs. Furthermore, for each DC capacity restrictions are given for the number of pick houses available, the number of bulk locations available, the number of order pickers available, the number of case packs a DC can handle and the number of inbound transport deliveries a DC can handle. For the NDC, in addition capacity restrictions are given for the number of outbound transport deliveries the NDC can handle and the number of flow racks in the NDC. Finally, the current assortment and current service rates in the DCs are maintained in the model.

## Model solving phase

The quantitative models are solved in the model solving phase. First the two alternative models are validated, which means that the models' representation of the reality is accurate. Subsequently, the best alternative model is selected to solve the inventory deployment problem at Jumbo Supermarkten. Suppliers and logistic service providers use scale prices for different truckloads, since not the complete transportation costs need to be paid, if less than a truckload is ordered at the supplier. These scale prices are approximated differently in each of the alternative models. Using the available scale prices at Jumbo Supermarkten, the *actual* cost function as shown in Figure II is used to select the alternative which estimates the inbound transport costs the most accurate. Based on the sum of squares, it is concluded that alternative 1 estimates the inbound transport costs better than alternative 2.

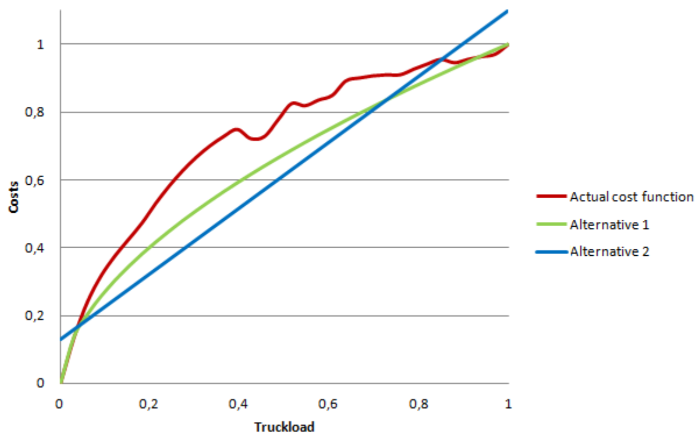


**Figure II: Inbound transportation costs of ordering a specific truckload for different cost functions**

A total cost saving of 11% can be realized using the DC- and storage type allocation found by model alternative 1. As shown in Figure III, the major cost savings are obtained in the inbound transportation costs. Jumbo Supermarkten also saves on handling costs compared to the current situation. The inter-DC transportation costs for alternative 1 are slightly higher than in the current situation.

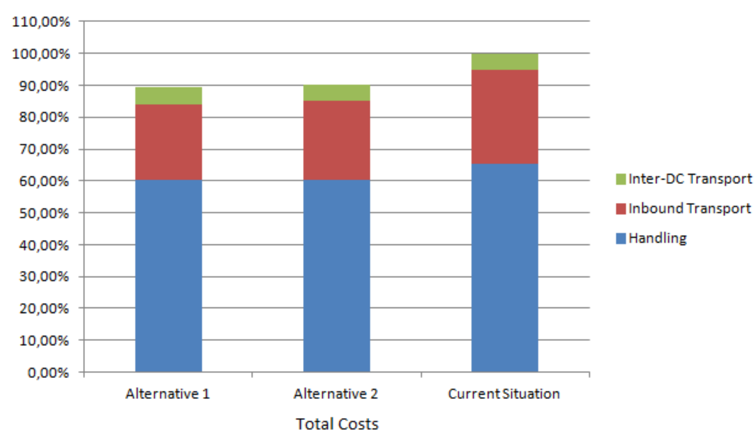


**Figure III: Cost split for alternative 1 & 2 and the current situation.**

## Implementation phase

Some implementation issues need to be overcome in order to use (the solution of) the quantitative model. First of all, accurate demand estimations are essential for using the model, since the demand of the upcoming period should be used as input of the model. Furthermore, Jumbo Supermarkten needs to determine when and for which period of time it will use the model. Due to the presence of seasonal assortment, the allocation of (seasonal) products to DCs and storage types needs to be changed several times per year, however products should not be re-allocated too often, as *investment* costs incur when products are re-allocated, since probably DC lay-outs should be changed. In order to make the model more robust, these *investment* costs could be included in the model. Another implementation issue is the actual change of the DC lay-out, as some bulk- and pick locations need to be changed to store the products. Furthermore, it needs to be examined for each supplier whether it is willing and able to deliver his products on another pallet height than currently agreed. It might be that additional cost or discounts are associated with these changes. Another implementation issue is that NDC Elst and NDC Veghel are considered as one NDC-location in the model, such that the products allocated to the NDC still needs to be divided over the DC sites Elst and Veghel.

## Conclusions

The results of the quantitative model show that the most important product characteristic in the inventory deployment decision is the volume sold per week for a product. In addition, the re-allocation of products to DCs is also for a big part determined by the potential volume delivered by the supplier to a DC, as economies of scale could be realized when a supplier is allocated to only the NDC (or RDC), as higher volumes result in lower inbound transport costs for the supplier. Using this insight in the inbound transport costs of the suppliers, Jumbo Supermarkten should be able to negotiate better purchase prices from suppliers. Based on the results of the model it can be concluded that deciding both on the product- and supplier-level where an article should be stored is beneficial.

However, there are a lot of interdependencies which determine the final allocation of a specific product. This is also the main advantage of using the model to solve the inventory deployment decision. Before this Master thesis, Jumbo Supermarkten only had some feeling for the costs associated to storing a product at the NDC or each of the RDCs in a specific storage type, however these costs were not quantified and complex trade-offs made these costs difficult to analyze. In the quantitative model all relevant product characteristics, costs and capacity limitations are quantified and modeled in an appropriate way, including the relevant costs of the suppliers, such that the inventory deployment decision is not made at the individual product-level, but on the whole assortment including the supplier-level, for a retail supply chain network of national and regional distribution centers with internal consolidation, which is the main contribution of this Master thesis.

# Preface

This report describes the Master thesis project which I have conducted at Jumbo Supermarkten in Veghel. With this Master thesis, I will fulfill my degree of Master of Science in Operations Management and Logistics at the School of Industrial Engineering at the Eindhoven University of Technology. Therefore I would like to thank all who have contributed in the realization of this Master thesis.

First of all, I would like to thank university supervisor Karel van Donselaar for his guidance during my Master program, but especially during my Master thesis project. It was always pleasant to discuss several topics on retail and modeling. Also, I would like to thank university supervisor Rob Broekmeulen, for his critical attitude towards my work, which was challenging and very instructive for me.

At Jumbo Supermarkten, my thanks go out to Jaap de Hoop for giving me the opportunity to carry out my Master thesis project at Jumbo Supermarkten. Furthermore, I would like to thank Maurice Gerts for his guidance during the Master thesis project. I appreciate your valuable insights in all the retail topics we discussed and your critical view on my work, which was very helpful in improving my Master thesis. Finally, I would like to thank the Supply Chain Development team and everyone I met at Jumbo Supermarkten for their contribution and support during my Master thesis project.

Finally, I would like to thank my family, especially my parents for their support during this thesis, but also for their support during my entire student life at Eindhoven University of Technology. Last but not least, I would like to thank Britt. Your support and encouragement helped me through the whole Master thesis project.

Stijn Geerts

## List of abbreviations

| | |
|---|---|
| **ABC** | Activity Based Costing |
| **BCG** | Boston Consulting Group |
| **CDC** | Central Distribution Center |
| **DC** | Distribution Center |
| **EDI** | Electronic Data Interchange |
| **EDLP** | Every Day Low Prices |
| **EPT** | Electronic Pallet Truck |
| **FLP** | Facility Location Problem |
| **FTL** | Full Truckload |
| **ILP** | Integer Linear Programming |
| **KPI** | Key Performance Indicator |
| **LP** | Linear Programming |
| **LSP** | Logistic Service Provider |
| **LTL** | Less Than Truckload |
| **MMKP** | Multidimensional Multiple-choice Knapsack Problem |
| **MOQ** | Minimum Order Quantity |
| **NDC** | National Distribution Center |
| **RDC** | Regional Distribution Center |
| **SKU** | Stock Keeping Unit |
| **VMI** | Vendor Managed Inventory |

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# 1. Introduction

In this chapter first some background information is given about the area of research of my Master thesis. Second, the structure of the report is described.

## 1.1 Background information

Many retailers operate one or more central distribution centers (CDCs) in addition to their regional distribution centers (RDCs), whereby the CDCs and RDCs are dedicated to specific types of goods (van der Vlist, 2007). For example, van der Vlist (2007) shows the distribution network of a retailer, operating three *fast-mover* RDCs serving their assigned stores in an area, and one *slow-mover* CDC, as shown in Figure 1.

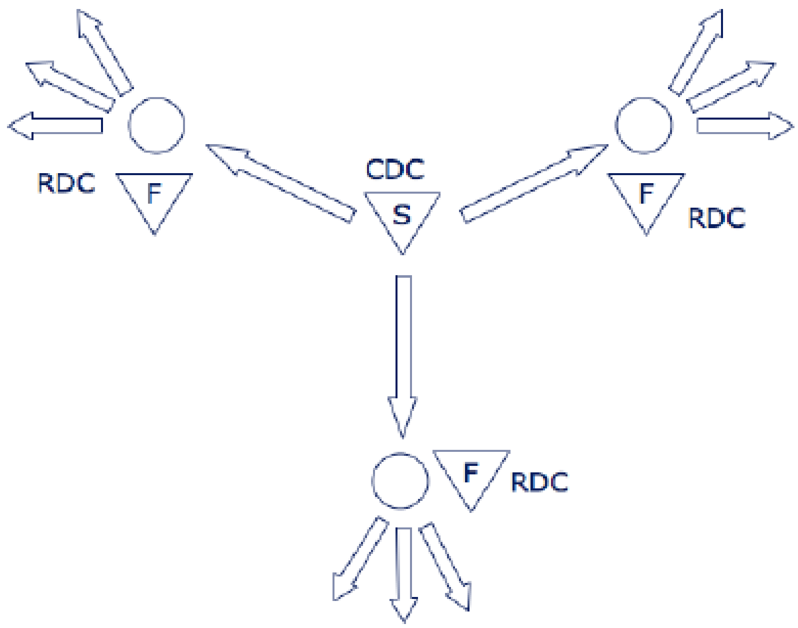


**Figure 1: Retail distribution network with one slow-mover CDC and three fast-mover RDCs (van der Vlist, 2007).**

The company at which the Master thesis project is carried out, is Jumbo Supermarkten. This is a grocery retailer with such a distribution network as shown in Figure 1, consisting of slow-mover CDCs (at Jumbo Supermarkten called national distribution centers (NDCs)) and fast-mover RDCs with internal consolidation. Later on in this report, the distribution network of Jumbo Supermarkten is described in more detail. Nonetheless, the problem Jumbo Supermarkten faces is how to decide whether an article should be stored in a NDC or in a RDC. This is called the inventory deployment decision. The inventory deployment decision is defined by Shapiro and Wagner (2009) as the problem at which distribution stage products or product families should be held in inventory and the volumes of these inventories. In short, the area of research of the Master thesis project is the inventory deployment decision at Jumbo Supermarkten.

## 1.2 Report structure

After this chapter, which serves as the name suggests as an introduction to the Master thesis report, a description of the company, its distribution network and its operational processes is given in Chapter 2. Subsequently, in Chapter 3, the company's problem is described and relevant research questions are identified. In addition, the academic relevance of the Master thesis is revealed by identifying gaps in the current state of research on the Master thesis' subject. The research design, consisting of the research methodology and research methods, is given in Chapter 4. Chapter 5 and 6 describe the development of a quantitative model used to solve the inventory deployment decision. In Chapter 5, the conceptualization phase is described. In the conceptualization phase, decisions are made about variables that need to be included in the model and the scope of the problem is defined. Subsequently the quantitative model is built in the modeling phase, which is described in Chapter 6. After this, the quantitative model is solved in the model solving phase. Chapter 7 provides the results of the solved model. In the implementation phase, which is described in Chapter 8, the main findings and implementation issues are listed. Finally, Chapter 9 provides the conclusions and limitations of this Master thesis project.

# 2. Company and process description

In this chapter, first a general description of Jumbo Supermarkten is given. Subsequently, the current distribution network of Jumbo Supermarkten is explained. Finally, the relevant processes in this distribution network are described in more detail.

## 2.1 Company description

The company, at which the Master thesis project is carried out, is Jumbo Supermarkten. This is a family owned company that already exists for more than ninety years. Jumbo Supermarkten originated from a wholesaler in colonial goods from Veghel, which was founded in 1921 by Johan van Eerdt and called 'Groothandel van Eerdt'. The wholesaler grew into a family business, and after the death of Johan, the company was taken over by his nephew, Frits. Under his leadership the wholesaler grew further, while the company's name was changed to 'Groothandel van Eerd'. In 1956 Frits is succeeded by his son Karel, who decided to make the switch from wholesaler to supermarket chain. After experimenting with several supermarket-formulas, the first Jumbo supermarket was opened in 1983 in Tilburg. This was the beginning of supermarket chain Jumbo Supermarkten, which spread quickly across the south of the Netherlands. In the 1990s Jumbo became very successful, when Jumbo Supermarkten developed the current Jumbo formula, based on a customer survey on the major annoyances of customers during shopping. In this entirely new formula, Jumbo Supermarkten combines the best service, the broadest assortment and the lowest price. The unique Jumbo formula is introduced together with some guarantees: "De 7 Zekerheden". These are guarantees that the customer can count on every day in every store, such as the lowest price, a high service, a broad assortment, fresh products and short waiting times. The customer-oriented formula with every day low prices (EDLP) and its guarantees became very successful and since its introduction Jumbo Supermarkten has been growing. In the past couple of years, the company has grown very fast through the acquisition of Super de Boer in 2009 and the acquisition of C1000 in 2012. Nowadays, Jumbo Supermarkten is the second largest supermarket retailer in the Netherlands. Now the acquisitions are finished, Jumbo Supermarkten has 580 stores with a market share of approximately 18,5%. Besides the supermarket stores, Jumbo Supermarkten also has food markets, where the focus is even more on a broad assortment with fresh, delicious, convenient and healthy food at a low price. Furthermore, customers can order their groceries online via Jumbo.com and the Jumbo app, whereby orders can be picked up at Pick Up Points or are delivered at home (in some regions).

## 2.2 The distribution network

In general, today's retail supply chain has a multi-echelon structure, with a series of interconnected stock points (van der Vlist, 2007), as shown in Figure 2. As can be seen, the distribution from the manufacturer's warehouse to the retail distribution center is called primary distribution, while the distribution from the retail distribution center to the retail stores is called secondary distribution. In this Master thesis the focus is on the primary and secondary distribution.

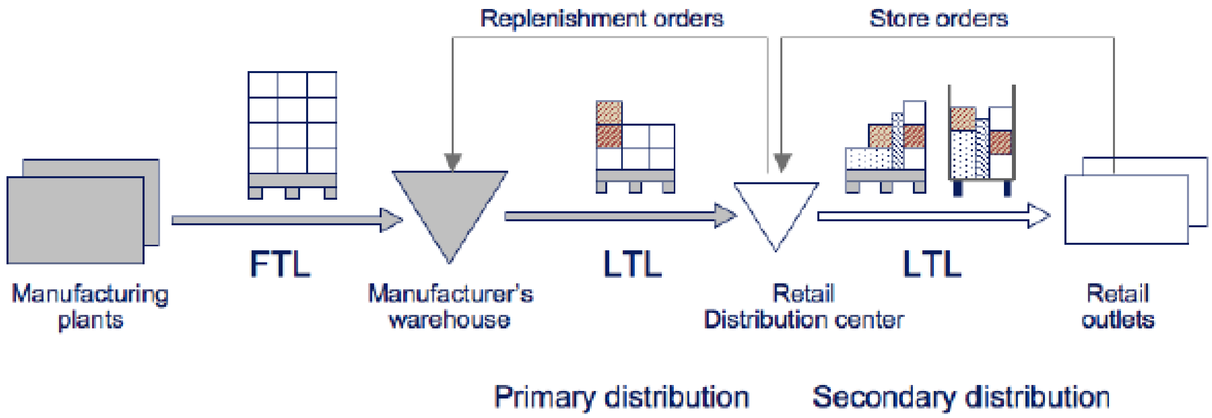


Figure 2: The retail supply chain (van der Vlist, 2007).

In general, the retail supply chain of Jumbo Supermarkten is quite similar to the retail supply chain shown in Figure 2. However, as mentioned in the first chapter, Jumbo Supermarkten has a distribution network consisting of slow-mover national distribution centers (NDCs) and fast-mover regional distribution centers (RDCs) with internal consolidation. Jumbo Supermarkten is operating four RDCs and three NDCs. As shown in Figure 3, the NDCs (colored yellow) are located in Veghel, Elst and Raalte, while the RDCs (colored red) are located in Woerden, Breda, Veghel and Beilen.

In the retail distribution network of Jumbo Supermarkten, incoming replenishment orders from the stores are being split in slow- and fast-moving articles: Order lines concerning slow-moving articles are picked and assembled in a slow-mover NDC, while the order lines concerning fast-moving articles are picked and assembled in the fast-mover RDC assigned to the store. The roll cages with the slow-moving articles are transported from the NDC to the fast-mover RDC, are cross-docked (consolidated with the fast-movers without storage in the RDC) and are being shipped to the stores jointly with the roll cages with fast-moving articles. This is the general distribution process, however there are several exceptions.

In the distribution network of Jumbo Supermarkten, there are three different NDCs in order to deal with articles with different temperature requirements; the NDCs are separated for frozen, chilled, and ambient articles. Each of the four RDCs store both ambient and chilled articles. Obviously, to deal with the different temperature requirements, separated storage areas are used for the ambient and chilled articles. In addition, two separated storage areas are used for the chilled articles, as some articles need to be stored at 2-4° Celsius and others at 12° Celsius. The RDCs don't deal with frozen articles, as the frozen articles are picked and assembled in the NDC in Raalte and subsequently directly delivered to the stores.

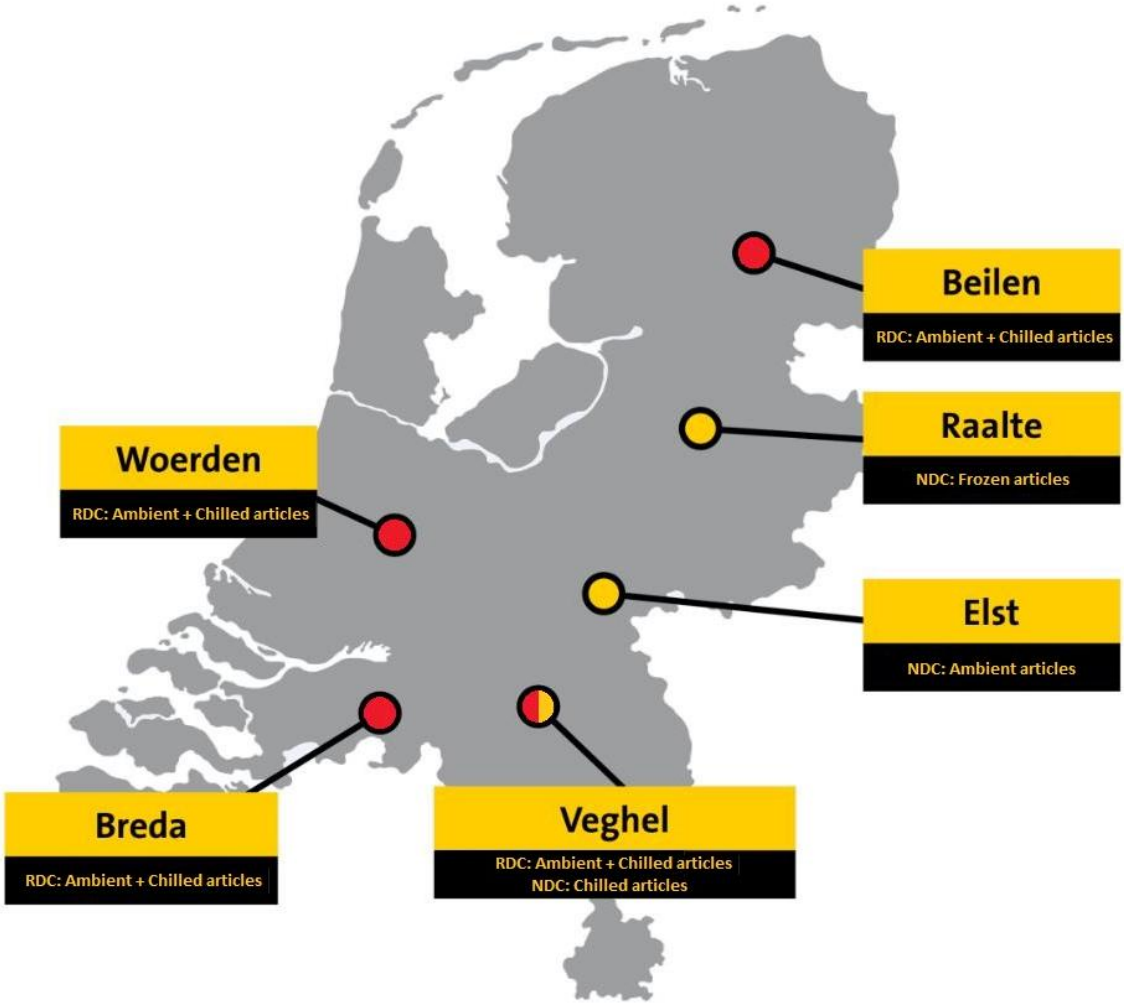


**Figure 3: The national and regional distribution centers of Jumbo Supermarkten.**

As shown in Figure 3, there is a RDC for ambient and chilled articles, called 'de Amert 409', and a NDC for chilled articles, called 'de Zuidkade', located in Veghel. However, there are two more distribution centers located in Veghel, called 'de Amert 504' and 'de Amert 602'. Due to capacity limitations in Elst, not all slow-moving ambient articles can be stored there. The remaining articles are stored in 'de Amert 504', which is thus also a NDC for ambient articles. In 'de Amert 602' fast-moving ambient articles are stored, due to capacity limitations in 'de Amert 409'. As a result, 'de Amert 602' is a RDC for ambient articles.

Besides the above mentioned distribution centers, Jumbo Supermarkten also operates the so-called VEEM-location in Deventer. This location is owned by a logistics service provider (LSP) and hired by Jumbo Supermarkten and other retailers. In this location, slow-moving ambient articles with extreme purchase conditions (a full truck load results in a high discount) or extreme long lead times are stored for a long-term period. Subsequently, the DC is delivered

from the VEEM-location when they place an order. In the near future, the VEEM-location in Deventer won't be used anymore; the products stored in Deventer will be stored in Raalte.
As determined by Jumbo Supermarkten, in the Master thesis project the focus is on the ambient articles, also called dry groceries. Therefore, in the remaining of this master thesis report, only these ambient articles are considered, while chilled and frozen articles are out of scope.

## 2.3 Process description

As mentioned in the previous paragraph, the focus is on the primary and secondary distribution. It is assumed that the retail supply chain starts upward of the manufacturer's warehouse and ends at the retail outlets. Therefore, it starts with the distribution of products from manufacturer's warehouses to retail distribution centers. Subsequently some processes take place in the retail distribution centers, while thereafter the products will be distributed from the NDC to the RDCs and from the RDC to the retail outlets. The relevant processes in the primary and secondary distribution are described in more detail in this paragraph. In the remaining report the manufacturer is called supplier.

### 2.3.1 Distribution from supplier's warehouse

Most of the suppliers deliver their articles in case packs on pallets to the NDC, each of the RDCs or the VEEM-location, dependent on where the article is stored by Jumbo Supermarkten. Jumbo Supermarkten has with each supplier different agreements on delivery frequencies, (minimum) order sizes, order moments, purchase prices, etcetera. For example, one supplier requires that minimal a full pallet should be ordered, while another supplier just requires a full pallet layer. Sometimes it is possible to order less than the agreed minimum order size at an additional cost, sometimes it is just impossible. Most deliveries are on two meter or one meter high pallets. Suppliers can deliver on two different pallet types. These are block pallets, with size 1m by 1,2m, and euro pallets, with size 0,8m by 1,2m. In total 26 block or 33 euro pallets fit in a truck. Each supplier delivers its product on either block or euro pallets, on which only one product is stored. However, pallets can be stacked on top of each other in the truck, when the pallet is not two meter high (i.e. one meter high or a pallet layer) and dependent on the type of product on the pallet. Furthermore, the supplier is responsible for the transportation from his warehouse(s) to Jumbo Supermarkten, however LSPs can carry out the transportation. Most of the time, deliveries take place in multi-stop routes, whereby a full truck delivers Jumbo Supermarkten and several other retailers in a multi-drop trip or whereby loads are consolidated by a LSP using additional loads from other locations. The costs for transport are included in the total purchase price of an order.
Besides delivery on pallets, some suppliers deliver their articles on store-level on roll cages at the specific RDC, such that at the RDC the received goods can be sent directly from the receiving docks to the shipping docks. This is called cross-docking. In this case, the orders of the

retail stores are directly forwarded to the specific supplier. Most of the articles that are cross-docked are articles that should remain fresh (and therefore often are chilled articles) and have high order volumes. However, also some ambient articles, like tobacco, are cross-docked.

Furthermore, vendor managed inventory (VMI) is used for some articles. VMI is the implementation of centralized planning, whereby an outside supplier manages the inventory at a retail distribution center for the products that this supplier delivers (van der Vlist, 2007). The distribution center provides several times a day the stock level of the product and the supplier determines whether and how many he delivers. The supplier determines this, as it is assumed that for certain products the supplier can generate more accurate forecasts on customer demand, as they also known the sales of other retailers. In this case, the supplier replenish the stocks on (preferably full) pallets in the DCs. Jumbo Supermarkten agreed with the supplier on the minimum and maximum space the supplier can use for storage of their products in the DCs.

Finally, some suppliers deliver their articles directly to the stores. These articles are often extreme slow-movers, like office-articles. Besides these, also articles with an extreme short shelf life, like newspapers, are directly delivered to the stores. In this case, the orders of the retail stores are directly forwarded to the specific supplier.

Other suppliers also deliver so-called pick-to-zero and transito, however this is not the case for ambient articles. For this reason, these delivery types are out of scope.

Besides above delivery types, whereby the suppliers transport their articles to Jumbo Supermarkten, Jumbo Supermarkten also picks up articles at the suppliers. Trucks on their way back from replenishing a store might pass by a supplier warehouse, pick up the supplier's articles and deliver these at the specific distribution center (van der Vlist, 2007). This is called backhauling. With each supplier of Jumbo Supermarkten is agreed whether the supplier delivers the articles or whether Jumbo Supermarkten picks up the articles.

### 2.3.2 Retail distribution center processes

A distribution center is a warehouse in which products from different suppliers are collected for delivery to a number of customers (van den Berg & Zijm, 1999), which are in the case of Jumbo Supermarkten the retail stores. The activities in a distribution center generally can be subdivided into five categories: Receiving, storage, order picking, shipping and cross-docking.

In both distribution stages of Jumbo Supermarkten (the NDC and RDC), the receiving activity starts with unloading the pallets with articles from the truck at the receiving dock. An electronic pallet truck (EPT) is used for the unloading. Subsequently a barcode is scanned, to register the arrival of the articles and to update the inventory record. Electronic Data Interchange (EDI) is used for data exchange between the supplier and Jumbo Supermarkten. Next, the quantities are verified and random quality checks are performed. These activities are conducted by so-called receivers. After the receiving activity, it is automatically determined whether unpacking or re-stacking the products is necessary for storage. This unpacking or re-stacking will be conducted before the storage activity.

Storage involves the transfer of received articles to storage locations, which generally consist of the reserve area, where products are stored in the most economical way (bulk storage) and the forward area, where products are stored (in smaller amounts) for easy retrieval by an order picker (Rouwenhorst et al., 2000). At both distribution stages of Jumbo Supermarkten, there are products stored (on pallets or in racks) on fixed floor locations for the picking process (the forward area) and there is bulk storage capacity above each of the pick locations (the reserve area), which can be used to replenish the pick locations underneath. The areas are shown in Figure 4. However, the bulk storage locations of a specific product are not necessarily exact above the fixed pick location of that specific product. The closest free bulk location to the specific pick location is used for storing the product. In the bulk locations all products are stored in case packs on pallets. These pallets are placed in pallet racks. The pallet racks in the bulk locations have different heights, but are mainly 1 meter and 2 meter high. The bulk storage operation, which is the transfer of the received articles to the bulk storage location, is conducted by the so-called reachtruckers using forklift trucks. The transfer from the reserve area to the forward area is called a replenishment and is also conducted by reachtruckers. When the pick location of a product is empty, received articles can also be directly transferred from the receiving dock to this pick location. Reachtruckers get their orders by voice via a headset.

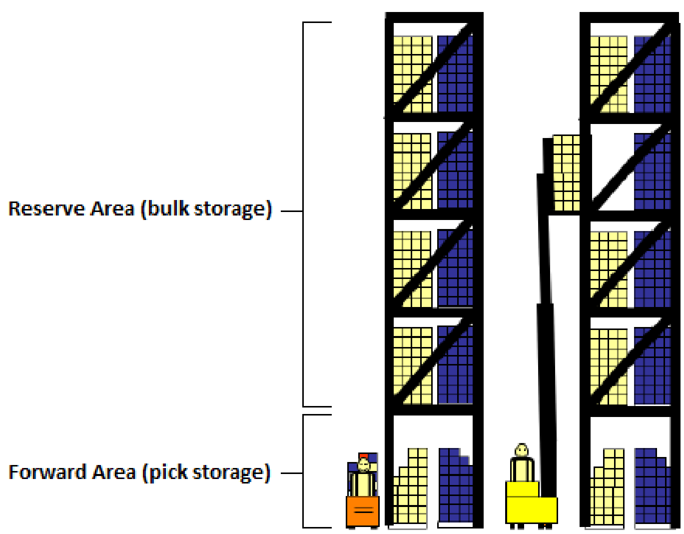


Figure 4: The reserve and forward area in the DCs of Jumbo Supermarkten (van der Vlist, 2007).

In the DCs of Jumbo Supermarkten, each product is assigned to one fixed pick location. In the RDCs, also in the pick locations all products are stored in case packs on pallets of 2 or 1 meter high. The 2 meter high pallet pick locations are used for fast-moving articles, while the 1 meter high pallet pick locations are used for relatively less fast-moving articles. In the pick locations of the NDC, besides products stored on pallets of 2 or 1 meter high, products could be stored in flow- or shelf racks. Since pallets don't fit in these racks, a pallet is retrieved from the bulk location and case packs are individually placed in the racks during the replenishment activity. When the flow- or shelf rack is full, the pallet with the remaining case packs is stored in the bulk location again. Case packs stored in flow racks are replenished at one side of the flow rack and roll to the other side of the flow rack, where the product can be picked. For this reason, the flow racks are located in aisles separated from the pallet and shelf rack pick locations. The flow racks are used for slow-moving articles, since less case packs can be stored in flow racks. The shelf racks are quite similar to the shelves in the stores, which can store a small amount of products. For this reason, these shelf racks are used for extreme slow-movers. The shelf rack pick locations could be located in the same aisle as the pallet pick locations.

The pick locations between two rack uprights are called pick houses. Each pick house contains a specific storage pick type, as described above. A pick house could contain two 2m high pallet pick locations, four 1m high pallet pick locations, ten flow rack pick locations or thirty-two shelf rack pick locations. In the RDC, one product could be assigned to one pick house, such that it is assigned to two 2m high pallet pick locations. These double 2m high pallet pick locations are used for extreme fast-moving products. As a result, in the RDCs products could be assigned to double 2m high, 2m high or 1m high pallet pick locations, while in the NDC products could be assigned to 2m high, 1m high pallet, flow- or shelf rack pick locations. A specific product allocated to the RDC, could be stored in different storage types in each of the RDC sites. For example, a specific product could be assigned to a 2m high pallet pick location in RDC Beilen, a double 2m high pallet pick location in RDC Breda and RDC Veghel, and a 1m high pallet pick location in RDC Woerden. The assigned storage type in the pick location determines the height of the pallet rack in the bulk location. Products assigned to 2m high pallet pick locations are assigned to 2m high pallet racks in the bulk. Products assigned to 1m high pallet, flow- and shelf rack pick locations are assigned to 1m high pallet racks in the bulk. When a supplier delivery is on a 2m high pallet, re-stacking is necessary when the specific product is assigned to a 1 meter high pallet rack bulk location. Each pallet type, block or euro pallet, fits in the pallet racks, which results in high flexibility. However it also implies that space is lost, for example when two 2m high euro pallets are placed in a pick house instead of two 2m high block pallets. Finally, an exception on the above is the block stacking area used for storing (fast-moving) beer crates in the RDCs. In the block stacking area pallets are stored on top of each other without using pallet racks.

The activity order picking refers to the retrieval of items from their storage locations in the forward area (Rouwenhorst et al., 2000). The pick operation is conducted by order pickers using picking trucks, getting their orders by voice via a headset.  The order picking method used, differs for the distribution stages at Jumbo Supermarkten. At the RDCs and the NDC in Elst, the order picking method is wave zone picking without batching. In zone picking, the storage space is divided into picking zones and each zone has one or more assigned pickers who only pick in their assigned zones (Gu, Goetschalckx, & McGinnis, 2010). In wave zone picking, orders are required to be picked in a predefined time-window known as a wave (Parikh & Meller, 2008). The picked items per zone are sent on roll cages to the specific shipping dock, where they are consolidated into a store order. Each roll cage is labeled at the end of the order picking activity. Usually, each order picker traverses all aisles in the assigned zone. Each aisle is traversed once; the order picker zigzags through the aisle. During one trip, an order picker can take at most four roll cages with him. So-called vertical stacking is used to load the roll cages, which means that first the first roll cage is loaded until it is full, subsequently the second until it is full, and so on. The reason for this is that Jumbo Supermarkten uses family grouping in their distribution centers. This means that groups of products that in the retail stores are presented on the shelves together as a family, are equally grouped together as a family in the distribution center, such that, when products have been picked, filling the shelves in the shops is easier (van der Vlist, 2007). On forehand it is determined which and how many products are stored on each roll cage, based on the volume and weights of the products (and the maximum volume and weight a roll cage can handle). In this calculation, a certain percentage for empty space is taken into account. As a result, the volume and weights of the products determine the number of roll cages. At the NDC in Veghel, the order picking method is wave zone picking with batching with sort-while-pick. This means the storage space is divided into picking zones and each zone has one or more assigned pickers who only pick in their assigned zones, while an order is required to be picked in a predefined time-window. Besides this, batch picking is conducted which means that a group of orders is assigned to an order picker to be picked simultaneously in one trip (Gu et al., 2010). These orders are sorted while picking. Just as at the RDCs and the NDC in Elst, an order picker can take at most four roll cages with him during trip. As a result, maximal four orders can be assigned to an order picker to be picked simultaneously in one trip, as the orders are sorted while picking on different roll cages.

In both distribution stages of Jumbo Supermarkten, during the shipping activity orders are checked and subsequently loaded into the truck at the shipping dock. At the NDC the receiving docks are at one side of the facility, and the shipping docks at the opposite side of the facility. The RDCs of Jumbo Supermarkten don't have specific receiving and shipping docks. However, a planning is made whereby docks are assigned as receiving or shipping dock.

Cross-docking only takes place at the RDCs, whereby the roll cages on store-level from the NDC (or from a supplier) are sent directly from the receiving docks to the shipping docks. At the receiving dock the truck is unloaded, subsequently the unloaded roll cages are sorted according to their destinations and finally loaded in the truck at the shipping docks for delivery to the stores (Gu, Goetschalckx, & McGinnis, 2007). Short stays may be required for consolidation, however the activities storage and order picking are not needed.

#### 2.3.3 Distribution from NDC to RDCs

The NDC always deliver their articles on specific store-level on roll cages at the specific RDC. A fixed delivery routing schedule is used, which is reconsidered three times per year. The delivery from the NDC to the RDCs can be done in single-stop delivery routes or in multi-stop delivery routes. In multi-stop delivery routes, trucks may take empty carriers back to the NDC or trucks may carry out backhauling. The distribution from the NDC to the RDCs is carried out by Jumbo Supermarkten itself or by LSPs. Jumbo Supermarkten offers the LSPs a fixed tariff per route, which is based on the fuel costs and hourly wage of a driver. In general, single-stop delivery routes are relatively more costly than multi-stop delivery routes, as in single-stop delivery routes trucks drive on their way back with empty trailers. However, this can be solved, by using LSPs, who have subsequent orders after they have replenished the RDC. The deliveries from the NDC in Elst to the RDCs are almost always in full truck loads, as they use the so-called head-tail method: Trucks wait until they have a full truck load or a time limit is reached. In the NDC in Veghel this head-tail method is not in use yet, resulting in lower load factors. In general, uniform trucks are used (both from LSPs and Jumbo Supermarkten itself) with a capacity of 54 roll cages.

### 2.3.4 Distribution from RDCs to retail outlets

After the roll cages with slow-moving articles are transported from the NDC to the fast-mover RDC and have been cross-docked with the roll cages with fast-moving articles, the slow- and fast-moving articles are jointly shipped from the RDC to the stores. These articles are often transported in so-called multi-temps, which are trucks that can transport both chilled and ambient articles, separated by a moveable wall inside the trailer. At one side of the wall the temperature is optimal for the chilled articles which need to be stored at 2-4° Celsius, while at the other side the temperature is optimal for the ambient articles. The chilled articles which need to be stored at 12° Celsius, are also transported in these multi-temps, at the side of the wall with the other chilled articles. Slipcovers are used to remain the required temperature of 12° Celsius. In general, chilled articles are delivered every day to the stores. The chilled articles for one store order are loaded in the multi-temp. The space left in the multi-temp is loaded with roll cages with ambient articles for the specific store order. In this case, one store order is loaded in the multi-temp. The roll cages with ambient articles of the store order which did not fit in the multi-temp, are loaded in a regular truck (in combination with one or two other store orders) and subsequently delivered to the specific stores. A multi-temp has a capacity of 50 roll cages, while a regular truck has a capacity of 54 roll cages. Besides these types of trucks, Jumbo Supermarkten also has double-decker trucks and city-trucks. Double-decker trucks have a capacity of 87 roll cages, while city trucks have a capacity of 33 till 41 roll cages. The city-trucks are used for stores located in the city centers, as it is hard for regular trucks to drive there. At Jumbo Supermarkten, for each store fixed order and delivery schedules are used.

# 3. Problem definition

In this chapter, first the company's problem is described. In the next paragraph, the main research question of the Master thesis is formulated based on the company's problem, and subsequently relevant sub-questions are identified in order to be able to answer the main research question. Finally, the academic relevance of the Master thesis is revealed by identifying gaps in the current state of research on the Master thesis' subject.

## 3.1 The company's problem

In the past couple of years, Jumbo Supermarkten has grown very fast through the acquisition of Super de Boer in 2009 and the acquisition of C1000 in 2012. The acquisition of C1000 has been finished in July 2015. Due to the acquisitions of Super de Boer and C1000, the focus of Jumbo Supermarkten was in the past couple of years mainly on the integration of these supermarket chains. Many stores are transformed to Jumbo supermarkets, the assortments are harmonized, ICT systems are integrated, departments are combined, etcetera. Obviously, also the logistics network of Jumbo Supermarkten has changed a lot, as distribution centers are acquisitioned, changed in function and/or closed. Now the acquisition and integration processes have been finished, Jumbo Supermarkten is focusing on the optimization of the formula, organization and operational processes. Regarding the operational processes, Jumbo Supermarkten wants a more cost efficient logistics network to take the next step towards perfection of every day low costs and as a result every day low prices for the customers.

In this context, Jumbo Supermarkten wants to know how to decide whether an article should be stored in a NDC or in a RDC, such that costs are lowest. This is called the inventory deployment decision. The inventory deployment decision is defined by Shapiro and Wagner (2009) as the problem at which distribution stage products or product families should be held in inventory and the volumes of these inventories. Besides this, Jumbo Supermarkten wants to know how to decide which of the in paragraph 2.3.2 mentioned storage types should be assigned to the product in the specific DC, such that costs are lowest.

In the current situation, in general, fast-moving articles are stored at the RDCs and slow-moving articles are stored at the NDC. Whether an article is classified as fast- or slow-mover is determined by its volume (in $m^3$) which is sold per year. This is expressed in volume, as the volume influences the utilization of trucks and carriers and as a result the transportation and handling cost per unit, for example. The storage type assigned to a product depends also on the volume sold per year, as the relatively more fast-moving articles are stored in bigger pick locations (i.e. double 2m, 2m or 1m high pallet pick locations) and the relatively more slow-moving articles are stored in smaller pick locations (i.e. flow or shelf racks). However, also some other product characteristics are taken into account in the inventory deployment decision. For instance, safety regulations play a role in the decision whether an article should be stored in a NDC or in each of the RDCs. As example, chlorides and inflammable articles need to be stored in a special storage space in the NDC, due to safety regulations. This special storage space can be closed off and special foam sprinkler systems are installed there. In short, it is safer (and also less expensive) to keep them under control in one NDC than in each of the RDCs. Furthermore, the decision whether an article should be stored in a NDC or in a RDC is not only made at the level of the individual article, but also at the supplier-level. For example, if a supplier delivers in total twelve articles to Jumbo Supermarkten, and ten of these articles are classified by its volume which is sold per year as fast-mover and two of these articles are classified as slow-mover, it might be cheaper for the supplier to deliver all twelve articles to the RDCs instead of delivering ten articles to the RDCs and two articles to the NDC. Subsequently Jumbo Supermarkten needs to negotiate the cost difference from the supplier.

Unfortunately, Jumbo Supermarkten does not know whether the articles are optimally allocated to the NDC and RDCs and whether they are assigned to the optimal storage type. As mentioned, some product characteristics are taken into account by deciding where to store an article, however it could be possible that more product characteristics affect the inventory deployment decision. Furthermore, there is some feeling for the costs associated to storing an article at the NDC or each of the RDCs in a specific storage type, however these costs are not quantified. Complex trade-offs make these costs difficult to analyze. For example, moving an article from each of the RDCs to the NDC saves on inventory costs and on storage space, however extra costs are associated with transporting the goods from the NDC to each of the RDCs (van der Vlist, 2007). For another example, if the storage type of a product is changed from a double 2m high pallet pick location to a 1m high pallet pick location, this saves on storage space in the pick area, however it could lead to more pallets in the bulk location and thus less storage space in the bulk area. In addition of the above, the costs at the supplier level are not quantified. For example, Jumbo Supermarkten does not know whether there is an advantage of deciding on the supplier level instead of the individual article level where an article should be stored. For example, for the supplier economies of scale (implying that as the transport volume increases, the transport costs per unit decreases) could be realized when products are allocated to the NDC instead of each of the RDCs, however for Jumbo Supermarkten extra costs are associated with transporting the goods from the NDC to each of the RDCs. In the context of the inventory deployment problem, the Boston Consulting Group (BCG) has conducted a benchmark analysis. BCG has indicated that the number of articles that are currently stored in the RDCs is too high to operate cost efficient. In the retail branch, Albert Heijn for example has stored approximately 1700 articles in a RDC, while Jumbo Supermarkten has stored approximately 3000 articles in a RDC.

For these reasons, Jumbo Supermarkten wants to know how to decide whether an article should be stored in a NDC or in a RDC and in which storage type, such that costs are lowest. Therefore, a model is needed which determines whether an article should be stored at the NDC or at each of the RDCs and which determines the storage type of the article in the DC. In this model, articles should be allocated to the DC and storage type based on the costs associated to this decision. However, as Jumbo Supermarkten has a very customer-oriented formula, lowering the costs should not be at the expense of the current customer service level, like less product availability or a smaller assortment. Jumbo Supermarkten wants to optimize their formula, which means having the best service, the lowest price and a broad assortment. Besides the costs and customer service level, also the capacity constraints of the current logistics network should be taken into account. The capacities of the distribution centers probably will influence the inventory deployment decision, as these specify the quantity of products which can be stored there (Georgiadis, Tsiakis, Longinidis, & Sofioglou, 2011).

## 3.2 Research questions

Based on the above problem description, the following main research question is formulated for my Master thesis:

*How should ambient articles be allocated to distribution stages, concerning central and regional distribution centers with internal consolidation in the retail supply chain, and storage types such that overall costs are lowest, while taking into account capacity and service constraints?*

The above main research question guides the Master thesis. As Jumbo Supermarkten faces the inventory deployment problem, it wants to know how to allocate articles to distribution stages and storage types, as is stated in the main research question. Jumbo Supermarkten has determined that the focus of the Master thesis project is on the ambient articles to limit the complexity of the project. Later on, ambient articles are defined in more detail. Since the current distribution network of Jumbo Supermarkten is considered, central and regional DCs with internal consolidation in the retail supply chain are taken into account. As Jumbo Supermarkten wants to optimize their formula, which means having the best service, the lowest price and a broad assortment, the purpose of the Master thesis is to obtain the lowest cost, however, while taking into account service constraints, like keeping the current product availability and current assortment. As the current distribution network of Jumbo Supermarkten is considered, also the capacity constraints of the current network should be taken into account. Finally, *overall* costs are explicitly mentioned as a retailer should not only know the consequences for the costs inside the retail organization, but also the consequences for the costs outside the retail organization itself; in the retail supply chain as a whole.

In order to be able to answer this main research question, the following sub-questions have been identified, based on the problem description, main research question and literature study:

1. *What are the resulting costs of the current allocation of ambient articles to the distribution stages at Jumbo Supermarkten? What are the relevant costs related to the inventory deployment decision?*
2. *What product characteristics could affect the inventory deployment decision?*
3. *What assumptions should be used to evaluate the inventory deployment decision?*
4. *How should the relevant costs related to the inventory deployment decision be modeled?*
5. *How should the relevant capacity and service constraints related to the inventory deployment decision be modeled?*
6. *How should the inventory deployment decision be modeled at the supplier level?*
7. *What factors have the biggest impact on the inventory deployment decision?*
8. *Which products should be stored at the national distribution center and which products should be stored at the regional distribution centers and in which storage type should they be stored?*

## 3.3 Gap in literature

In this paragraph, the academic relevance of the Master thesis is revealed by identifying gaps in the current state of research on the Master thesis' subject; the inventory deployment decision. The previously literature study showed that the inventory deployment decision is part of the logistics network design problem, for which optimization models can be used to solve the problem. However, in past research the inventory deployment decision is often ignored in these network optimization models. In the current literature there are just a few mathematical modeling papers which are applicable in the grocery retail supply chain and explicitly address three (or more) tiers including two different distribution stages (e.g. national and regional distribution centers) and stores. However, the distribution networks in these papers differ with the distribution network of Jumbo Supermarkten. Georgiadis et al. (2011), Manzini and Bindi (2009), and Tsiakis, Shah and Pantelides (2001) only take into account NDCs and RDCs as distribution stages, without cross-docking (internal consolidation). In these articles, each product flows from supplier to NDC, from NDC to RDC, and then to the store. Gebennini, Gamberini and Manzini (2009), Guericke, Koberstein, Schwarts and Voß (2012), Manzini and Gebennini (2008), Paksoy, Bektas & Özceylan (2011) and Perea-López, Ydstie and Ignacio (2003) also only take into account NDCs and RDCs as distribution stages, without cross-docking (internal consolidation), however products may flow from a supplier directly to a RDC or from a NDC directly to a store. Jayaraman and Ross (2003), and Ross and Jayaraman (2008) only take into account NDCs and pure cross-dock sites as distribution stages. In these articles, each product flows from the supplier to the NDC, from the NDC to the cross-dock site, and then to the store. Finally, Ambrosino and Scutella (2005) take into account NDCs, RDCs and pure cross-dock sites, however in this article, each product flows from the NDC to the RDC or to the pure cross-dock site. In short, none of the above papers model exactly the supply chain network of Jumbo Supermarkten, as in this network the products stored in the NDC are cross-docked with the products stored in the RDC and then are being shipped jointly to the stores. While, according to Kuhn and Sternbeck (2013), many retailers operate this type of network consisting of central and regional distribution centers with internal consolidation. Klincewicz (1990) does model a supply chain network likewise the network of Jumbo Supermarkten (excluding the stores), as it models sources (=suppliers), terminals (=NDC) and destinations (=RDCs) with direct and indirect shipments. However, no decisions are made on specific storage types for the articles, which at Jumbo Supermarkten influence the costs and determine to what extent capacities (like the number of pick- and bulk locations) are exceeded. The inventory deployment decision at Jumbo Supermarkten is even more complex, as a specific product allocated to the RDC, could be stored in different storage types in each of the RDC sites. As a result, a small gap in the current state of research on the inventory deployment decision is identified. The Master thesis fills this gap by developing a model to solve the inventory deployment decision for a network consisting of central and regional distribution centers with internal consolidation. This model allocates articles to distribution stages and storage types.

Bartholdi and Hackman (2014) showed that the decision whether an article should be stored in the forward area or reserve area of a DC, which is quite similar to the decision whether an article should be stored in the RDC or NDC, is similar to a knapsack problem and solved this problem for each individual article by using a greedy heuristic. However, the decision whether an article should be stored in a NDC or in a RDC should not only be made at the level of the individual article, but also at the supplier-level. Besides this, at Jumbo Supermarkten a specific product could be stored in different storage types in each of the RDC sites. As a result, a small gap in the current state of research on the inventory deployment decision is identified.

In addition, the previously conducted literature study has dealt with the relevant costs related to the inventory deployment decision and the modeling of these costs. According to the literature study the relevant costs were transportation, fixed and variable warehousing, and inventory costs. The Master thesis validates whether these costs are relevant for the inventory deployment decision at Jumbo Supermarkten. Furthermore, the most appropriate way to incorporate the relevant costs, and capacity and service constraints in the model are determined.

# 4. Research design

In this chapter, the research design is described. The research design consists of the research methodology and research methods that are used during the Master thesis project.

## 4.1 Research methodology

The research methodology of the Master thesis project is based on the research model developed by Mitroff, Betz, Pondy and Sagasti (1974), as shown in Figure 5. The research model is appropriate for quantitative model-based research with a problem solving orientation, like this Master thesis project. The model consists of the phases Conceptualization, Modeling, Model solving and Implementation. Mitroff et al. (1974) mention that applying shortcuts in the research cycle, by skipping a phase, often leads to less than desirable research designs (Bertrand & Fransoo, 2002). Therefore, the Master thesis project has gone through all phases of the research model.

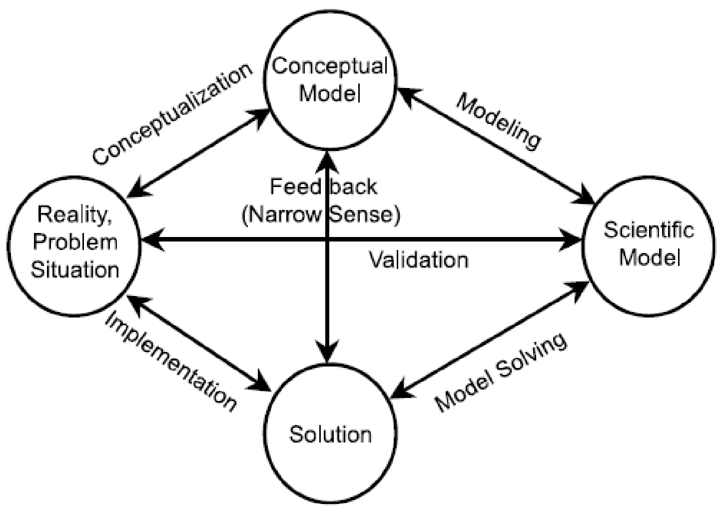


Figure 5: Research model developed by Mitroff et al. (1974).

The research model starts with the problem situation, which is already described in paragraph 3.1. In the conceptualization phase, a conceptual model of the problem situation is made. In this phase, the researcher should make decisions about the variables that need to be included in the model, and the scope of the problem and model to be addressed (Bertrand & Fransoo, 2002). Research sub-questions 1 and 2 are answered in this phase. Subsequently, in the modeling phase, the scientific model is build. In this phase, an appropriate modeling approach should be chosen, assumptions underlying the model should be defined and relationships between variables should be modeled. Research sub-questions 3 to 6 are answered in this phase. After this, the quantitative model is solved in the model solving phase. In this phase, also the solution of the model is evaluated. Finally, in the implementation phase, the results of the model should be implemented. However, the real implementation of the results of the model (the actual re-allocation of products to distribution stages and storage types) is out scope for the Master thesis project. Therefore, in the implementation phase, the main findings and some implementation issues are described. Jumbo Supermarkten can decide on the basis of the Master thesis project and its limitations what they wish to implement. Research sub-questions 7 and 8 are answered in this phase.

## 4.2 Research methods

First of all, it was important to get a general image of the company Jumbo Supermarkten, its distribution network, its operational processes and the problem it faces. This current problem situation of Jumbo Supermarkten, as described in chapter 2 and 3, is analyzed by using qualitative data collection methods: interviews, observations, documents and websites. Interviews are conducted with two project managers of the supply chain development department, with a data analyst of the supply chain development department, with two specialists of inter-DC transport, with two supply chain managers of the replenishment department, with the manager of the procurement department, with supply chain controllers, and with the site-manager of the NDC in Elst. These interviews were semi-structured, as on forehand certain subjects and relevant questions were be specified, however, during the interviews questions were modified, added or omitted. Subjects included in the interviews were for example the supply chain structure, the flow of goods, the handling activities at the DCs, the transportation processes, the inventory deployment decision, and etcetera. Through observations at the RDC in Veghel for ambient and chilled articles (de Amert 409) and at the NDC in Elst for ambient articles a better image of the distribution center activities is obtained. Furthermore, corporate documentations and websites are used as a source of information, mainly for the general description of the company Jumbo Supermarkten. Additionally, to offer an overview of relevant literature published on the inventory deployment decision and to identify gaps in the literature, a literature study is conducted, using scholarly articles, books and other sources (e.g. dissertations) relevant to the area of research.

The purpose of the Master thesis is to determine how ambient articles should be allocated to distribution stages and storage types, such that overall costs are lowest, while taking into account capacity and service constraints. Therefore, a model is needed which allocates articles to DCs and storage types based on the costs. Later on in this report, the developed quantitative model to evaluate the inventory deployment decision at Jumbo Supermarkten is described. The quantitative data needed for this model is retrieved from databases of Jumbo Supermarkten.

# 5. Conceptualization phase

In the conceptualization phase, a conceptual model of the problem situation is made. In this phase, the researcher should make decisions about the variables that need to be included in the model, and the scope of the problem and model to be addressed (Bertrand & Fransoo, 2002). Therefore, in this chapter first the scope of the Master thesis is defined. Subsequently, the resulting costs of the current allocation of ambient articles to the distribution stages are analyzed, such that can be determined which costs are relevant in the inventory deployment decision at Jumbo Supermarkten. As a result, research sub-question 1 is answered in this chapter. Finally, it is determined what product characteristics could affect the inventory deployment decision, as these should be included in the model. As a result, research sub-question 2 is answered in this paragraph.

## 5.1 Scope

In this paragraph the scope of the Master thesis project is defined, in order to limit the complexity of the problem.

Not all products are in scope of the Master thesis project. Jumbo Supermarkten has determined that the focus is on the ambient articles. The ambient articles are the articles that don't require specific storage conditions to slow the deterioration rate. However, some ambient articles are perishable, like bread and newspapers. The articles with an extreme short shelf life are out of scope, as these articles should be delivered directly to the stores due to their extreme short shelf-life; it makes no sense to keep these articles on stock in one of the distribution stages. As a result, the so-called ambient articles in scope are articles that don't require specific storage conditions to slow the deterioration rate and have a shelf life of minimal a few days, such that they can be stored in one of the distribution stages.

The scope of the Master thesis project is on the current ambient distribution network of Jumbo Supermarkten, consisting of NDCs and RDCs with internal consolidation. The number, location, function (i.e. RDC or NDC) and type (i.e. frozen, chilled and/or ambient) of distribution centers is fixed. The VEEM-location itself is out of scope, as the articles currently stored there continue to be stored in the VEEM-location, however the inbound transport from the VEEM-location to the DCs is in scope. Each distribution center lay-out and corresponding activities in the DC are modeled as in the current situation, mentioned in paragraph 2.3.2. The exact pick location assignment of products is out of scope; it is only determined in which DC and in which storage type each product is stored. The products which must be allocated to the NDC due to safety regulations are in scope, however can only be allocated to the NDC. So-called reverse supply chain activities, like recycling activities, are also out of scope.

The scope of the Master thesis project is on the primary and secondary distribution, as shown in Figure 2. It is assumed that the retail supply chain starts upward of the supplier's warehouse and ends with the arrival of articles at the retail outlets. As a result, the current stores of Jumbo

Supermarkten are in scope, however the activities conducted at the stores are out of scope. The number and location of stores is fixed to the current situation. Also the allocation of stores to RDCs is fixed as in the current situation. The food markets are considered as regular stores. The online orders via Jumbo.com and the Jumbo app are out of scope.

As the retail supply chain starts upward of the supplier's warehouse, the current suppliers of ambient articles are in scope, however the activities conducted at the supplier's warehouses are out of scope. The number and location of their warehouses is fixed to the current situation. A supplier can deliver the articles to the distribution centers or directly to the stores. As mentioned in paragraph 2.3.1, the deliveries to the distribution centers can be *regular*, VMI, cross-dock, pick-to-zero or transito. However, the ambient articles in scope are not delivered pick-to-zero or transito. As a result, these delivery types are out of scope. Articles, for which VMI is used, are considered as regular articles, whereby Jumbo Supermarkten orders at the suppliers. The cross-docking and direct deliveries are out of scope for the Master thesis project, as these articles won't be stored at the distribution centers. Besides above delivery types, whereby the suppliers transport their articles to Jumbo Supermarkten, Jumbo Supermarkten also picks up articles at the suppliers, which is called backhauling. The products which are backhauled are in scope, however are considered as if the supplier delivers the products at Jumbo Supermarkten. The optimization of delivery frequencies and order quantities is out of scope for the Master thesis project, as it is in the scope of another Master thesis project conducted at Jumbo Supermarkten. The delivery frequencies and order sizes itself are in scope, as they are used as input for the model.

## 5.2 Relevant retail supply chain costs

The resulting costs of the current allocation of ambient articles to the distribution stages and storage types are analyzed to determine which costs are relevant in the inventory deployment decision at Jumbo Supermarkten. According to the conducted literature study, transportation, fixed and variable warehousing, and inventory costs are the relevant costs in the inventory deployment decision. However, also costs due to waste are examined. An estimation of the cost break-down structure of the distribution network of Jumbo Supermarkten for ambient articles is shown in Figure 6. Transportation costs can be divided in inbound (from supplier to DC), inter-DC (from NDC to RDC) and outbound (from RDC to customer) transportation costs. However, the supplier is responsible for the transportation from his warehouse to Jumbo Supermarkten and the costs for transportation are included in the total purchase price of an order. As a result, the inbound transportation costs are not known at Jumbo Supermarkten and therefore not included in the figure. The variable warehousing costs mentioned in literature are called handling costs. The costs at the suppliers (handling) and costs at the stores (handling, inventory, waste) are not included, as these are out of scope.

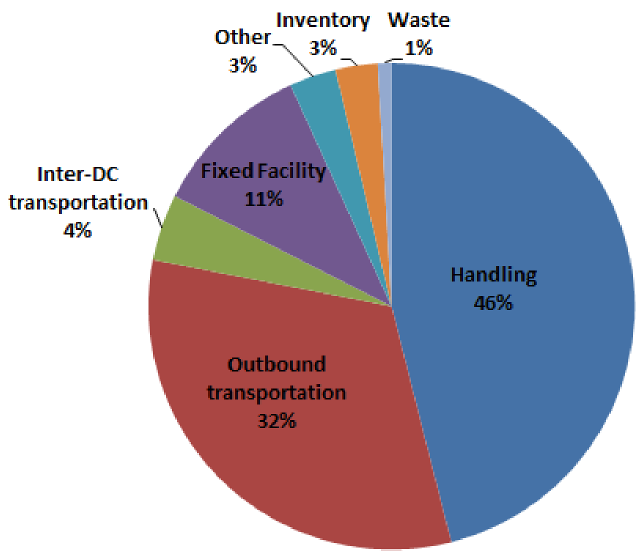


Figure 6: Cost break-down structure of the primary and secondary distribution network of Jumbo Supermarkten.

As shown in Figure 6 the majority of the costs of the primary and secondary distribution network at Jumbo Supermarkten for ambient articles are handling costs and outbound transportation costs. However, as the demand of the retail stores is independent of the inventory deployment decision (whether a product is stored in the NDC or each of the RDCs, the demand of the store is the same), it can be assumed that the number of roll cages and thus the number of trucks transported from the RDCs to the stores will be the same. As a result, the outbound transportation costs are fixed and independent of the inventory deployment decision; these costs are not relevant in the inventory deployment decision. The handling costs depend on the inventory deployment decision and are therefore relevant in modeling the inventory deployment decision. The fixed facility costs also have a substantial part in the cost break-down structure and consist of rental costs and costs for electricity, equipment, management staff, maintenance, security, etcetera. However, as these costs are also independent of the inventory deployment decision, the fixed facility costs are not relevant in the inventory deployment decision. The costs due to inventory and waste are considered as negligible in modeling the inventory deployment decision (considering only ambient articles), as these costs have a limited effect on the total costs, while they are time-consuming to model. Obviously, the small costs due to other factors are also ignored in modeling the inventory deployment decision. A minor part of the total costs consist of inter-DC transportation costs, however these should be examined in more detail as these costs only hold for products stored in the NDC and for these products stored in the NDC, the inter-DC transportation costs are on average approximately 12% of the total costs. On the individual article level these costs probably could affect the inventory deployment decision whether to store the product in the NDC or each of the RDCs. Finally, based on the literature study, it can be assumed that inbound transportation costs are relevant in the inventory deployment decision. As a conclusion, the handling, inbound and inter-DC transportation costs are the costs that are relevant in modeling the inventory deployment decision at Jumbo Supermarkten. This answers research sub-question 1.

## 5.3 Relevant product characteristics

In this paragraph, several product characteristics that could affect the inventory deployment decision according to literature are explained.

According to Kuhn and Sternbeck (2013) the most important product characteristic affecting the inventory deployment decision is the demand rate, as higher rates of SKU turnover result in higher order quantities, which make it less necessary to bundle product flows by routing via the national distribution center. The reduction of distances becomes more important when order quantities increases. Therefore, according to Chopra (2003) fast-moving items should be stored close to the customers, which means at the RDCs, while slow-moving items should be stocked at the NDC. However, according to Smaros, Angerer, Fernie, Toktay and Zotteri (2004), the classification as slow-mover or fast-mover (i.e. the allocation to NDC or RDC) should not only be based on the article's demand rate, but for instance also on their size and weight, shelf-life, storing conditions and supplier of the product. The size (or volume) of a product is an important product characteristic in the inventory deployment decision. The volume influences the number of trucks and carriers required for the transportation of products from the suppliers via the distribution centers to the stores, as trucks and carriers have a maximum volume they can handle. As a result, the volume influences the transportation and handling costs, which play an important role in the inventory deployment decision. However, trucks and carriers also have a maximum weight they can handle. Therefore, also the weight influences the number of trucks and carriers required for the transportation of products from the suppliers via the distribution centers to the stores: The weight influences the transportation and handling costs. The storage condition and shelf-life, mentioned by Smaros et al. (2004) and Kuhn and Sternbeck (2013) as important products characteristics, are less relevant in the inventory deployment decision at Jumbo Supermarkten, as the products in scope don't require specific storage conditions to slow the deterioration rate and all have a shelf life of minimal a few days. Furthermore, the decision whether an article should be stored in a NDC or in a RDC should not only be made at the level of the individual article, but also at the supplier-level. For the supplier, economies of scale could be realized when products are allocated to the NDC instead of each of the RDCs. These economies of scale imply that as the transport volume increases, the transport costs per unit decreases, which results in cost savings for the supplier. Subsequently Jumbo Supermarkten needs to negotiate the cost difference from the supplier, such that the total costs for Jumbo Supermarkten are lower. Also the sourcing conditions that have been arranged with suppliers are mentioned by Kuhn and Sternbeck (2013) as an important product characteristic. Jumbo

Supermarkten has with each supplier different agreements on (minimum) order sizes and purchase prices. For example, there could be agreed that Jumbo must order full pallets of 2m high or that ordering less than full pallets leads to additional costs. This is influencing the inventory deployment decision. For instance, if for a certain article of a supplier the demand of the stores served by a RDC is less than a full pallet, shifting that article to the NDC might facilitate delivery in a full pallet resulting in a lower purchase price (van der Vlist, 2007).
Kuhn and Sternbeck (2013) also pointed out the demand forecast error for SKUs, which is the result of demand variability. As the safety stock is generally set to be proportional to the standard deviation of the demand during the lead time (Kang & Kim, 2012), the need for safety stocks is higher when the demand variability increases (and as a result the forecast error increases). Assuming that demands from different retail stores are independent, the variance of the sum of the demands from a set of retail stores is smaller than the sum of the variances of the demand from those retail stores and as a result the safety stock needed for pooled demands is generally less than the sum of safety stocks for individual demands (Kang & Kim, 2012). Therefore one may use inventory pooling, which means that the demands from all sources are pooled by a centralized system, such that the demand variability will decrease and as a result the inventory levels and costs will decrease (Eppen, 1979). Due to inventory pooling or the so-called centralization effect, the retailer safety stocks are smaller overall when the article is stored in the NDC than when in several RDCs, as the demand variability is reduced. As the overall safety stocks are smaller, the inventory holding costs will be lower. However, as the costs due to inventory are very low in the current situation and have a limited effect on the total costs, the inventory costs are considered as negligible in modeling the inventory deployment decision at Jumbo Supermarkten. On the other hand, a smaller safety stock due to storing an article in the NDC instead of each of the RDCs, results in less inventory for that article which could save on storage space. As a result, the centralization effect influences the inventory deployment decision, as it influences for instance the number of bulk locations necessary to store the inventory of products. In addition, an article allocated to the NDC consumes one pick location while an article allocated to the RDC consumes four pick locations (one pick location per RDC site). As a result, storing an article in the NDC instead of each of the RDCs could save on storage space (i.e. the total number of pick locations consumed).
Finally, safety regulations play a role in the decision whether an article should be stored in a NDC or in each of the RDCs. For instance, chlorides and inflammable articles need to be stored in a special storage space in the NDC, due to safety regulations. This special storage space can be closed off and special foam sprinkler systems are installed there. In short, it is safer (and also less expensive) to keep them under control in one NDC than in each of the RDCs.

# 6. Modeling phase

In the modeling phase, the scientific model is build. In this phase, an appropriate modeling approach should be chosen, assumptions underlying the model should be defined and relationships between variables should be modeled. Therefore, in this chapter first the assumptions underlying the model are listed. As a result, research sub-question 3 is answered in this chapter. Finally, the quantitative model is explained, which answers research sub-questions 4 to 6 how the relevant costs and constraints should be modeled at the individual and supplier level.

## 6.1 Assumptions

In this paragraph, the assumptions underlying the model are listed. As a result, research sub-question 3 is answered in this paragraph.

- Demand is deterministic and equal to the actual supply of period 9 of 2015, which is weeks 33 to 36. There is chosen for period 9, as before this period the acquisition of C1000 was not finished and after this period several articles were being re-allocated to the distribution centers. In the model, the average weekly demand is used as input. A week pattern in the demand is ignored.
- NDC Elst and NDC Veghel are considered as one NDC-location, located in Elst. As a result, the model makes no choice for a specific NDC site. The capacities, like the number of available pick and bulk locations, of the two NDCs are aggregated. This assumption implies that the order picking method in the NDC is wave zone picking without batching, while in reality in NDC Veghel wave zone picking with batching with sort-while-pick is used as order picking method. For the inter-DC and inbound transportation costs this assumption implies that the distances from and to the NDC are determined as if the NDC is located in Elst. The assumption is made in order to limit the complexity of the problem and because Jumbo Supermarkten wants to expand NDC Elst in the future, such that the products currently stored in the NDC in Veghel also can be stored in the NDC in Elst.
- It is assumed that enough pallets are stored in the VEEM-location to satisfy the demand of the DCs. The inbound transport costs of suppliers delivering to the VEEM-location are out of scope. The VEEM-location is seen as a new supplier; the inbound transport from the VEEM-location to the DCs is in scope.
- Jumbo Supermarkten also picks up products at the suppliers, which is called backhauling. However, it is modeled as if the supplier delivers the products at Jumbo Supermarkten, since the modeled costs for transport will be the same. The only difference is that the transportation costs are paid by Jumbo Supermarkten instead of the supplier.
- If a product is allocated to a 2m high pallet pick location, it is always delivered on a 2m high pallet and always stored in a 2m high pallet rack bulk location. If a product is allocated to a

1m high pallet, flow- or shelf rack pick location, it is delivered on a 2m or 1m high pallet (dependent on the supplier). If it is delivered on a 2m high pallet, it is restacked to 1m high pallets. The delivered and restacked 1m high pallets are always stored in 1m high pallet rack bulk locations.

- Each DC has its own lay-out with a certain number of 2m and 1m high pallet rack bulk locations. However, 2m high pallet rack bulk locations could be split in two 1m high pallet rack bulk locations, while two 1m high pallet rack bulk locations can be merged into one 2m high pallet rack bulk location. The costs for changing bulk locations are negligible and therefore not included in the model. The capacity of the bulk locations of a DC is therefore expressed in one number, namely the total number of 1m high pallet rack bulk locations (whereby current 2m high pallet rack bulk locations are counted as two 1m high pallet rack bulk locations).
- Each DC has its own lay-out with a certain number of 2m high pallet, 1m high pallet, flow- and shelf rack pick locations. However, 2m high pallet pick locations can easily be changed to 1m high pallet pick locations or shelf rack pick locations and vice versa. The costs for changing these locations are negligible and therefore not included in the model. However, flow racks are hard to convert to pallet or shelf rack pick locations, which is also very expensive. Therefore it is assumed that the number of available flow racks can't be changed. The capacity of the pick locations of a DC is expressed in one number, namely the number of pick houses. As mentioned, one pick house can contain one double 2m high pallet, two 2m high pallet, four 1m high pallet, ten flow rack or thirty-two shelf rack pick locations.
- Due to efficiency reasons and the presence of seasonal assortment, not all available bulk- and pick locations can be occupied. As a result, only 85% of the available bulk locations and only 90% of the available pick locations can be used. These numbers are commonly used at Jumbo Supermarkten.
- As mentioned, some beer crates are currently stored in the block stacking area. These beer crates are included in the model, as costs for transport and handling occur, however they don't consume any pick- and bulk locations. Furthermore, it is assumed that the block stacking area is large enough to store all the beer crates.
- Each DC of Jumbo Supermarkten has a given number of docks, however they don't have specific receiving and shipping docks. Each day a planning is made whereby docks are assigned as receiving or shipping dock. Therefore, it is assumed that half of the docks are assigned as receiving dock and half of the docks are assigned as shipping dock for each DC.
- For each product, there are always some case packs available in the DC; stock-outs do not occur. As a result, there are always some case packs in the pick-location. Therefore, all pallets will be placed in bulk storage after arrival at the DC.

- The utilization rate of trucks used for inter-DC transport is assumed to be constant for each specific NDC-RDC movement. This assumption is reasonable, as the so-called head-tail method is used in the NDC: Trucks wait until they have a full truck load or a time limit is reached. In practice this means that all trucks have a full truck load, except the last truck of a time period. As a result, the changes in utilization rate are negligible, when products switch from NDC to RDC or vice versa.
- When Jumbo Supermarkten decides to change the storage location of a product, it is assumed that suppliers are willing and able to deliver to the changed DC-location.
- The actual costs for transportation from the supplier to a DC are included in the total purchase price of an order. It is assumed that only the transportation costs will change when the DC-location or storage types of products are changed, while the purchase costs (excl. transportation costs) will remain the same. Jumbo Supermarkten has with each supplier different agreements on purchase prices and minimum order sizes. For example, there could be agreed that Jumbo must order full pallets of 2m high or that ordering less than full pallets leads to additional costs on the purchase price. However, these agreements are different with each supplier. Therefore, it is assumed that suppliers currently delivering their products on 1 meter high pallets are willing and able to deliver their products on 2 meter high pallets. This is reasonable, as suppliers will prefer to deliver 2 meter high pallets. There are no additional supplier costs or discounts incurred for changing pallet heights from 1 meter to 2 meter high. Furthermore it is assumed that suppliers currently delivering their products on 2 meter high pallets are not willing to deliver their products on 1 meter high pallets, due to present agreements.
- The delivery schedule to the DCs is assumed to be fixed, whether a product is allocated to the NDC or RDC. The optimization of delivery frequencies and order quantities is out of scope for the Master thesis project, as it is the scope of another Master thesis project conducted at Jumbo Supermarkten. When a product which is currently stored at the NDC will be stored at the RDC sites, the current delivery schedule of the NDC is used as delivery schedule for the RDC sites. The current delivery schedules of a product currently stored at the RDC could be different for each RDC site. When a product which is currently stored at the RDC will be stored at the NDC, the most frequent delivery schedule of the RDC sites is used as schedule for the NDC. However, in some cases there are two (or more) most frequent delivery schedules. Then the delivery schedule with the most order moments is chosen as delivery schedule for the NDC. As it is assumed that Jumbo Supermarkten has chosen the optimal delivery schedules for the RDC sites and one RDC site needs a certain number of order moments, the NDC will also need at least this number of order moments, since the demand is even higher at the NDC.
- Each fixed order moment is used to order a product at the supplier. This means that at each delivery moment all products of a so-called supplier group are delivered by the supplier. For

clarity, this does not mean that all products of the supplier are delivered each order moment. For almost all products in scope this is currently the case at Jumbo Supermarkten. This assumption is made to determine the truckload per delivery moment, such that inbound transport costs can be calculated.

- Pallets of 1 meter high can sometimes be stacked on top of each other in order to save space in the truck. This depends on the type of product (i.e. the shape and hardness of a product). For some products it is known whether they can be stacked or not. For the remaining products it is assumed that products can't be stacked, as this is the case for most products according to several employees of Jumbo Supermarkten.

## 6.2 Mathematical formulation

In the following sections the quantitative model is explained. The notation used in the mathematical formulation is as follows:

*Sets*

| | | |
|---|---|---|
| $H$ | Set of locations (index = $h$) | $1, \ldots, l$ |
| $I$ | Set of storage types (index = $i$) | $1, \ldots, m$ |
| $I_h$ | Set of storages types available in location $h$ | |
| $J$ | Set of products (index = $j$) | $1, \ldots, n$ |
| $K$ | Set of resources (index = $k$) | $1, \ldots, o$ |

*Parameters*

| | |
|---|---|
| $C_{hk}$ | capacity of resource $k$ at location $h$ |
| $HC_{hij}$ | handling costs of product $j$ allocated to location $h$ and storage type $i$ |
| $IDCTC_{hij}$ | inter-DC transport costs of product $j$ allocated to location $h$ and storage type $i$ |
| $ITC_{hij}$ | inbound transport costs of product $j$ allocated to location $h$ and storage type $i$ |
| $TC_{hij}$ | total costs of product $j$ allocated to location $h$ and storage type $i$ |
| $w_{hijk}$ | resource consumed of resource $k$ by product $j$ allocated to location $h$ and storage type $i$ |
| $z_{hj}$ | 0-1 parameter; 1 if product $j$ must be allocated to the NDC $(h = 1)$ due to safety regulations, 0 otherwise |

*Decision variables*

| | |
|---|---|
| $x_{hj}$ | 0-1 decision variable; 1 if product $j$ allocated to location $h$ is selected, 0 otherwise |
| $y_{hij}$ | 0-1 decision variable; 1 if product $j$ allocated to storage type $i$ at location $h$ is selected, 0 otherwise |

The set of locations consists of 5 locations. The locations are NDC Elst, RDC Beilen, RDC Breda, RDC Veghel and RDC Woerden. A product is allocated either to NDC Elst or to each of the four

RDC sites. Thus, if a product is allocated to the RDC, it is stored in Beilen, Breda, Veghel and Woerden.

The set of storage types consists of 5 different storage pick types. The storage types are double 2m high pallet pick location, 2m high pallet pick location, 1m high pallet pick location, flow rack pick location and shelf rack pick location. If a product is allocated to NDC Elst, it can be stored in the following storage pick types: 2m high pallet, 1m high pallet, flow rack or shelf rack pick location. If a product is allocated to the RDC sites, it can be stored in the following storage pick types: double 2m high pallet, 2m high pallet or 1m high pallet pick location. However, a product can be stored in different storage pick types in each of the RDCs. For instance, a specific product could be assigned to a 2m high pallet pick location in RDC Beilen, a double 2m high pallet pick location in RDC Breda and RDC Veghel, and a 1m high pallet pick location in RDC Woerden.

The set of products consists of 11.325 products in total.

The set of resources consists of 7 resources in total. Each of the five DCs has five resources which could be consumed by products. These resources are the number of pick houses available, the number of bulk locations available, the number of order pickers available in a DC, the number of case packs a DC can handle and the number of inbound transport deliveries a DC can handle. The NDC has in addition two extra resources which could be consumed by products. These are the number of outbound transport deliveries the NDC can handle and the number of flow racks available in the NDC. These resources are explained in more detail in paragraph 6.4.

In terms of the above notation, the mathematical formulation of the model is given by

$$\text{Min} \sum_{h \in H} \sum_{i \in I_h} \sum_{j \in J} TC_{hij} y_{hij} \tag{1}$$

S.T.

$$\sum_{i \in I_h} \sum_{j \in J} w_{hijk} y_{hij} \leq C_{hk} \qquad h = 1, \dots l; k = 1, \dots, 6 \tag{2}$$

$$\sum_{j \in J} w_{hijk} y_{hij} \leq C_{hk} \qquad h = 1; i = 4; k = 7 \tag{3}$$

$$\sum_{h=1}^{2} x_{hj} = 1 \qquad j = 1, \dots, n \tag{4}$$

$$x_{2j} = x_{3j} = x_{4j} = x_{5j} \qquad j = 1, \dots, n \tag{5}$$

$$\sum_{i \in I_h} y_{hij} = x_{hj} \qquad h = 1, \dots, l; j = 1, \dots, n \qquad (6)$$

$$x_{hj} \geq z_{hj} \qquad h = 1; j = 1, \dots n \qquad (7)$$

$$x_{hj} \in \{0,1\} \qquad h = 1, \dots, l; j = 1, \dots, n \qquad (8)$$

$$y_{hij} \in \{0,1\} \qquad h = 1, \dots, l;\ i = 1, \dots, m; j = 1, \dots, n \qquad (9)$$

where:

$$TC_{hij} = HC_{hij} + ITC_{hij} + IDCTC_{hij} \qquad h = 1, \dots, l;\ i = 1, \dots, m; j = 1, \dots, n \qquad (10)$$

The above model is derived from the multidimensional multiple-choice knapsack problem (MMKP). In general, the MMKP can be described as follows: Given a set of items that are divided into several groups and given different types of limited resources, whereby each item requires a certain amount of each resource and generates a profit, the purpose of the MMKP is to select exactly one item from each group such that the total profit of the selected items is maximized while the consumption of each resource does not exceed the given limit (Chen & Hao, 2014). In the model above, there is a set of $j$ products each of which can be allocated to $h$ locations and $i$ storage types, and different types of $k$ limited resources, whereby each product allocated to a location and storage type requires a certain amount of each resource $w_{hijk}$ and requires a certain cost $TC_{hij}$. The purpose is to select exactly one distribution stage (NDC Elst or each of the four RDC locations) and one storage type for each selected location, such that the total costs are minimized while the consumption of each resource does not exceed the given limit $C_{hk}$.
The objective of the model is to minimize the total costs, as given in (1). The total costs consist of handling, inbound transport and inter-DC transport costs, as given in (10). Constraint (2) and (3) ensure that the consumption of resources by products does not exceed the given limit. Constraint (3) is separated from constraint (2), as constraint (3) ensures that the consumption of flow racks ( $i = 4$) by products $j$ allocated to NDC Elst $(h = 1)$ does not exceed the given limit $(k = 7)$. Constraint (4) makes sure that each product is allocated to either NDC Elst $(h = 1)$ or either RDC Beilen $(h = 2)$. In combination with constraint (5) it ensures that each product is allocated to exactly one DC type (NDC Elst or each of the four RDC locations). In addition, constraint (6) ensures that a product is allocated to one storage type $i$ in location $h$, if the product is allocated to that location $h$. Subsequently constraint (7) is included to ensure that products which must be allocated to the NDC due to safety regulations indeed are allocated to the NDC. The binary constraint for decision variable $x_{hj}$ is given in (8) and for decision variable $y_{hij}$ in (9). The model represented above is a binary integer linear

programming (ILP) problem. However, before the mathematical model can be solved, it is required to calculate some parameters in advance. For each product-location-storage type combination, the handling costs, inbound transport and inter-DC transport costs are calculated. These costs can be calculated on forehand, as it is assumed that demand is deterministic and equal to actual supply of period 9 of 2015. Besides the cost parameters, also the resource parameters are calculated in advance. It is calculated which amount of each resource is consumed by each product-location-storage type combination. These calculations are explained in the following paragraphs. As a result, research sub-questions 4 and 5 are answered in the following paragraphs.

## 6.3 Activity based costing

In order to assign handling, inbound transport and inter-DC transport costs to each product allocated to a specific location and storage type, so-called Time-Driven Activity Based Costing (ABC) is used (Kaplan & Anderson, 2004). In ABC costs are assigned to activities and the costs for a product are based on the activities performed on the product in the supply chain. In Time-Driven ABC duration drivers are used, which estimate the time required to perform the activity. Using Time-Driven ABC, first all relevant activities in the retail supply chain are identified. Subsequently, for each activity the time required to perform an activity and the costs per unit time are estimated. As a result, the costs per single activity can be calculated. Finally, for each activity the cost driver, which determines the number of times the activity is performed, is determined. Cost drivers could be the number of pallets, the number of case packs or the distance traveled, for example.

In the following paragraphs is explained in more detail how handling, inbound transport and inter-DC transport costs are assigned to each product-location-storage type combination.

### 6.3.1 Handling costs

First all relevant handling activities are identified. The handling activities in a distribution center are receiving, unpacking, restacking, storage, replenishing, order picking, shipping, receiving cross-dock (roll cages from NDC) and shipping cross-dock (roll cages from NDC), as mentioned in paragraph 2.3.2. All of these activities are relevant in modeling the inventory deployment problem, except for the activity unpacking. Unpacking is irrelevant, as the number of case packs which should be unpacked is always the same for a product and does not depend on the allocation of the product to a specific location and/or storage type (it is assumed that the durations and labor costs for unpacking are the same at each DC).

Each single handling activity takes a certain amount of time and is conducted by a specific employee. Some activities also include material costs, like the costs per unit time for reachtrucks and picking trucks. To calculate the costs per single activity, the duration of the activity is multiplied with the labor costs per unit time of the specific employee and the material costs per unit time. The durations and labor costs of a specific activity differ for each of the DCs. The durations depend for example on the productivity of the personnel in the DC, type of operations in the DC, and lay-out of the DC. The labor cost per activity differs for each of the DCs, as the average hourly wages differ due to different age compositions of the employees in the DCs. The durations of the activities and labor and material costs per unit time are estimated for each of the DCs based on productivity rates and financial results available at Jumbo Supermarkten. In addition, for replenishing and order picking, the duration of the activities differ in the DC dependent on the storage pick type the product is allocated to. This is explained in more detail in Appendix A.

Finally, for each activity the costs driver is specified, which determines the number of times the handling activity is performed. As shown in Table 1 in Appendix B, the cost drivers for the handling activities are the number of case packs, the number of (2m or 1m high) pallets and the number of roll cages. For the restacking activity, the cost driver is the number of case packs which needs to be restacked, which is the difference between the number of case packs on a 2m high pallet and a 1m high pallet. For the sub-activities stopping and grabbing a case pack of the order picking activity the cost driver is the number of case packs. The sub-activity traveling has no cost driver, as the costs for traveling are fixed for each product-location-storage type combination. The number of case packs (and as a result the number of pallets and roll cages) depends on the allocation of products to a specific location, as the demand is different for each of the DC sites. The number of pallets also depends on the allocation of products to a specific storage type, as the storage type determines the height of the pallet. Therefore, for each product-location-storage type combination these cost drivers are calculated, which is explained in paragraph 6.3.4. The cost drivers are calculated in numbers per week, such that the handling costs are calculated in costs per week.

### 6.3.2 Inbound transport costs

First all relevant inbound transport activities are identified. The relevant inbound transport activities are loading, traveling, stopping and unloading. However, the actual costs for transportation from supplier to DC are included in the total purchase price of an order. As a result, the actual inbound transportation costs are not known at Jumbo Supermarkten. Therefore, it will be hard to give a good estimation of the inbound transportation costs and duration of the activities, since they can’t be validated with actual figures. For this reason, time and cost estimations are approximated by using transport data of Jumbo Supermarkten.

Each identified single activity takes a certain amount of time and is conducted by the truck driver. The activity unloading is conducted by an employee of Jumbo Supermarkten in the specific DC, and therefore also considered as a handling activity, however the truck driver has to wait and sign papers during the unloading, such that it is also included in the transportation costs. Time estimates for loading and unloading a pallet, are based on standard times used at Jumbo Supermarkten. The cost driver for these activities is the number of pallets. The activity stopping is different from loading and unloading, since stopping is independent of the number of pallets in the truck. The stopping activity includes finding the location and positioning at the shipping dock of the supplier's warehouse and at the receiving dock of the DC of Jumbo Supermarkten. For the stopping activity the time estimation is also based on a standard time used at Jumbo Supermarkten. The costs for the traveling activity not only depends on the duration of the activity, but also on the distance traveled, as also fuel costs need to be considered. The travel time and distance are estimated for each supplier-DC combination using Shortrec. Shortrec is a tool used at Jumbo Supermarkten for calculating distances and travel times for trucks (and for planning purposes), which considers actual road networks and estimates the average speed travelled by a truck for each road. For the top 100 suppliers in sales volume, who account for 85% of the volume sold, the locations of the warehouses is determined by interviewing supply chain operators of Jumbo Supermarkten. For the remaining suppliers the billing address of the supplier is used as location of the warehouse. These locations are used as input in Shortrec.

As a result, the inbound transport costs are determined by the costs per unit distance (fuel costs) and the costs per unit time (wage of the truck driver). As the hourly wages of the drivers and fuel costs differ for each of the suppliers and are unknown, the estimates for these costs are based on transport data available at Jumbo Supermarkten.

Now for each product-location-storage type combination, the inbound transport costs can be calculated. For each product-location-storage type combination, first the costs for a full truckload (FTL) are calculated. The capacity of a truck, i.e. the full truckload of a truck, depends on the type of pallet and the height of the pallet of the specific product-location-storage type combination. In addition, 1m high pallets can sometimes be stacked on top of each other in order to save space in the truck (i.e. add capacity). This depends on the type of product (for instance the shape and hardness of a product). Whether products can be stacked or not, is known on a supplier level for the top 100 suppliers in sales volume. For the remaining suppliers it is assumed that products can't be stacked, as this is the case for most products according to several employees of Jumbo Supermarkten. As a result, the possible capacities of a truck (in number of pallets) are shown in Table 2 in Appendix C, dependent on the pallet height, pallet type and the possibility to stack 1m high pallets.

As for each product-location-storage type combination, the number of pallets in a FTL is known, the costs for a FTL are calculated, based on the cost drivers; number of pallets, traveling distance and traveling time. However, if less than a truckload is ordered at the supplier, not the complete transportation costs need to be paid. Deliveries of suppliers could take place in multi-stop routes whereby a full truck delivers Jumbo Supermarkten and several other retailers in a multi-drop trip. Van der Vlist and Broekmeulen (2006) have found an approximation for the costs for a less than truckload (LTL) shipment, as given in formula (11). In this approximation they use a shape parameter $r$, which expresses the efficiency of the vehicle routing costs per stop. In this approximation a value of 0.435 is chosen for the shape parameter $r$, which means that moving half of a FTL requires two-third of the cost of moving a full truck load, as shown in Figure 7.

$$LTL_{costs} = FTL_{costs} * \left(\frac{LTL_{pallets}}{Cap_{truck}}\right)^{1-r} \quad (11)$$

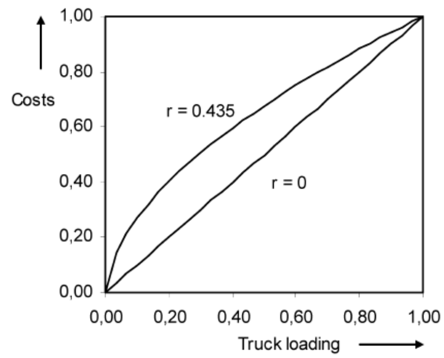


Figure 7: Routing efficiency with *r* = 0.435 (van der Vlist & Broekmeulen, 2006).

For each product-location-storage type combination, the costs of a full truck load $(FTL_{costs})$ and capacity of a truck $(Cap_{truck})$ are determined. However, on a product-level the truckload of a supplier is unknown and variable: When the model determines to switch products from DC location and/or to switch products from storage type (which influences the height of the pallets delivered), the number of pallets per supplier-DC combination will change and as a result the truckloads of suppliers will change. Unfortunately, it is considered impossible to determine on forehand the truckloads of a supplier for all possible product-location-storage type combinations of a supplier. Later on, in paragraph 6.5, two alternatives are given to overcome this problem in calculating the inbound transport costs.

### 6.3.3 Inter-DC transport costs

Just as for the inbound transport costs, the relevant inter-DC transport activities are loading, traveling, stopping and unloading. Each single activity takes a certain amount of time and is conducted by the truck driver. The activities loading (at the NDC) and unloading (at the RDC) are conducted by an employee of Jumbo Supermarkten, and therefore also considered as a handling activity, however the truck driver has to wait and sign papers during the loading and unloading, such that it is also included in the Inter-DC transport costs.

However, as mentioned in paragraph 2.3.3 Jumbo Supermarkten uses fixed tariffs per trip (from NDC to RDC site), which are based on loading, traveling, stopping and unloading times and the costs per kilometer and hourly wage of a driver. These average fixed tariffs are used to calculate the inter-DC transportation costs. The cost driver for the activity inter-DC transport is the average number of roll cages per week. The average number of roll cages in a truck is calculated for each RDC site, given the average utilization rate of the trucks for each RDC site and given that uniform trucks are used for inter-DC transport with a capacity of 54 roll cages. Finally, for each product the percentage of the truckload occupied is calculated. Since the inter-DC transport costs for one trip from NDC to RDC site is known (the fixed tariff), the inter-DC transport costs per product is equal to the percentage of truckload occupied by the product multiplied with the fixed tariff for the trip. When an article is allocated to the NDC, these (weekly) inter-DC transport costs are added to the total costs.

### 6.3.4 Cost drivers

For each product the average weekly demand in number of case packs is given for the DC it is allocated to. As a result, for products currently allocated to the NDC respectively RDCs, the average weekly demand in number of case packs is known for the NDC site respectively each RDC site. When a product currently allocated to the RDC switches to the NDC, the average weekly demand in number of case packs for the NDC is the sum of the average weekly demand in number of case packs for the four RDC sites. When a product currently allocated to the NDC switches to the RDC, the average weekly demand in number of case packs for the NDC is divided over the RDC sites according to the determined demand percentages of the RDC sites. For each product currently allocated to the RDC, the number of case packs of one RDC site relative to the number of case packs of all RDC sites is calculated. Subsequently these percentages are averaged over all products for each RDC site, which is the demand percentage of the RDC site.

Subsequently, the average weekly demand in number of (1m and 2m high) pallets and roll cages are calculated based on the volume and weight of the case packs and based on the maximum volume and weight a pallet or roll cage can handle. In the calculation for the number of roll cages a certain percentage for empty space is taken into account. The number of case packs which fit in a flow- and shelf rack is based on the volume of the case packs and the maximum volume which can be stored in the flow- and shelf rack.

## 6.4 Resource consumption

Each product allocated to a location and storage type requires a certain amount of each resource $w_{hijk}$. In the following paragraphs is explained in which way these resource consumptions are calculated and assigned to product-location-storage combinations. For some resources is also explained in which way the capacity limit of the resource is determined.

### 6.4.1 Number of pick houses (and number of flow racks)

The number of pick houses consumed by a product depends on the allocated storage pick type. As mentioned, one pick house can contain one double 2m high pallet pick location, two 2m high pallet pick locations, four 1m high pallet pick locations, ten flow rack pick locations or thirty-two shelf rack pick locations. As a result, a product allocated to a 2x2m pallet rack consumes 1 pick house, and so on. The number of pick houses consumed by a product allocated to a specific storage pick type is shown in Table 3 in Appendix D.

### 6.4.2 Number of bulk locations

The number of bulk locations consumed by a product depends on the average inventory of the product held in the DC. The average inventory of a product depends on the service fill rate of the DC. The service fill rates are different for each of the DCs.

First of all, the actual service fill rates of the DCs are determined by using the DoBr-tool. The service fill rate results for each product in a certain minimal reorder level, which result in an average inventory (in days) for each product. For each DC, the average inventory in days over all products is calculated and validated on the actual average inventory in days over all products in period 9 2015. When the average inventory was too low (or high), the service fill rate of the DC has been increased (or decreased), such that the calculated average inventory became more or less equal to the actual average inventory. The service fill rates of the DCs are determined in order to calculate for each product-location-storage type combination the average inventory. The use of the DoBr-tool is described in more detail in Appendix E.

As for each DC the service fill rate is calculated, for each product-location-storage type combination the average inventory (in number of case packs) can be calculated by using the same functions of the DoBr-tool as described in Appendix E. When the average inventory on hand in number of case packs is calculated, it is determined which part is stored in the pick location and which part in the bulk location. The average inventory for a 1m high and 2m high pallet pick location is equal to (the number of case packs on) 0,5 pallet, while the average inventory for a double 2m high pallet pick location is equal to (the number of case packs on) 1,5 pallet. The replenishment of a double 2m high pallet pick location is always planned when one pallet position is empty, such that on average 1,5 pallet is stored in the pick location. For the flow- and shelf racks the average inventory is equal to the expected inventory on hand at the begin and end of a cycle. The expected inventory on hand at the beginning is equal to the capacity of the racks (in number of case packs). The expected inventory on hand at the end is equal to the replenishment level (in number of case packs); when this replenishment level is reached, the pick location will be replenished.  For the pallet pick locations these replenishment levels are negligible. Subsequently, the remaining average inventory, which is not stored in the pick location, is stored in bulk locations. The number of bulk locations occupied by a product-location-storage type combination is calculated by dividing the average inventory in case packs in the bulk by the number of case packs per pallet and rounding this number up to integer bulk locations of 1m high (it is multiplied with 2 in case the pallet is 2m high).

### 6.4.3 Number of order pickers

Each DC has a given limit on the number of order pickers, due to efficiency reasons. It is examined by Jumbo Supermarkten that the efficiency of the picking process decreases, when the average distance between order pickers in a DC is lower than 25 meters. Therefore, for each DC the maximum number of order pickers is determined based on the total distance inside the aisles available for the order picking process. This is the capacity limit in the model.

For each product-location-storage type combination the time necessary to pick all (daily) demanded case packs is calculated based on the time estimates for order picking. Order pickers work in two shifts of 8 hours, such that in total 16 hours per day is available for order picking. Given these 16 hours per day and the time necessary to pick all (daily) demand, for each product-location-storage type combination the necessary number of order pickers is calculated.

### 6.4.4 Number of case packs

Each DC has a given limit on the number of case packs (per week) it can handle, as otherwise the workload is too high. For each product allocated to a specific DC site the average weekly demand in number of case packs is calculated, as explained in paragraph 6.3.4. Since the storage type (i.e. pick location) does not influence the number of case packs per product per DC, these are also the number of case packs per product-location-storage type combination.

### 6.4.5 Number of inbound and outbound transport deliveries

Each DC has a given number of docks for inbound and outbound transport deliveries. As estimated by Jumbo Supermarkten, each dock can be used a limited times per day. It is assumed that half of the docks are used for inbound transport deliveries and half of the docks for outbound transport deliveries. This way the maximum number of inbound transport deliveries per week a DC can handle is determined (and the maximum number of outbound transport deliveries for the NDC). These are the capacity limits in the model.

The number of inbound transport deliveries for the RDC sites is equal to the number of inbound transport deliveries from the suppliers and the Inter-DC transport deliveries from the NDC. The number of inbound transport deliveries for the NDC is equal to the number of inbound transport deliveries from the suppliers. The number of outbound transport deliveries for the NDC is equal to the number of Inter-DC transport deliveries to all the RDC sites. The number of inbound transport deliveries from a supplier depends on the truckload of the supplier, for which the calculations are explained in the next paragraph.

## 6.5 Solution alternatives

Before the mathematical model can be solved, it is required to calculate the input parameters in advance. However it is hard to calculate for each product-location-storage type combination the inbound transport costs in advance, since it is considered impossible to determine on forehand the truckloads of a supplier for all possible product-location-storage type combinations of a supplier. Therefore, two alternatives are developed to overcome this problem in calculating the inbound transport costs and solving the model. In the following paragraphs these solution alternatives are explained; research sub-question 6 is answered.

### 6.5.1 Alternative 1: Updating inbound transport costs

The main idea of this alternative is to start by approximating the inbound transport costs, and successively solve the model, and then update the inbound transport costs given the solution of the model and solve the model again. This procedure of updating the inbound transport costs and solving the model is repeated until the change in costs is negligible.

As initial inbound transport costs, 4 different variants are used to examine whether a local or global optimum is reached. In variant 1, first the number of pallets per delivery moment per supplier-DC combination is calculated, as if each supplier delivers all his products only to the NDC and as if each supplier delivers all his products only to the RDC. Hereby, it is assumed that each supplier delivers the pallet heights it is currently delivering to the DCs. Initially, this is the most extreme situation whereby for each supplier-DC combination the number of pallets per delivery moment is highest. As a result, the utilization rate of the trucks is optimal; economies of scale are realized. In variant 2, the number of pallets per delivery moment per supplier-DC combination is calculated, as if each supplier delivers only one product to the NDC and as if each supplier delivers only one product to the RDC. The number of pallets per delivery moment per product-location-storage type combination is the total number of pallets per delivery moment the supplier delivers. Initially, this is the most extreme situation whereby for each supplier-DC combination the number of pallets per delivery moment is lowest (only one product). In variant 3, the number of pallets per delivery moment per supplier-DC combination is equal to the current situation. And finally, in variant 4, the number of pallets per delivery moment per supplier-DC combination is randomly chosen.

As the number of pallets per delivery moment per supplier-DC combination ($TL_{pallets}$) is initially approximated, for each supplier-DC combination the inbound transport cost ($ITC_{sup}$) per delivery moment is calculated following formula (12). The first part of the formula determines the number of full truckloads and corresponding costs, while the second part of the formula determines the costs of the remaining less than truckload part, based on the approximation of van der Vlist and Broekmeulen (2006) for the costs for a LTL shipment, as given in formula (11). The costs of a FTL shipment ($FTL_{costs}$) and the capacity of a truck ($Cap_{truck}$) are determined previously.

$$ITC_{sup} = FTL_{costs} * \left\lfloor \frac{TL_{pallets}}{Cap_{truck}} \right\rfloor + FTL_{costs} * \left( \frac{TL_{pallets} - \left\lfloor \frac{TL_{pallets}}{Cap_{truck}} \right\rfloor * Cap_{truck}}{Cap_{truck}} \right)^{1-r} \quad (12)$$

Finally, for each product-location-storage type combination the percentage of the truckload occupied (of the total truckload of the supplier) is calculated for each delivery moment. Since the inbound transport cost for each supplier-DC combination is known, the inbound transport costs per product-location-storage type combination is equal to the percentage of truckload occupied by the product-location-storage type combination multiplied with the total inbound transport costs for the specific supplier-DC combination. The inbound transport cost per week

for each product-location-storage combination is the sum over the inbound transport costs per delivery moment.
As now all input parameters are calculated, the mathematical model can be solved. The main idea is to start by dropping integrality constraint (9) for decision variable $y_{hij}$ of the binary ILP problem, and successively solve the resulting Linear Programming (LP) problem, and then round the solution to a feasible integral solution. This method is derived from Chen and Hao (2014), who used this method for solving several MMKP instances. When studying several typical MMKP instances, Chen and Hao (2014) observed that the binary optimum and the LP-relaxation optimum share selected items (i.e. corresponding variables receive the value of 1 in both the binary optimum and the LP-relaxation optimum). As a result, once a variable is assigned to the value of 1 in the LP-relaxation, this variable is highly likely to be part of the optimal solution of the ILP problem and is therefore fixed to the value of 1.
The LP-relaxation is solved for each of the different variants in AIMMS 4.9 with ILOG CPLEX 12.6 on an Intel®Core™i5 processor with 2,67 GHz and 4 GB of RAM. As for less than 0,05% of the products no integer solution is found (for each iteration of each variant), rounding the solution of the LP-relaxation to an feasible integral solution is negligible. Given the solution of the LP-relaxation, the average number of pallets per delivery moment per supplier-DC combination can be calculated again. This way, the inbound transport costs per product-location-storage type combination is calculated as explained above. Subsequently, the same LP-relaxation of the mathematical model is solved again, however with new input for the inbound transport costs. This procedure of updating the inbound transport costs and solving the model, is repeated until the change in total costs is negligible (<0,001%).
Calculating the inbound transport costs is conducted in Excel. The solution of the LP-relaxation in AIMMS is automatically exported to Excel, which automatically updates the inbound transport costs per product-location-storage type combination. These costs are automatically retrieved as input parameter in AIMMS, such that the model can be solved again and so on.

### 6.5.2 Alternative 2: Facility-location problem

The main idea of this alternative is to determine for each supplier whether it is beneficial to deliver a specific DC; only when it is beneficial, products of the supplier could be allocated to this DC. The mathematical model as given in paragraph 6.2 is changed to a kind of facility-location problem.
The notation used in the mathematical formulation is as follows:

*Sets*

| | | |
|---|---|---|
| $H$ | Set of locations (index = $h$) | $1, \dots, l$ |
| $I$ | Set of storage types (index = $i$) | $1, \dots, m$ |
| $I_h$ | Set of storages types available in location $h$ | |
| $J$ | Set of products (index = $j$) | $1, \dots, n$ |

| | | |
|---|---|---|
| $J_s$ | Set of products delivered by supplier $s$ | |
| $K$ | Set of resources (index = $k$) | $1, \dots, o$ |
| $S$ | Set of suppliers (index = $s$) | $1, \dots, p$ |

*Parameters*

| | |
|---|---|
| $C_{hk}$ | capacity of resource $k$ at location $h$ |
| $FC_{hs}$ | fixed (stopping) costs of supplier $s$ delivering at location $h$ |
| $HC_{hij}$ | handling costs of product $j$ allocated to location $h$ and storage type $i$ |
| $IDCTC_{hij}$ | inter-DC transport costs of product $j$ allocated to location $h$ and storage type $i$ |
| $ITC_{hij}$ | inbound transport costs of product $j$ allocated to location $h$ and storage type $i$ |
| $M$ | so-called big M; "large number" |
| $VC_{hij}$ | assignment costs of product $j$ allocated to location $h$ and storage type $i$ |
| $w_{hijk}$ | resource consumed of resource $k$ by product $j$ allocated to location $h$ and storage type $i$ |
| $z_{hj}$ | 0-1 parameter; 1 if product $j$ must be allocated to the NDC $(h = 1)$ due to safety regulations, 0 otherwise |

*Decision Variables*

| | |
|---|---|
| $x_{hs}$ | 0-1 decision variable; 1 if location $h$ is opened for supplier $s$, 0 otherwise |
| $y_{hij}$ | 0-1 decision variable; 1 if product $j$ allocated to storage type $i$ at location $h$ is selected, 0 otherwise |

The set of locations, storage types, products and resources are the same as for the mathematical model given in paragraph 6.2. The set of suppliers consists of 471 suppliers in total. Each product $j$ is delivered by one supplier $s$.

In terms of the above notation, the mathematical formulation of the model is given by

$$\text{Min} \sum_{h \in H} \sum_{i \in I_h} \sum_{j \in J} VC_{hij} y_{hij} + \sum_{h \in H} \sum_{s \in S} FC_{hs} x_{hs} \qquad (13)$$

S.T.

$$\sum_{i \in I_h} \sum_{j \in J} w_{hijk} y_{hij} \leq C_{hk} \qquad h = 1, \dots l; k = 1, \dots, 6 \qquad (14)$$

$$\sum_{j \in J} w_{hijk} y_{hij} \leq C_{hk} \qquad h = 1; i = 4; k = 7 \qquad (15)$$

$$\sum_{h=1}^{2}\sum_{i\in I_h} y_{hij} = 1 \qquad j = 1, \dots, n \qquad (16)$$

$$\sum_{i\in I_h} y_{2ij} = \sum_{i\in I_h} y_{3ij} = \sum_{i\in I_h} y_{4ij} = \sum_{i\in I_h} y_{5ij} \qquad j = 1, \dots, n \qquad (17)$$

$$\sum_{j\in J_s}\sum_{i\in I_h} y_{hij} \leq Mx_{hs} \qquad h = 1, \dots, l; s = 1, \dots, p \qquad (18)$$

$$\sum_{i\in I_h} y_{hij} \geq z_{hj} \qquad h = 1; j = 1, \dots n \qquad (19)$$

$$x_{hs} \in \{0,1\} \qquad h = 1, \dots, l; j = 1, \dots, n \qquad (20)$$

$$y_{hij} \in \{0,1\} \qquad h = 1, \dots, l; i = 1, \dots, n; j = 1, \dots, n \qquad (21)$$

where:

$$VC_{hij} = HC_{hij} + ITC_{hij} + IDCTC_{hij} \qquad h = 1, \dots, l; i = 1, \dots, n; j = 1, \dots, n \qquad (22)$$

The above model is derived from the facility location problem (FLP). In general, the FLP can be described as follows: Given are a set of customers and a set of possible facilities. If a facility is opened, a fixed cost is incurred. If a customer is assigned to the open facility, an assignment cost is incurred. The problem is to choose open facilities and customer assignments that minimize fixed costs plus assignment costs (Klincewicz, 1990). In the model above, there is a set of $j$ products each of which can be allocated to $h$ locations and $i$ storage types and each product is delivered by a supplier $s$. If a location is opened for supplier $s$, a fixed cost $FC_{hs}$ is incurred for that supplier. If a product $j$ of supplier $s$ is assigned to the open location, assignment costs are incurred dependent on the location $h$ and storage type $i$. The problem is to select open facilities for supplier $s$ and assign products of supplier $s$ to the open facilities and select one storage type such that fixed costs plus assignment costs are minimized. Furthermore, there are different types of $k$ limited resources, whereby each product allocated to a location and storage type requires a certain amount of each resource $w_{hijk}$. The consumption of each resource may not exceed the given limit $C_{hk}$.

The objective of the model is to minimize the fixed costs of supplier $s$ delivering at location $h$ and assignment costs of product $j$ allocated to location $h$ and storage type $i$ costs, as given in (13). The assignment costs consist of handling, inbound transport and inter-DC transport costs, as given in (22). Constraint (14) and (15) ensure that the consumption of resources by products does not exceed the given limit. Constraint (15) is separated from constraint (14), as constraint

(15) ensures that the consumption of flow racks ( $i = 4$) by products $j$ allocated to NDC Elst ($h = 1$) does not exceed the given limit ($k = 7$). Constraint (16) makes sure that each product is allocated to either NDC Elst ($h = 1$) or either RDC Beilen ($h = 2$). In combination with constraint (17) it ensures that each product is allocated to exactly one DC type (NDC Elst or each of the four RDC locations). In addition, constraint (18) prohibits that products are allocated to locations that are not open for the supplier of the product, and if the location is open then M is chosen so big that there is no restriction on the number of products of the supplier allocated to the location. Subsequently constraint (19) is included to ensure that products which must be allocated to the NDC due to safety regulations indeed are allocated to the NDC. The binary constraint for decision variable $x_{hs}$ is given in (20) and for decision variable $y_{hij}$ in (21). The model represented above is a binary integer linear programming (ILP) problem. Before the mathematical model can be solved, it is required to calculate all parameters in advance. For each product-location-storage type combination, the handling costs, inter-DC transport costs and resource parameters are calculated as described in paragraph 6.3 and 6.4.

For each supplier, the average fixed costs per week for each location are determined. These fixed costs are the stopping costs, as the stopping activity is independent of the number of pallets in the truck. The stopping activity includes finding the location and positioning at the shipping dock of the supplier's warehouse and at the receiving dock of the DC of Jumbo Supermarkten. For the stopping activity the time estimation is based on a standard time used at Jumbo Supermarkten.

The assignment costs of a product depend on the location $h$ and storage type $i$ it is allocated to; the number of pallets is the cost driver. Therefore the costs per pallet are calculated. For each product-location-storage type combination the cost per pallet is equal to the FTL costs of the supplier minus the fixed costs of the supplier, divided by the number of pallets in a FTL. These costs per pallet are multiplied with the number of pallets delivered for each product-location-storage type combination, such that total costs are known.

As now all input parameters are calculated, the mathematical model can be solved. First integrality constraint (21) for decision variable $y_{hij}$ of the binary ILP problem is dropped, such that successively the resulting Linear Programming (LP) problem can be solved. Subsequently the solution of the LP problem can be rounded to a feasible integral solution.

The LP-relaxation is solved in AIMMS 4.9 with ILOG CPLEX 12.6 on an Intel®Core™i5 processor with 2,67 GHz and 4 GB of RAM. As for less than 0,05% of the products no integer solution is found, rounding the solution of the LP-relaxation to an feasible integral solution is negligible.

Since two alternatives are developed to model the inventory deployment decision at the supplier-level, research sub-question 6 is answered in this chapter. In the next chapter, the model solving phase will be described.

## 7. Model solving phase

The quantitative models are solved in the model solving phase. In this phase, also the solutions of the models are evaluated. First the two alternative models are validated, which means that the accuracy of the model's representation of the reality is checked. Subsequently, the results of the two alternative models are presented. After this, the best alternative to solve the inventory deployment at Jumbo Supermarkten is selected. Finally, a sensitivity analysis is conducted to determine what factors have the biggest impact on the inventory deployment decision.

### 7.1 Model validation

Since a model is a simplified representation of reality, the accuracy of the model's representation of the reality needs to be checked, which is called validation. Before the model alternatives were solved, input parameters like the time required to perform activities and the costs per unit time are retrieved from Jumbo Supermarkten and checked on inconsistencies. Furthermore, each model alternative is validated through a comparison of the output of the model, using for each product the DC- and storage type allocation of period 9 2015 as input for the model, with actual data of period 9 2015 at Jumbo Supermarkten. However, not only the outcomes of the model (i.e. the costs) are checked, also the calculated number of cost drivers are checked. Using for each product the DC- and storage type allocation of period 9 2015 as input for the two alternative models, the only difference between the two alternative models are the inbound transport costs, since only these are modeled in a different way. However, the actual inbound transport costs are unknown, such that these costs can't be compared with the outcome of the model. As a result, the model validation is the same for the two alternative models. Based on the comparison of the model and actual situation at Jumbo Supermarkten, some input parameters are slightly transformed such that the accuracy of the model's representation of the reality is higher. The results of the model validation are shown in Figure 8.

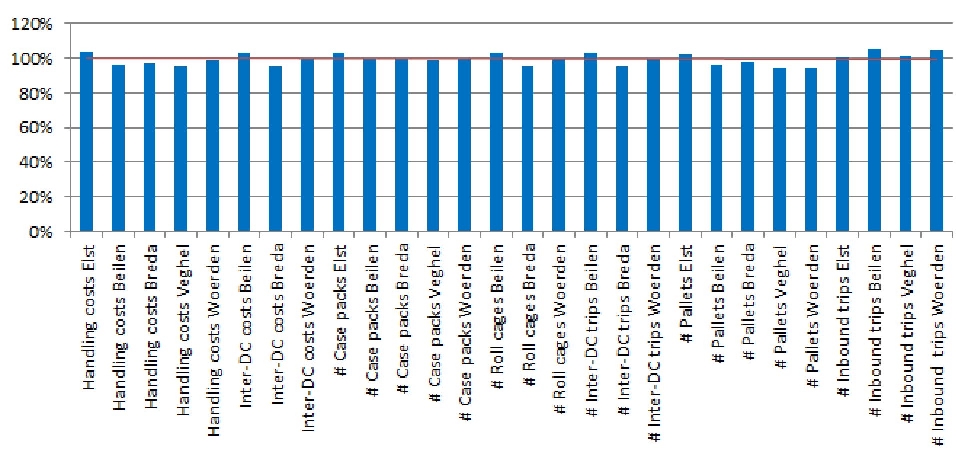


Figure 8: Results model validation.

Figure 8 shows for each DC the relative percentage of the model to the actual situation for the handling costs, inter-DC costs (for the RDCs), number of case packs picked, number of roll cages received (in the RDCs), number of inter-DC trips (to the RDCs), number of pallets received, and number of inbound transport trips (from the suppliers to the DCs), whereby the actual situation is equal to 100% as shown with the red line. As shown, the maximum difference between the model and actual situation is 5%. Therefore, it is concluded that the model's representation of the reality is accurate. The inter-DC costs and trips for RDC Veghel and inbound transport trips to RDC Breda are not validated, as the actual numbers can't be retrieved at Jumbo Supermarkten. However, as the model is quite accurate on these numbers for the other DCs, it can be assumed that the model is accurate for all DCs.

## 7.2 Results

In this paragraph, the results of the two alternative models are presented. In total 13125 products are considered delivered by 471 suppliers.

### 7.2.1 Costs alternative 1

In alternative 1, four different variants are used as initial inbound transport costs to examine whether a local or global optimum is reached. As mentioned, variant 1 is the maximum truckload, variant 2 is the minimum truckload, variant 3 is the current truckload and variant 4 is a random truckload. For each initial variant, the LP-relaxation is solved and subsequently the inbound transport costs are updated such that the model can be solved again. This procedure of updating the inbound transport costs and solving the model, is repeated until the change in total costs is negligible (<0,001%).

The total costs per iteration for each variant is shown in Figure 9 on the next page. Notice that these costs are calculated with the correct inbound transport costs (based on the solution for the DC- and storage type allocation of products), and are not the cost outcomes of the model, since these outcomes are incorrect due to incorrect inbound transport costs. After a maximum of 7 iterations, the change in total costs is negligible for each variant. After these 7 iterations, the maximum difference in total costs between the variants is 0,25%, such that it can be concluded that the initial input for the inbound transport costs is irrelevant for the total costs.

Since the initial input for the inbound transport costs of variant 1 result in the lowest costs, the following results are based on the solution of variant 1 (of iteration 7). The resulting costs per week of the DC- and storage type allocation found by model alternative 1 and the costs per week of the current situation are shown in Figure 10 for the NDC and RDC in Period 9 2015. The costs of the current situation is obtained from model alternative 1 using for each product the DC- and storage type allocation of period 9 2015 as input for the model. A total cost saving of 11% can be realized using the DC- and storage type allocation found by model alternative 1. Both the costs for the NDC and RDC are lower in alternative 1 compared to the current situation, however the costs savings for the NDC are bigger than for the RDC. The major cost savings are obtained on the inbound transport activity. However, the paradox is that these costs are saved at the supplier. Jumbo Supermarkten needs to negotiate on the purchase price of the supplier in order to obtain cost savings. Jumbo Supermarkten also saves on handling costs compared to the current situation. The inter-DC transportation costs for alternative 1 are slightly higher than in the current situation.

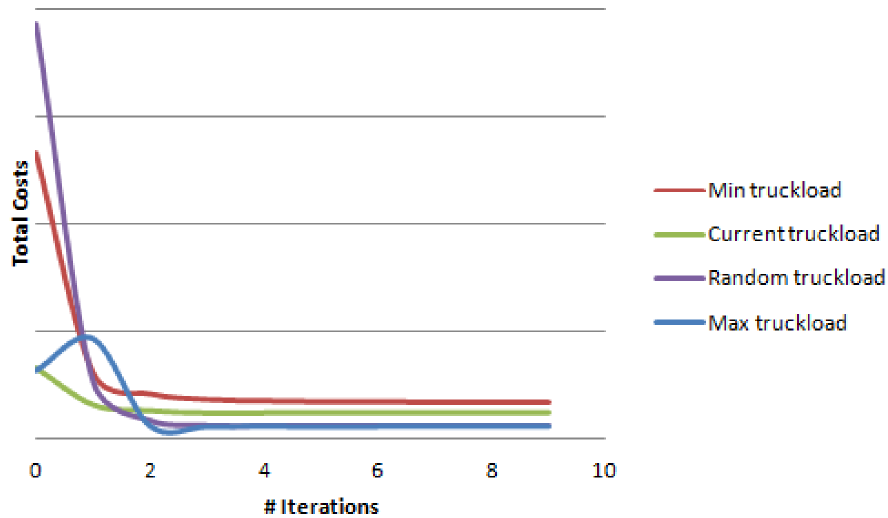


Figure 9: Total costs per iteration for each variant

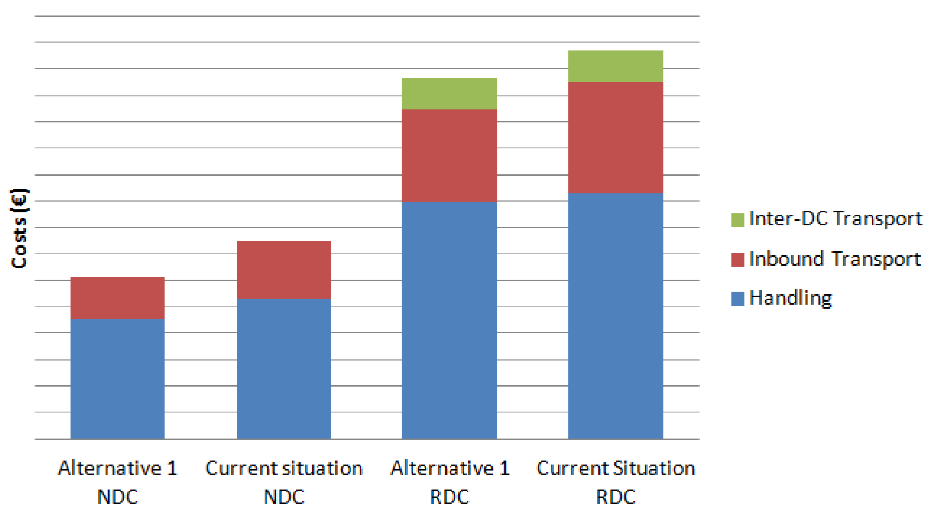


Figure 10: Cost split per DC type for alternative 1 and current situation.

### 7.2.2 Costs alternative 2

The resulting costs per week of the DC- and storage type allocation found by model alternative 2 and the costs per week of the current situation are shown in Figure 11 for the NDC and RDC in Period 9 2015. The costs of the current situation are obtained from model alternative 2 using for each product the DC- and storage type allocation of period 9 2015 as input for the model. A total cost saving of 11% can be realized using the DC- and storage type allocation found by model alternative 2. Both the costs for the NDC and RDC are lower in alternative 2 compared to the current situation, however the costs savings for the NDC are bigger than for the RDC. The major cost savings are obtained in the inbound transportation costs. Again, the paradox is that these costs are saved at the supplier. Jumbo Supermarkten needs to negotiate on the purchase price of the supplier in order to obtain cost savings. Jumbo Supermarkten also saves on handling and inter-DC transportation costs compared to the current situation.

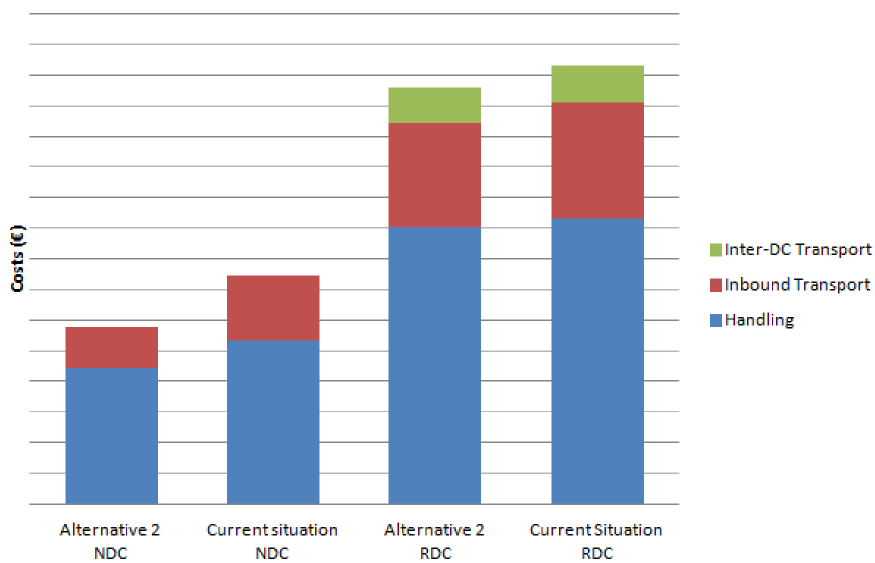


Figure 11: Cost split per DC type for alternative 2 and current situation.

### 7.2.3 KPIs alternatives

In order to examine how the above cost savings are obtained, the key performance indicators (KPIs) of the alternative models are compared with the KPIs of the current situation. The KPIs of the current situation, alternative 1 and alternative 2 are shown in Appendix F in Tables 4, 5, 6 and 7. As shown in Table 6, in both alternatives the number of products allocated to the NDC increases to approximately 10.375 products, while the number of products allocated to the RDC decreases to approximately 2.750 products. However, in alternative 1 less products have changed from DC-type compared to alternative 2. Besides changes in DC-location, there are also changes in storage type. Compared to the current situation, in general less products are allocated to 1m high pallet pick locations in the RDCs. In the NDC more products are allocated to 1m high pallet pick locations, as more products are allocated to the NDC and less products are allocated to 2m high pallet pick locations. Remarkable is the high number of storage type changes in the NDC for both alternatives. Despite the above changes, the total volume handled and total number of case packs picked is more or less the same for each DC in alternative 1. In alternative 2, the volume handled in the NDC even decreases and the volume handled in the RDC increases. The total number of case packs picked is more or less the same for each DC in alternative 2. However, in both alternatives the volumes handled and the number of case packs picked per storage type are divided differently over the storage types. In general, less volume is allocated to the smaller storage types (to the flow and shelf rack pick locations in the NDC and to the 1m high pallet pick locations in the RDCs) and more volume is allocated to the bigger storage types (the 2m high pallet pick locations in the NDC and the double 2m high pallet pick locations in the RDCs). Finally, due to the re-allocation of products to DCs and storage types, the percentage of pick locations occupied increases for NDC Elst, while it decreases for RDC Veghel, as shown in Table 7. The increase of pick locations occupied in NDC Elst makes sense, as more products are allocated to the NDC. For RDC Beilen, RDC Breda and RDC Woerden the percentage of pick locations occupied is the same as in the current situation, due to the re-allocation of products to storage types. The percentage of bulk locations occupied decreases for all DCs, especially for RDC Woerden, which is probably also due to the re-allocation of products to storage types, causing that on average more volume is stored into the pick location and less volume is stored in the bulk locations.

In order to examine how cost savings are obtained on handling in the DCs, a closer look is taken on the activities and cost drivers of handling. The relevant handling activities are receiving, restacking, storage, replenishing, order picking and shipping. The cost drivers for these activities are the number of pallets delivered (i.e. received), the number of pallets stored and replenished, the number of case packs picked and the number of roll cages shipped. As shown in Table 8 and 9, in both alternatives for each handling activity cost savings are obtained, except for the activity shipping (i.e. loading roll cages into trucks) for which the total costs are more or less the same as in the current situation. This makes sense, as the total number of case packs shipped to the stores remains the same, and as a result the total number of roll cages loaded into trucks remains more or less the same. In the current situation and in both alternatives, the majority of the handling costs are the costs due to the order picking activity (approximately 70%). However, the cost savings obtained on order picking are relatively low. Since in both alternatives the number of pick houses occupied is more or less the same as in the current situation, the distance traveled during order picking is more or less the same such that no cost savings are obtained on the traveling activity. However, due to the re-allocation of products to DC's and storage types, the number of case packs picked per storage type is changed, as shown in Table 4. As a result, cost savings are obtained on order picking, as in total less case packs are picked from 1m high pallet pick locations, for which the time to pick is highest. Furthermore, cost savings are obtained on the receiving activity, as for each DC the total number of pallets delivered is decreased significantly. As shown in Table 4, the total number of pallets is decreased for each DC, since more pallets of 2m high are delivered instead of 1m high. As a result, one would expect that the costs for restacking are increased, however this is not the case due to storage type changes; as shown in Table 6 less products are stored in 1m high pallet, flow or shelf rack pick locations, such that less products are stored in 1m high pallet rack bulk locations. In addition, more products which are always delivered on 2m high pallets by the supplier are stored in 2m high pallet rack bulk locations instead of 1m high pallet rack bulk locations, such that restacking is not necessary. Due to the re-allocation of products to DCs and storage types, the volumes handled per storage type are changed, as shown in Table 6. The total volumes handled of products allocated to 1m high pallet rack bulk locations are decreased significantly, while the total volumes handled of products allocated to 2m high pallet rack bulk locations are increased. Obviously, the number of pallets handled depend on these volumes. As a result, the total number of pallets is decreased, as the increase in 2m high pallets is less than the decrease in 1m high pallets. Therefore, cost savings are obtained for the activities storage and replenishing, which depend on the number of pallets stored and replenished. However, the cost savings obtained for replenishing shelf racks are extremely high. The reason for this is that in the solution of the two alternative models only products with the lowest volumes sold per week are allocated to shelf racks, while in the current situation products with too high volumes sold per week are stored in the shelf racks. As a result the costs savings are extremely high, because in the current situation a shelf rack needs to be replenished a lot (due to the higher demand): Only a small amount of case packs fit in the shelf rack, such that it needs to be replenished very often and after each replenishing activity the pallet with remaining case packs needs to be stored in the bulk again (these *re-storage* costs are allocated to the replenishing activity). As shown in Table 8 and 9, the cost savings on replenishing shelf racks are the major part of the cost savings on handling. However, some of the products which are re-allocated to other storage types must be stored in shelf racks. For example, some case packs can't be stacked on top of each other due to certain product characteristics, like the shape and hardness of (the case pack) of the product. These products are often delivered by the suppliers in carton boxes and unpacked to case packs at Jumbo Supermarkten. When these unpacked products are excluded from the cost analysis, the cost savings are only 5% lower. However, probably there are more products (than only the unpacked products) that must be stored in shelf racks, such that the cost savings become lower. As a result of the above analysis on the handling costs, it can be concluded that in both alternatives the cost savings obtained on handling are mainly caused by the re-allocation of products to storage types, whereby especially the re-allocation of products to storage types in the NDC result in high cost savings. In particular, the re-allocation of products to shelf racks result in high cost savings on the replenishing activity.

In order to examine how costs are changed for inter-DC transport, a closer look is taken on the KPIs of inter-DC transport. As mentioned, the number of products allocated to the NDC increases in both alternatives. However, in alternative 1 there is just a small increase in the total volume handled in the NDC. As the volume of the products determines the number of roll cages which are transported from the NDC to the RDC sites, there is also a small increase in the total number of roll cages received at the RDC sites. As a result, there is a small increase in the number of inter-DC trips and thus also in the inter-DC transportation costs in alternative 1. In alternative 2, the total volume handled in the NDC even decreases, despite the increase in number of products allocated to the NDC. As this volume determines the number of roll cages, which determines the number of inter-DC trips, the inter-DC transportation costs are decreased in alternative 2.

In order to examine how cost savings are obtained for inbound transport, a closer look is taken on the KPIs of inbound transport. There are several causes for the decrease in inbound transport costs. First of all, cost savings are obtained due to the re-allocation of products to the DCs. As a result of the re-allocation, many suppliers currently delivering their products both to the NDC and RDC only need to deliver to the NDC (and not to the RDC) in both alternative models, as shown in Table 5. In the current situation 234 suppliers deliver their products only to the NDC, while in both alternative models circa 315 suppliers deliver their products only to the NDC. As a result of the re-allocation of products to DC's, economies of scale are realized for these suppliers delivering only to the NDC, which implies that the transport volume is increased, such that the transport costs per unit are decreased. In alternative 2, also more suppliers are delivering their products only to the RDC (and not to the NDC) compared to the current situation, such that also economies of scale are realized for these suppliers delivering only to the RDC. As a result, only 104 suppliers are delivering their products to both the NDC and RDC instead of 193 in the current situation. In alternative 1, less suppliers are delivering their products only to the RDC in comparison with the current situation. Only 122 suppliers are delivering their products to both the NDC and RDC in alternative 1 instead of 193 suppliers in the current situation. As a result of the above, one would expect that the average truckload increases for the inbound transport to the NDC (as the transport volume is increased) and for the inbound transport to the RDC (since the suppliers with relatively low truckloads for each RDC site transport their products to the NDC in higher truckloads and only suppliers with relatively high truckloads for each RDC site transport their products to the RDC, such that the truckloads of the inbound transport to the RDC are on average higher). However, the average truckload of the inbound transport to the NDC is decreased, as shown in Table 5. This is due to the decrease in the total number of pallets delivered by the suppliers at the NDC, as more 2m high pallets are delivered instead of 1m high pallets, which sometimes can't be stacked on top of each other. However, as a result of the decrease in the total number of pallets delivered, the number of inbound trips is decreased (for each DC), as shown in Table 5, which also results in cost savings. In addition, the average kilometers traveled per inbound transport trip is decreased for most DCs, as shown in Table 5. As distance is the main cost driver of inbound transport costs, this also results in cost savings. In alternative 1, the total distance traveled decreases for 157 suppliers, while it increases for 31 suppliers. In alternative 2, the total distance traveled decreases for 137 suppliers, while it increases for 61 suppliers. As a result of the above, it can be concluded that in both alternatives the cost savings obtained on inbound transport are mainly caused by the re-allocation of products (and as a result the re-allocation of suppliers) to DCs.

## 7.3 Selection of best alternative for Jumbo Supermarkten

The purpose of this Master thesis is to determine how ambient articles should be allocated to distribution stages and storage types, such that overall costs are lowest, while taking into account capacity and service constraints. Therefore, two alternative models are developed which allocate articles to DCs and storage types based on the costs. Jumbo Supermarkten can use both alternative models to solve the inventory deployment problem.

However, obviously Jumbo Supermarkten wants to know which of the two alternatives is the best model to solve the inventory deployment problem. The only difference between the two alternatives is the way the inbound transport costs are modeled. However, as the actual inbound transport costs are unknown, it is hard to determine which alternative estimates these costs the most accurate.

Suppliers and logistic service providers use scale prices for different truckloads, since not the complete transportation costs need to be paid, if less than a truckload is ordered at the supplier. These scale prices (i.e. inbound transportation costs) are approximated differently in each of the alternative models. Using the available scale prices at Jumbo Supermarkten, the *actual* cost function as shown in Figure 12 is used to select the alternative which estimates the inbound transport costs the most accurate.

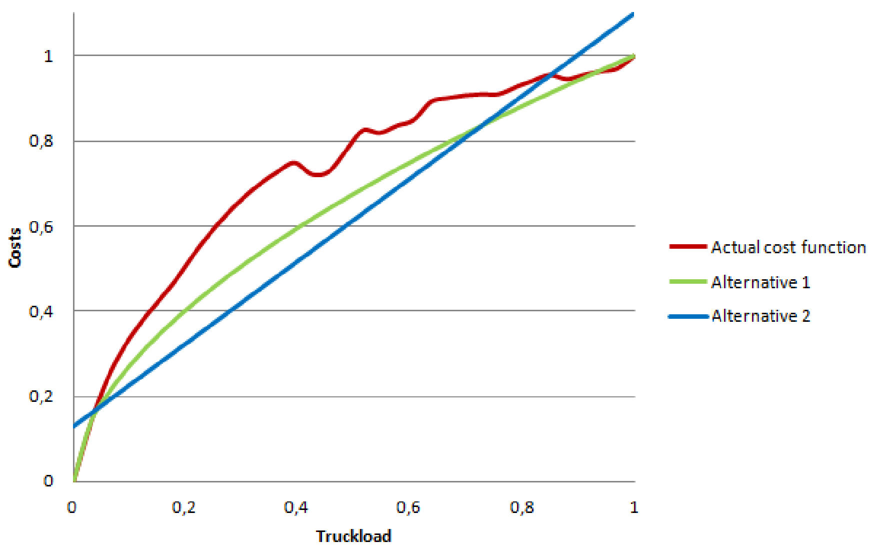


**Figure 12: Inbound transportation costs of ordering a specific truckload for different cost functions.**

The cost function of alternative 2 shown in Figure 12 is the cost function averaged over all suppliers. For each supplier the inbound transport costs are calculated using the *actual* cost function and the cost function modeled in the specific alternative, based on the DC- and storage type allocation found by the specific alternative. For each supplier the difference between the inbound transport costs of the *actual* cost function and the inbound transport costs of the specific alternative are squared and summed, to determine which alternative estimates the inbound transport costs closest to the *actual* inbound transport costs. As the sum of squares for alternative 1 is lower than the sum of squares for alternative 2, it is concluded that alternative 1 estimates the inbound transport costs better than alternative 2. In Figure 13 the differences between the inbound transport costs per DC are shown for the *actual* cost function and the costs functions used in the alternatives.

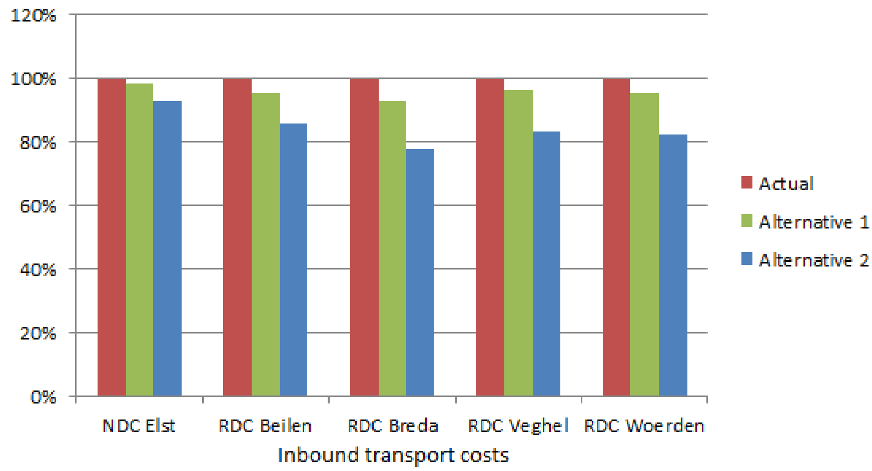


**Figure 13: Difference between the inbound transport costs per DC for the *actual* cost function and both alternatives.**

In addition, for each alternative the total inbound transport costs are calculated using the *actual* cost function as shown in Figure 12, based on the DC- and storage type allocation found by the specific alternative, such that the inbound transport costs of the two alternatives can be compared. The *actual* inbound transport costs of alternative 1 are 5% lower than the *actual* inbound transport costs of alternative 2. As a result, the total costs of alternative 1 are 1% lower than the total costs of alternative 2 and 11% lower than the total costs of the current situation, as shown in Figure 14. It can be concluded that the DC- and storage type allocation found by model alternative 1 results in lower costs than the DC- and storage type allocation found by model alternative 2.

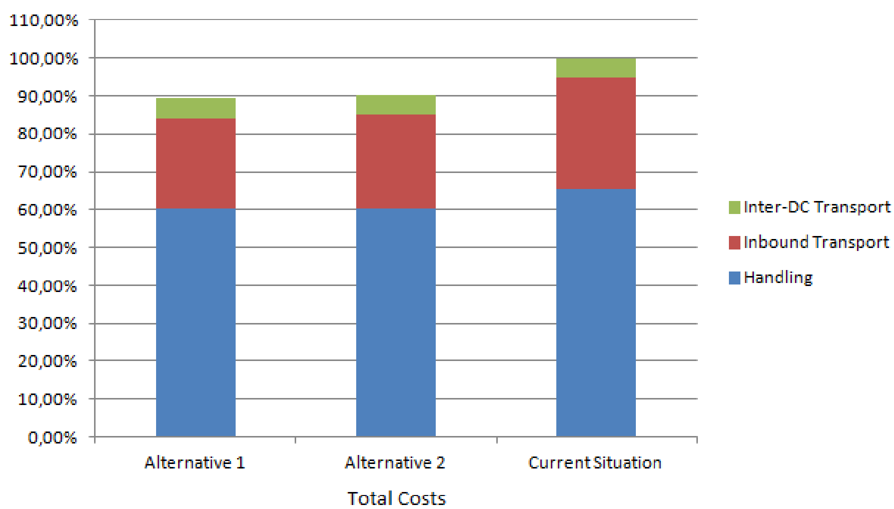


**Figure 14: Total costs per week of alternative 1 & 2 and the current situation based on the actual cost function for the inbound transport costs.**

## 7.4 Sensitivity analysis

The sensitivity analysis is conducted on model alternative 1 (with variant 1 and each time 7 iterations ran), as in the previous paragraph is chosen for this alternative. A sensitivity analysis investigates the changes to the solution of a model as the result of changes in input data (Bisschop, 2015). When a small change in a specific input parameter leads to big changes in the solution, the specific parameter has a big impact on the inventory deployment decision. It is important to gain quantifiable knowledge about what parameters have a big impact on the inventory deployment decision, as it might be possible for Jumbo Supermarkten to adapt some of these parameters such that total costs can be even more reduced. The sensitivity analysis indicates on which parameters Jumbo Supermarkten should focus.

### 7.4.1 Change in costs parameters

The cost parameters that are varied are the handling costs, the inbound transport costs and inter-DC costs. These parameters are included in the sensitivity analysis to determine which of these costs have the biggest impact on the inventory deployment decision. The main KPIs of the sensitivity analyses are shown in Table 10, 11 and 12 in Appendix H. In these tables, the allocations of products to the distribution stages and storage types of the solution of the sensitivity analyses are compared with the allocation found by model alternative 1.

The results of the sensitivity analyses show that a change in the inter-DC transport costs leads to the biggest change in the allocation of products to the distribution stage. When the inter-DC transport costs are increased by 25%, the volume allocated to the NDC decreases compared to alternative 1 (while the number of products allocated to the NDC is more or less the same). When the inter-DC transport costs are decreased by 25%, the volume allocated to the NDC increases compared to alternative 1 (while less products are allocated to the NDC). These results as shown in Table 10 make sense, as the volume allocated to the NDC determines the number of roll cages and the number of inter-DC trips and thus the inter-DC transport costs. As a result, it becomes more important to decrease the volume allocated to the NDC when costs for inter-DC transport increase, and vice versa. Products are also re-allocated to different storage types, in order to make the re-allocation of products to another DC stage possible.

Changing the inbound transport costs also leads to a change in the allocation of products to the distribution stages. When the inbound transport costs are increased by 25%, the volume allocated to the NDC increases compared to alternative 1 (while the number of products allocated to the NDC slightly decreases). When the inbound transport costs are decreased by 25%, the volume allocated to the NDC decreases compared to alternative 1 (while the number of products allocated to the NDC slightly decreases). These results as shown in Table 11 make sense, as it becomes more important to consolidate volumes in order to realize economies of scale when the inbound transport costs are high. Products are also re-allocated to different storage types, in order to make the re-allocation of products to another DC stage possible.

Changing the handling costs mainly leads to a re-allocation of products to storage types instead of a re-allocation of products to distribution stages, as shown in Table 12. Especially in NDC Elst products are re-allocated to storage types. When the handling costs are increased by 25%, the volume handled in flow- and shelf racks in the NDC decreases compared to alternative 1. When the handling costs are decreased by 25%, the volume handled in flow- and shelf racks in the NDC increases compared to alternative 1. As the volume handled determines the number of replenishments (which seems to be an important cost component of handling), higher handling costs result in lower volumes allocated to the flow- and shelf racks.

The results of the sensitivity analyses show that the inter-DC transport costs and inbound transport costs have the biggest impact on the allocation of products to the distribution stages, while the handling costs have the biggest impact on the allocation of products to storage types. However, the number of changes in the solution (i.e. the number of re-allocations) is more or less the same for each of the three input parameters. The changes in the solution are small, when one of the three input parameters is changed, as a maximum of 5% of the products is changed.

### 7.4.2 Unlimited capacity at the DCs

A sensitivity analysis is conducted in which the capacities of the DCs are unlimited in order to determine the optimal allocation of products to distribution stages and storage pick types. The results of the model (with DC capacity restrictions) seems to be in line with the indication of the BCG that the number of articles that are currently stored in the RDCs is too high to operate cost efficient, since according the model less products should be stored in the RDCs. However, the BCG benchmarked that approximately 1700 articles should be stored in a RDC, while according to the model approximately 2750 products need to be stored in the RDC. An explanation for this difference could be that the capacity limits of NDC Elst are reached, such that no more products fit in the NDC and as a result more products are stored in the RDC. Therefore, no limit is set on the capacity of the NDC in this sensitivity analysis, such that the indication of the BCG may possibly be confirmed. However, as it is also possible that it is better to store more products in the RDC, also the capacity of the RDCs is unlimited, such that with this sensitivity analysis it is also possible to reject the indication of the BCG.

The results of the sensitivity analysis show that more products are allocated to the RDC and less products to the NDC. In total, 6.057 products are allocated to the NDC, while 7.068 products are allocated to the RDCs. As a result, the volume handled at the NDC decreases with 67%, while the volumes handled at the RDCs increase with approximately 15% per DC. This result is in contrast with the indication of the BCG that fewer products should be stored at the RDC. A potential explanation could be the assumption made that the order moments for the stores are fixed (and the stores always use these order moments); it is assumed that the number of orders per week is independent of the inventory deployment decision. This assumption has resulted in an incorrect solution of the sensitivity analysis. The estimated traveling time of the order picking activity is based on this number of orders per week, since each order implies that each aisle is traversed once. However, in the solution of the sensitivity analysis the volume handled in the RDC increases tremendously, while the volume handled in the NDC decreases tremendously. According to Jumbo Supermarkten, the number of order moments will increase for the RDCs and decrease for the NDC, which leads to a change in handling costs for both the NDC and RDCs. However, in the model the number of orders is fixed, which results in incorrect handling costs and as a result in an incorrect solution of the sensitivity analysis. Therefore, another sensitivity analysis is conducted in which the capacities of the DCs are unlimited and in which the number of orders in the NDC is decreased, while the number of orders in the RDC is increased. The results of this new sensitivity analysis show that now less products are allocated to the RDC and more products are allocated to the NDC compared to alternative 1. However, due to the re-allocation the number of order moments will change which again leads to a change in handling costs for both the NDC and RDCs. It can be concluded that in order to conduct this sensitivity analysis, in which the capacities of the DCs are unlimited, the number of order moments may not be fixed and hence the model in its current form cannot be used for this type of sensitivity analysis. For the same reason, no sensitivity analysis is conducted in which the weekly demand in number of case packs is varied, as this also results in big changes in volume handled at the distribution stages.

As a final remark, it needs to be emphasized that the solution of model alternative 1 is correct. Since in model alternative 1 the volume handled in the NDC and RDC is the same as in the current situation, the number of orders is correct, such that the handling costs are also correct.

# 8. Implementation phase

In the implementation phase, the results of the model should be implemented. However, the real implementation of the results of the model is out scope for the Master thesis project. Therefore, in this chapter, the main findings are described such that Jumbo Supermarkten has more insight in the inventory deployment problem and is able to solve the problem. As a result, research sub-questions 7 and 8 are answered in this chapter. Finally some implementation issues are described, which need to be overcome first in order to use the quantitative model.

## 8.1 Main findings

Jumbo Supermarkten wants to know how to decide whether a product should be stored in a NDC or in a RDC and in which storage type, such that costs are lowest, while taking into account capacity and service constraints. Therefore a model is developed which allocates products to DCs and storage types based on the costs associated to this decision. Jumbo Supermarkten can use this model to solve the inventory deployment problem.

The results of the quantitative model show that the most important product characteristic to determine which products should be allocated to which DC and which storage type is the volume sold per week. In general, the model allocates the products to DCs and storage types as follows: The products with the highest volumes sold per week are allocated to the RDC and stored in double 2m high pallet pick locations, while the products with a relatively high volume sold per week, but not the highest, are also allocated to the RDC, but stored in 2m high pallet pick locations. Subsequently, the products with an *average* volume sold per week are allocated to the NDC and stored in 2m high pallet pick locations or are allocated to the RDC and stored in 2m or 1m high pallet pick locations. Whether the product is allocated to the NDC or RDC depends on the costs of the supplier to deliver the NDC or RDC, which depends on the other products allocated to the NDC and/or RDC, as economies of scale could be obtained. Whether the product in the RDC is stored subsequently in a 2m or 1m high pallet pick location depends on the volume sold per week and the available space in the DC (i.e. in the smaller DC sites Breda and Woerden products are stored more often in 1m high pallet pick locations as less space is available, while in the bigger DC sites Beilen and Veghel products are stored more often in 2m high pallet pick locations). The products with a relatively low volume sold per week are stored in the NDC in 1m high pallet pick location, while the products with the lowest volumes sold per week are stored in the NDC in flow and shelf racks. However, it should be emphasized that the above is a very general description of the decision-making of the model and that there are a lot of interdependencies which determine the final allocation of a specific product. This is also the main advantage of using the model to solve the inventory deployment decision. Before this Master thesis, Jumbo Supermarkten only had some feeling for the costs associated to storing a product at the NDC or each of the RDCs in a specific storage type, however these costs were not quantified and complex trade-offs made these costs difficult to analyze. In the quantitative model all relevant costs and capacity limitations are quantified, including the relevant costs of the supplier, such that all interdependencies are considered and several trade-offs are made. This means that the inventory deployment decision should not be made at the individual product-level, but on the whole assortment including the supplier-level.

The results of the quantitative models show that significant cost savings could be obtained. Cost savings can be obtained on handling mainly due to the re-allocation of products to storage types. Especially the re-allocation of products to storage types in the NDC may result in high cost savings. As mentioned, the most important product characteristic to determine which products should be allocated to which storage type is the volume sold per week. However, in the current situation products are not optimally allocated to storage locations. For example, products with too high volumes are stored in shelf racks, such that the handling costs are very high, as these shelf racks need to be replenished very often. Jumbo Supermarkten needs to reconsider the allocation of products to storage types, using the quantitative model.

As mentioned, the quantitative model also has included inbound transportation costs. As a result, the model can be used to estimate the inbound transportation costs made by the supplier, as these costs are not known at Jumbo Supermarkten, since these costs are included in the total purchase price of an order. This insight in the inbound transportation cost of the supplier has several advantages. First of all, Jumbo Supermarkten can use this insight to determine whether the products of the supplier should be allocated to the NDC or RDC, since the model quantifies the costs of the supplier including economies of scale which could be realized by re-allocating products to DCs. Based on the results of the model it can be concluded that deciding both on the product- and supplier-level where an article should be stored is beneficial, as economies of scale are included on a supplier-level and can result in high cost savings. In addition, the model can be used to determine whether the supplier should deliver the products on pallets of 1m high or 2m high. The paradox is that these allocation decisions will result in cost savings for the suppliers. However, Jumbo Supermarkten can use the insight in the inbound transportation costs of the supplier in negotiations on purchase prices; Jumbo Supermarkten should be able to negotiate better prices (the cost savings) from suppliers. During negotiations Jumbo Supermarkten also needs to convince suppliers to separate the transport costs from the purchase price. This way, the model can be used to review the current transport costs calculated by the supplier. When the transport costs calculated by the supplier are much higher than estimated by the model, Jumbo Supermarkten can negotiate for lower prices or may propose to backhaul these products, such that cost savings are obtained.

Based on the results of the model, it can be concluded that cost savings on inter-DC transport could be obtained by decreasing the total volume handled in the NDC. However, decreasing the total volume handled in the NDC might reduce the cost savings on inbound transport, as less consolidated volume is transported to the NDC. Instead the volume is separated and transported to each of the RDC sites, which leads to relatively higher inbound transport costs.

Finally, the results of the sensitivity analyses show that the inter-DC transport costs and inbound transport costs have the biggest impact on the allocation of products to the distribution stages, while the handling costs have the biggest impact on the allocation of products to storage types. The number of re-allocations is low when one of the cost components is lowered; the impact of changing the cost components on the inventory deployment decision is low.

## 8.2 Implementation issues

Some implementation issues need to be overcome in order to use (the solution of) the quantitative model. The quantitative model is optimized over period 9 of 2015, while it is assumed that demand is deterministic and equal to the actual supply of the period. The average weekly demand in case packs is used as input of the model. However, when Jumbo Supermarkten wants to use the quantitative model, estimations for the demand need to be used, since the model will be used to solve the inventory deployment decision for the upcoming periods. As a result, accurate demand estimations are essential for using the model. Furthermore, Jumbo Supermarkten needs to determine when and for which period of time it will use the model. Due to the presence of seasonal assortment, the allocation of (seasonal) products to DCs and storage types needs to be changed several times per year, however products should not be re-allocated too often, as *investment* costs incur when products are re-allocated, as probably DC lay-outs should be changed and new supplier agreements should be made. In order to make the model more robust, these *investment* costs could be included in the model. For example, costs could be included when a product changes from bulk- or pick location or when a supplier needs to deliver the product to another DC site or on another pallet height. Another implementation issue is the actual change of the DC lay-out, as some bulk- and pick locations need to be changed to store the products. Furthermore, it needs to be examined for each supplier whether it is willing and able to deliver his products on another pallet height than currently agreed. It might be that additional cost or discounts are associated with these changes, which could also be included in the model. In short, more information is necessary about supplier agreements, however also more information is necessary about the suppliers itself. Only for the top 100 suppliers in sales volume the location of the warehouse is determined; for the remaining suppliers the billing address of the supplier is used as location of the warehouse. These locations need to be checked. Another implementation issue is the fact that NDC Elst and NDC Veghel are considered as one NDC-location in the model, such that when the model is solved, the products allocated to the NDC still needs to be divided over the DC sites Elst and Veghel. One simple solution could be to allocate the suppliers based on the distance to the locations. Finally, the last implementation issue is that the delivery schedule of a product could change when it is changed from DC site, which should be taken into account before solving the inventory deployment decision.

# 9. Conclusions and limitations

This chapter provides the conclusions of the Master thesis project. First the main research question is answered. Subsequently the academic and practical relevance of the Master thesis is discussed. Finally, the limitations of the Master thesis and suggestions for future research are described.

## 9.1 Conclusions

Based on the problem description, the following main research question was formulated for my Master thesis:

*How should ambient articles be allocated to distribution stages, concerning central and regional distribution centers with internal consolidation in the retail supply chain, and storage types such that overall costs are lowest, while taking into account capacity and service constraints?*

As Jumbo Supermarkten wants to know how to decide whether a product should be stored in a NDC or in a RDC and in which storage type, such that costs are lowest, this Master thesis has examined first the relevant costs in this so-called inventory deployment decision. It has been found that handling, inbound and inter-DC transportation costs are the costs that are relevant in modeling the inventory deployment decision for ambient products. Subsequently, it is found that several product characteristics could affect the inventory deployment decision, like the demand rate, the volume of the product, the supplier of the product (and supplier characteristics like the distances to the DCs), supplier agreements and safety regulations. The relevant costs are incorporated in the quantitative model to solve the inventory deployment decision making use of Time-Driven Activity Based Costing, while the relevant product characteristics determine these costs.

The results of the quantitative model show that the most important product characteristic to determine which products should be allocated to which DC and which storage type is the volume sold per week for a product. In addition, the re-allocation of products to DCs is also for a big part determined by the potential volume delivered by the supplier to a DC, as economies of scale could be realized when a supplier is allocated to only the NDC (or RDC), as higher volumes result in lower inbound transport costs for the supplier. Based on the results of the model it can be concluded that deciding both on the product- and supplier-level where an article should be stored is beneficial, as economies of scale are included on a supplier-level and can result in high cost savings. Jumbo should be able to negotiate better purchase prices from suppliers, using the insight in the inbound transport costs of the supplier.

However, there are a lot of interdependencies which determine the final allocation of a specific product. This is also the main advantage of using the model to solve the inventory deployment decision.

## 9.2 Academic and practical relevance

In previous academic research, the inventory deployment decision is often ignored in network optimization models. As shown in paragraph 3.3, there are no mathematical modeling papers solving the inventory deployment decision for the retail supply chain network considered in this Master thesis. This specific retail supply chain network consists of national and regional distribution centers with internal consolidation: In this network products are stored either in the NDC or RDC, whereby products stored in the NDC are cross-docked with the products in the RDC and then are being shipped jointly to the stores. In addition, products can be stored in different storage types in each of the DC sites. The Master thesis contributes to the academic literature, as it solved the inventory deployment decision for this type of network, which is used by many retailers. As a result, the Master thesis is also applicable to other retailers than Jumbo Supermarkten. A quantitative model is developed which allocates articles to distribution stages and storage types. In the quantitative model all relevant product characteristics, costs and capacity limitations are quantified and modeled in an appropriate way, including the relevant costs of the suppliers, such that the inventory deployment decision is not made at the individual product-level, but on the whole assortment including the supplier-level, for a retail supply chain network of national and regional distribution centers with internal consolidation, which is the main academic contribution of this Master thesis.

For Jumbo Supermarkten the Master thesis is useful as the quantitative model developed provides for each product explicitly the optimal DC-location and storage type, which results in significant cost savings. Before this Master thesis, Jumbo Supermarkten only had some feeling for the costs associated to storing a product at the NDC or at each of the RDCs in a specific storage type; now these costs are quantified. In addition, the quantitative model also gives a better insight in the inventory deployment problem. Finally, the model can be used to estimate the inbound transport costs of the supplier, which can be used in the negotiations on purchase prices.

## 9.3 Limitations

The assumptions made in developing the model are the main limitations of the model. First of all, NDC Elst and NDC Veghel are considered as one NDC-location, located in Elst. This assumption influences the inter-DC and inbound transportation costs as Elst is located more central in the Netherlands than Veghel. Another limitation of the research is that the seasonal assortment of Jumbo Supermarkten is not studied in detail, as it is assumed that using only a certain percentage of the available bulk- and pick locations is sufficient. However, these percentages are provided by Jumbo Supermarkten and are commonly used in their calculations. Furthermore, a lack of information on the suppliers has resulted in some limitations. First of all, it is assumed that the production/handling costs of the supplier remains the same whether it should deliver 2m high pallets or 1m high pallets. However, it is assumed that suppliers currently delivering products on 1m high pallets, are willing and able to deliver their products on 2m high pallets (as production/handling costs are lower), while that suppliers currently delivering products on 2m high pallets, are not willing to deliver their products on 1m high pallets (as production/handling costs are higher). It might be that additional cost or discounts are associated with these changes, which could also be included in the model. Furthermore, for the products for which it is unknown whether they can be stacked on top of each other in a truck, it is assumed that they can't be stacked. As a result, for these products a 1m high pallet occupies the same space in a truck as a 2m high pallet, such that ordering a 2m high pallet results in much lower inbound transport costs per case pack. However, for the top 100 suppliers in sales volume, who account for 85% of the volume sold, it is known whether products can be stacked on top of each other or not.

Furthermore, another limitation of the Master thesis is the assumption that each fixed order moment is used to order a product at the supplier. This assumption is made to determine the truckload per delivery moment, such that inbound transport costs can be calculated. If this assumption in reality is not true for a certain product or supplier, the inbound transport costs are estimated too high as in reality the truckloads per delivery moment are higher, which results in lower costs. However, almost all products in scope are ordered each fixed order moment. Moreover, the new delivery schedule of a product, when it is switched from NDC to RDC or vice versa, is unknown. For this reason, the delivery schedule is estimated as good as possible in the Master thesis project. Finally, another limitation of the model is that cannot be confirmed (or rejected) that less products should be stored at the RDC, as indicated by the BCG. This is due to the assumption that the number of orders per week is fixed for each DC.

## 9.4 Future research

First of all, to improve the quantitative model future research is necessary on the above described limitations of the Master thesis. Especially, it needs to be examined in which way the number of order moments change due to the re-allocation of products to distribution stages, such that this can be included in the model. Probably it can be included in the model likewise the inbound transport costs are included in model alternative 1; one can estimate the number of order moments initially and successively solve the model, and then update the number of order moments given the solution of the model, and solve the model again. This procedure of updating the number of order moments and solving the model can be repeated until the change in costs is negligible. As a result, the model can be used to confirm (or reject) that less products should be stored at the RDC, as indicated by the BCG.

Finally, the quantitative model forms a first start in order to determine the optimal allocation of perishable products to DC stages and storage types. However, additional research is necessary, as for example costs due to waste and special delivery types for perishables like pick-to-zero and transito are not incorporated in this research.

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# Appendices

## Appendix A

For the activities replenishing and order picking, the duration of the activities differs in the DCs dependent on the storage pick type the product is allocated to.

The estimated time for replenishing a double 2m high pallet pick location is lowest, as the replenishment of this pick location is always planned when one pallet position is empty, such that a pallet can be directly transferred from the bulk to the pick location. The estimated time for replenishing a 2m high pallet pick location is a little bit higher, as there will be some case packs left on the pallet, which need to be replaced and subsequently replaced on the replenished pallet. The same holds for the replenishment of a 1m high pallet pick location, however as it is more difficult to replace case packs in the smaller 1m location, the activity takes longer than replenishing a 2m high pallet pick location. Finally, the estimated time for replenishing flow- and shelf racks is highest, because no pallets fit in these racks and therefore case packs must be placed individually in the racks. Always some case packs are left in the racks and only some case packs of the pallet fit in the flow- or shelf rack. As a result, afterwards, the pallet with the remaining case packs is stored in the bulk again. The time and costs to store the pallet with the remaining case packs in the bulk again, is approximated as storage activity.

The activity order picking consists of three different sub-activities. The activities are traveling, making a stop, and grabbing a case pack. Each sub-activity takes a certain amount of time.
The estimated traveling time is based on the number of orders per week. The number of orders per week is independent of the inventory deployment decision, as the order moments for the stores are fixed and the stores always use these order moments. The order picking method used in NDC Elst and the RDCs is wave zone picking without batching, whereby each order picker traverses all aisles in the assigned zone once. Assuming that for each order, each picking zone is visited (which is realistic), each order implies that each aisle is traversed once, which implies that for each order each pick house is pass through once. The distance traveled passing one pick house is divided over the number of products in the pick house. The number of products stored in a pick house depends on the type of pick location, as a pick house could consist of one double 2m high pallet pick location (i.e. 1 product), two 2m high pallet pick locations (i.e. 2 products), four 1m high pallet locations (i.e. 4 products), etcetera. The total distance traveled per product-location-storage type combination is calculated by multiplying the distance of passing by the specific storage type with the fixed number of orders per week. As the number of orders per week is fixed, the total distance traveled per product-location-storage type combination is fixed (therefore, the number of orders per week is not mentioned as cost driver in Appendix B). Subsequently the amount of time traveling per product-location-

storage type combination is calculated using a speed estimate which is commonly used at Jumbo Supermarkten. As a result, the total distance traveled in a DC depends on the number of products allocated to the DC, as each product requires a certain distance (dependent on the storage type) which should be traveled. When less products are allocated to a DC, less pick houses are necessary, and as a result shorter (or less) aisles have to be traversed.

At each stop, an order picker can pick an estimated average number of case packs (which differs per DC). Based on this number and an estimated average time to stop, the duration of the single handling activity of stopping at a case pack can be calculated. The cost driver of this sub-activity is the number of case packs which need to be picked.

The estimated time for grabbing a case pack depends on the type of pick location. Products stored in flow- and shelf racks are easy to grab as these products are always within easy reach, and as a result least time consuming. The estimated grab time for products stored in double 2m high pallets pick locations are also relatively low, while the estimated grab times for products stored in 2m high pallet pick locations are higher and for products stored in 1m high pallet pick locations are highest, as it is harder to grab case packs from these pallet racks. The cost driver of this activity is the number of case packs which need to be picked.

## Appendix B

Table 1: Overview of handling activities, employees and cost drivers for NDC and RDC

| Activity | Employee | Cost driver | NDC | RDC |
|---|---|---|---|---|
| Receiving pallets from supplier | Receiver | # Pallets | X | X |
| Restacking 2m pallet to 1m pallet | Restacker | # Case packs to restack | X | X |
| Storage of pallets into bulk | Reachtrucker | # Pallets | X | X |
| Replenishing double 2m high pallet pick location | Reachtrucker | # 2m high Pallets | | X |
| Replenishing 2m high pallet pick location | Reachtrucker | # 2m high Pallets | X | X |
| Replenishing 1m high pallet pick location | Reachtrucker | # 1m high Pallets | X | X |
| Replenishing flow rack pick location | Reachtrucker | # 1m high Pallets | X | |
| Replenishing shelf rack pick location | Reachtrucker | # 1m high Pallets | X | |
| Order picking double 2m high pallet pick location | Order Picker | # Case packs | | X |
| Order picking 2m high pallet pick location | Order Picker | # Case packs | X | X |
| Order picking 1m high pallet pick location | Order Picker | # Case packs | X | X |
| Order picking  flow rack pick location | Order Picker | # Case packs | X | |
| Order picking shelf rack pick location | Order Picker | # Case packs | X | |
| Shipping roll cages | Dispatcher | # Roll cages | X | X |
| Receiving roll cages cross-dock (from NDC) | Receiver | # Roll cages | | X |
| Shipping roll cages cross-dock (to stores) | Dispatcher | # Roll cages | | X |

# Appendix C

**Table 2: The capacity of a truck in number of pallets, dependent on the pallet height, pallet type and possibility to stack.**

| Pallet height | Pallet type | Possible to stack | Truck capacity (# pallets) |
|---|---|---|---|
| 2 meter | Block | No | 26 |
| 2 meter | Euro | No | 33 |
| 1 meter | Block | No | 26 |
| 1 meter | Euro | No | 33 |
| 1 meter | Block | Yes | 52 |
| 1 meter | Euro | Yes | 66 |

# Appendix D

Table 3: Number of pick houses consumed per storage pick type

| Storage pick type | Number of pick houses consumed |
|---|---|
| **Double 2m high pallet pick location** | 1 |
| **2m high pallet pick location** | 0,5 |
| **1m high pallet pick location** | 0,25 |
| **Flow rack pick location** | 0,1 |
| **Shelf rack pick location** | 0,03125 |

# Appendix E

The actual service fill rates of the DCs are determined by using the so-called DoBr-tool. The service fill rate results for each product in a certain minimal reorder level, which result in an average inventory (in days) for each product.

Using the function "DoBr_TargetFillRateReorderLevel" of the DoBr-tool the minimal reorder level (in number of case packs) that satisfies a given target fill rate is calculated for each product. The required input parameters for this function are the lead time, the review period, the mean daily demand, the standard deviation of the daily demand, the case pack size, the minimum order quantity (MOQ), the target fill rate and whether there are lost sales or backorders. The lead time and review period of the products are known at Jumbo Supermarkten. Since demand is deterministic and equal to the actual supply of period 9 of 2015, the mean daily demand $\mu$ (in number of case packs) has been easily determined. The standard deviation of the daily demand $\sigma$ (in number of case packs) is given by the following formula $\sigma = 1{,}18 * \mu^{0{,}77}$ as retrieved from Broekmeulen & van Donselaar (2016). The 'case pack size' is expressed as the number of case packs on a pallet. Since suppliers deliver 1m or 2m high pallets, the 'case pack size' of a currently delivered 1m high pallet is the number of case packs on a 1m high pallet, and the 'case pack size' of a currently delivered 2m high pallet is the number of case packs on a 2m high pallet. The minimum order quantity is set to one. As a result, DCs have to order multiples of a 1m high pallet (if suppliers deliver currently 1m high pallets) or multiples of a 2m high pallet (if suppliers deliver currently 2m high pallets). The target fill rate is changed until the calculated average inventory became less or more equal to the actual average inventory of P9 2015. Finally, a situation with backordering is assumed (instead of lost sales), since in case of out of stocks there is a peak in the demand of the stores at the following order moment.

Using the functions "DoBr_EIOH_Begin" and "DoBr_EIOH_End" the expected inventory on hand at the begin of a review cycle and end of a review cycle are calculated (in number of case packs). The required input parameters are the lead time, the review period, the mean daily demand, the standard deviation of the daily demand, the reorder level, the case pack size, the minimum order quantity and whether there are lost sales or backorders. These input parameters have been explained above. The average inventory on hand in number of case packs is the average over the expected inventory on hand at the begin and end of a review cycle. Subsequently the average inventory in days over all products is calculated and validated with the actual average inventory in days in P9 2015.

## Appendix F

Table 4: KPIs (1) of the current situation, alternative 1 and alternative 2 (in numbers per week).

| KPIs (in numbers per week) | Current Situation | Alternative 1 | % Dif | Alternative 2 | % Dif |
|---|---|---|---|---|---|
| ***# Case packs delivered*** | | | | | |
| NDC Elst | 1.322.548 | 1.332.486 | -1% | 1.304.230 | 1% |
| RDC Beilen | 789.748 | 788.336 | 0% | 799.604 | -1% |
| RDC Breda | 461.564 | 463.110 | 0% | 466.864 | -1% |
| RDC Veghel | 868.519 | 862.553 | 1% | 874.038 | -1% |
| RDC Woerden | 715.239 | 711.098 | 1% | 712.848 | 0% |
| RDC Total | 2.835.881 | 2.825.098 | 0% | 2.853.353 | -1% |
| **Total** | **4.186.414** | **4.157.584** | **1%** | **4.157.583** | **1%** |
| ***# Pallets delivered*** | | | | | |
| NDC Elst | 12.230 | 10.168 | 17% | 9.751 | 20% |
| RDC Beilen | 8.778 | 7.993 | 9% | 8.145 | 7% |
| RDC Breda | 5.362 | 4.613 | 14% | 4.704 | 12% |
| RDC Veghel | 8.838 | 8.625 | 2% | 8.778 | 1% |
| RDC Woerden | 8.749 | 7.376 | 16% | 7.484 | 14% |
| RDC Total | 31.729 | 28.607 | 10% | 29.111 | 8% |
| **Total** | **43.959** | **38.774** | **12%** | **38.861** | **12%** |
| ***# Pallets delivered (2m, 1m)*** | | | | | |
| NDC Elst (2m, 1m) | (6.145, 6.085) | (8.489, 1.679) | - | (8.104, 1.647) | - |
| RDC Beilen (2m, 1m) | (7.739, 1.039) | (7.992, 1) | - | (8.142, 3) | - |
| RDC Breda (2m, 1m) | (4.235, 1.127) | (4.595, 18) | - | (4.639, 64) | - |
| RDC Veghel (2m, 1m) | (8.838, 0) | (8.624, 1) | - | (8.777, 0) | - |
| RDC Woerden (2m, 1m) | (7.675, 1.074) | (6.769, 607) | - | (6.849, 635) | - |
| ***# Case packs picked*** | | | | | |
| NDC Elst | 1.350.533 | 1.359.506 | -1% | 1.331.545 | 1% |
| RDC Beilen | 789.958 | 788.815 | 0% | 800.000 | -1% |
| RDC Breda | 461.688 | 463.393 | 0% | 467.098 | -1% |
| RDC Veghel | 868.768 | 863.091 | 1% | 874.487 | -1% |
| RDC Woerden | 715.467 | 711.576 | 1% | 713.249 | 0% |
| RDC Total | 2.835.881 | 2.826.875 | 0% | 2.854.834 | -1% |
| **Total** | **4.186.414** | **4.186.381** | **0%** | **4.186.379** | **0%** |
| ***# Case packs picked per storage type*** | | | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (569k, 575k, 114k, 93k) | (789k, 348k, 179k, 44k) | - | (773k, 347k, 167k, 44k) | - |
| RDC Beilen (2x2m, 2m, 1m) | (376k, 339k, 76k) | (435k, 353k, 526) | - | (438k, 361k, 571) | - |
| RDC Breda (2x2m, 2m, 1m) | (171k, 163k, 128k) | (144k, 313k, 6k) | - | (156k, 302k, 9k) | - |
| RDC Veghel (2x2m, 2m, 1m) | (497k, 372k, 0) | (603k, 260k, 187) | - | (614k, 260k, 105) | - |
| RDC Woerden (2x2m, 2m, 1m) | (143k, 476k, 97k) | (345k, 300k, 67k) | - | (349k, 302k, 62k) | - |

Table 5: KPIs (2) of the current situation, alternative 1 and alternative 2 (in numbers per week).

| KPIs (in numbers per week) | Current Situation | Alternative 1 | % Dif | Alternative 2 | % Dif |
|---|---|---|---|---|---|
| ***# Roll cages received*** | | | | | |
| RDC Beilen | 6.444 | 6.456 | 0% | 5.948 | 8% |
| RDC Breda | 4.089 | 4.061 | 1% | 3.816 | 7% |
| RDC Veghel | 6.394 | 6.512 | -2% | 6.008 | 6% |
| RDC Woerden | 6.828 | 6.974 | -2% | 6.901 | -1% |
| **RDC Total** | **23.754** | **24.002** | **-1%** | **22.673** | **5%** |
| ***# Inter-DC trips*** | | | | | |
| RDC Beilen | 124 | 125 | 0% | 115 | 8% |
| RDC Breda | 77 | 76 | 1% | 72 | 7% |
| RDC Veghel | 120 | 122 | -2% | 113 | 6% |
| RDC Woerden | 124 | 127 | -2% | 126 | -1% |
| **RDC Total** | **446** | **450** | **-1%** | **425** | **5%** |
| ***# Inbound transport trips*** | | | | | |
| NDC Elst | 1.064 | 992 | 7% | 1.014 | 5% |
| RDC Beilen | 665 | 514 | 23% | 589 | 12% |
| RDC Breda | 543 | 393 | 28% | 473 | 13% |
| RDC Veghel | 683 | 549 | 20% | 605 | 11% |
| RDC Woerden | 656 | 482 | 27% | 566 | 14% |
| RDC Total | 2.547 | 1.938 | 24% | 2.233 | 12% |
| **Total** | **3.611** | **2.929** | **19%** | **3.247** | **10%** |
| ***Average kilometers traveled per trip*** | | | | | |
| NDC Elst | 165 | 145 | 12% | 135 | 18% |
| RDC Beilen | 205 | 197 | 4% | 208 | -1% |
| RDC Breda | 134 | 114 | 15% | 129 | 3% |
| RDC Veghel | 123 | 105 | 15% | 119 | 3% |
| RDC Woerden | 119 | 101 | 15% | 116 | 3% |
| ***Average truckload*** | | | | | |
| NDC Elst | 52% | 43% | - | 40% | - |
| RDC Beilen | 64% | 84% | - | 70% | - |
| RDC Breda | 42% | 50% | - | 42% | - |
| RDC Veghel | 62% | 85% | - | 73% | - |
| RDC Woerden | 65% | 77% | - | 62% | - |
| ***# Suppliers delivering DC*** | | | | | |
| NDC only | 234 | 315 | -35% | 316 | -35% |
| RDC only | 44 | 34 | 23% | 51 | -16% |
| NDC and RDC | 193 | 122 | 37% | 104 | 46% |

Table 6: KPIs (3) of the current situation, alternative 1 and alternative 2 (in numbers per week).

| KPIs (in numbers per week) | Current Situation | Alternative 1 | % Dif | Alternative 2 | % Dif |
|---|---|---|---|---|---|
| ***# Products per DC-type*** | | | | | |
| NDC | 10.095 | 10.374 | -3% | 10.376 | -3% |
| RDC | 3.030 | 2.751 | 9% | 2.749 | 9% |
| ***# Products per storage type*** | | | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (2511, 2348, 3000, 2236) | (2322, 2876, 3190, 1986) | - | (2335, 2847, 3190, 2004) | - |
| RDC Beilen (2x2m, 2m, 1m) | (304, 2245, 481) | (382, 2290, 79) | - | (375, 2314, 60) | - |
| RDC Breda (2x2m, 2m, 1m) | (211, 1765, 1054) | (96, 2396, 259) | - | (114, 2345, 290) | - |
| RDC Veghel (2x2m, 2m, 1m) | (644, 2386, 0) | (759, 1931, 61) | - | (770, 1937, 42) | - |
| RDC Woerden (2x2m, 2m, 1m) | (57, 2280, 693) | (341, 1727, 684) | - | (338, 1736, 674) | - |
| ***Volume handled (m3)*** | | | | | |
| NDC Elst | 11.050 | 11.154 | -1% | 10.506 | 5% |
| RDC Beilen | 14.189 | 14.187 | 0% | 14.431 | -2% |
| RDC Breda | 8.042 | 8.058 | 0% | 8.167 | -2% |
| RDC Veghel | 15.220 | 15.158 | 0% | 15.419 | -1% |
| RDC Woerden | 12.564 | 12.508 | 0% | 12.542 | 0% |
| RDC Total | 50.016 | 49.911 | 0% | 50.559 | -1% |
| **Total** | **61.066** | **61.065** | **0%** | **61.065** | **0%** |
| ***Volume handled per storage type (m3)*** | | | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (5.855, 3.903, 833, 459) | (7.932, 2.380, 751, 90) | - | (7.331, 2.386, 699, 91) | - |
| RDC Beilen (2x2m, 2m, 1m) | (8.309, 5.035, 846) | (8.582, 5.595, 11) | - | (8.578, 5.841, 11) | - |
| RDC Breda (2x2m, 2m, 1m) | (3.869, 2.631, 1.542) | (2.716, 5.272, 70) | - | (2.885, 5.1999, 84) | - |
| RDC Veghel (2x2m, 2m, 1m) | (9.903, 5.318, 0) | (11.146, 4.010, 2) | - | (11.314, 4.103, 2) | - |
| RDC Woerden (2x2m, 2m, 1m) | (3.417, 8.018, 1.129) | (6.343, 5.154, 1.011) | - | (6.416, 5.262, 864) | - |
| ***# Products changed in DC-type*** | | | | | |
| RDC --> NDC | - | 855 | - | 954 | - |
| NDC --> RDC | - | 576 | - | 672 | - |
| Total | - | 1.431 | - | 1.626 | - |
| ***# Products changed in storage type*** | | | | | |
| NDC Elst | - | 5.423 | - | 5.275 | - |
| RDC Beilen | - | 523 | - | 498 | - |
| RDC Breda | - | 919 | - | 845 | - |
| RDC Veghel | - | 411 | - | 398 | - |
| RDC Woerden | - | 813 | - | 721 | - |

Table 7: KPIs (4) of the current situation, alternative 1 and alternative 2.

| KPIs | Current Situation | Alternative 1 | % Dif | Alternative 2 | % Dif |
|---|---|---|---|---|---|
| ***% Pick houses occupied*** | | | | | |
| NDC Elst | 85% | 90% | -6% | 90% | - |
| RDC Beilen | 90% | 90% | 0% | 90% | - |
| RDC Breda | 90% | 90% | 0% | 90% | - |
| RDC Veghel | 90% | 85% | 5% | 86% | - |
| RDC Woerden | 90% | 90% | 0% | 90% | - |
| ***% Bulk locations occupied*** | | | | | |
| NDC Elst | 87% | 85% | - | 85% | - |
| RDC Beilen | 82% | 75% | - | 77% | - |
| RDC Breda | 59% | 55% | - | 55% | - |
| RDC Veghel | 45% | 41% | - | 42% | - |
| RDC Woerden | 98% | 85% | - | 85% | - |

# Appendix G

**Table 8: Cost savings per week on handling activities per DC per storage type of alternative 1 compared to the current situation.**

| Cost savings Alternative 1 | | Receiving | Restacking | Storage | Replenishing | Order picking | Shipping | Total |
|---|---|---|---|---|---|---|---|---|
| **NDC Elst** | 2m pallet | € -1.469 | € - | € -3.379 | € -5.020 | € -29.426 | € -877 | € -40.171 |
| | 1m pallet | € 2.345 | € 1.008 | € 6.163 | € 9.564 | € 31.370 | € 636 | € 51.084 |
| | flowrack | € -23 | € -482 | € 29 | € 6.542 | € -8.766 | € 36 | € -2.662 |
| | shelfrack | € 159 | € 649 | € 710 | € 33.102 | € 6.584 | € 154 | € 41.359 |
| | **Total** | **€ 1.012** | **€ 1.175** | **€ 3.523** | **€ 44.188** | **€ -238** | **€ -50** | **€ 49.611** |
| **RDC Beilen** | 2x2m pallet | € -111 | € - | € -208 | € -280 | € -7.126 | € -105 | € -7.830 |
| | 2m pallet | € -52 | € - | € -98 | € -149 | € -1.883 | € -261 | € -2.442 |
| | 1m pallet | € 703 | € -10 | € 1.305 | € 2.064 | € 10.204 | € 371 | € 14.637 |
| | **Total** | **€ 540** | **€ -10** | **€ 999** | **€ 1.635** | **€ 1.194** | **€ 5** | **€ 4.364** |
| **RDC Breda** | 2x2m pallet | € 415 | € - | € 827 | € 1.121 | € 3.268 | € 580 | € 6.210 |
| | 2m pallet | € -940 | € - | € -1.875 | € -2.857 | € -18.375 | € -1.286 | € -25.333 |
| | 1m pallet | € 1.030 | € 906 | € 2.994 | € 4.766 | € 15.611 | € 705 | € 26.012 |
| | **Total** | **€ 505** | **€ 906** | **€ 1.947** | **€ 3.029** | **€ 503** | **€ -1** | **€ 6.889** |
| **RDC Veghel** | 2x2m pallet | € -445 | € - | € -888 | € -1.196 | € -17.169 | € -613 | € -20.313 |
| | 2m pallet | € 625 | € - | € 1.245 | € 1.887 | € 19.924 | € 646 | € 24.327 |
| | 1m pallet | € -2 | € -3 | € -6 | € -9 | € -138 | € -1 | € -158 |
| | **Total** | **€ 178** | **€ -3** | **€ 352** | **€ 682** | **€ 2.616** | **€ 31** | **€ 3.856** |
| **RDC Woerden** | 2x2m pallet | € -980 | € - | € -2.334 | € -3.182 | € -26.294 | € -1.564 | € -34.354 |
| | 2m pallet | € 1.597 | € - | € 2.443 | € 3.747 | € 24.393 | € 1.546 | € 33.727 |
| | 1m pallet | € 349 | € -127 | € 379 | € 606 | € 4.099 | € 54 | € 5.360 |
| | **Total** | **€ 967** | **€ -127** | **€ 488** | **€ 1.172** | **€ 2.198** | **€ 36** | **€ 4.733** |
| **All DCs** | **Total** | **€ 3.202** | **€ 1.941** | **€ 7.308** | **€ 50.706** | **€ 6.274** | **€ 21** | **€ 69.453** |
| | **Percentage** | **5%** | **3%** | **11%** | **73%** | **9%** | **0%** | **100%** |

Table 9: Cost savings per week on handling activities per DC per storage type of alternative 2 compared to the current situation.

| Cost savings Alternative 2 | | Receiving | Restacking | Storage | Replenishing | Order picking | Shipping | Total |
|---|---|---|---|---|---|---|---|---|
| **NDC Elst** | 2m pallet | € -1.287 | € - | € -2.961 | € -4.400 | € -27.427 | € -628 | € -36.704 |
| | 1m pallet | € 2.332 | € 1.101 | € 6.118 | € 9.494 | € 31.537 | € 633 | € 51.216 |
| | flowrack | € 13 | € -385 | € 157 | € 7.406 | € -7.216 | € 58 | € 33 |
| | shelfrack | € 158 | € 626 | € 698 | € 33.130 | € 6.620 | € 154 | € 41.387 |
| | **Total** | **€ 1.216** | **€ 1.343** | **€ 4.011** | **€ 45.630** | **€ 3.515** | **€ 217** | **€ 55.932** |
| **RDC Beilen** | 2x2m pallet | € -119 | € - | € -222 | € -298 | € -7.498 | € -102 | € -8.238 |
| | 2m pallet | € -141 | € - | € -265 | € -401 | € -2.857 | € -362 | € -4.026 |
| | 1m pallet | € 703 | € -6 | € 1.308 | € 2.068 | € 10.219 | € 370 | € 14.663 |
| | **Total** | **€ 444** | **€ -6** | **€ 822** | **€ 1.370** | **€ -136** | **€ -94** | **€ 2.400** |
| **RDC Breda** | 2x2m pallet | € 347 | € - | € 692 | € 938 | € 1.923 | € 497 | € 4.398 |
| | 2m pallet | € -911 | € - | € -1.817 | € -2.769 | € -16.928 | € -1.250 | € -23.674 |
| | 1m pallet | € 1.010 | € 957 | € 2.989 | € 4.757 | € 15.135 | € 699 | € 25.548 |
| | **Total** | **€ 446** | **€ 957** | **€ 1.865** | **€ 2.927** | **€ 131** | **€ -54** | **€ 6.272** |
| **RDC Veghel** | 2x2m pallet | € -542 | € - | € -1.082 | € -1.457 | € -19.062 | € -700 | € -22.843 |
| | 2m pallet | € 594 | € - | € 1.184 | € 1.794 | € 19.982 | € 600 | € 24.155 |
| | 1m pallet | € -1 | € -1 | € -2 | € -3 | € -91 | € -1 | € -98 |
| | **Total** | **€ 51** | **€ -1** | **€ 100** | **€ 334** | **€ 829** | **€ -101** | **€ 1.214** |
| **RDC Woerden** | 2x2m pallet | € -1.011 | € - | € -2.400 | € -3.273 | € -26.745 | € -1.602 | € -35.030 |
| | 2m pallet | € 1.544 | € - | € 2.356 | € 3.615 | € 24.050 | € 1.497 | € 33.061 |
| | 1m pallet | € 367 | € 170 | € 667 | € 1.069 | € 4.764 | € 136 | € 7.173 |
| | **Total** | **€ 900** | **€ 170** | **€ 624** | **€ 1.411** | **€ 2.069** | **€ 31** | **€ 5.205** |
| All DCs | **Total** | **€ 3.057** | **€ 2.462** | **€ 7.422** | **€ 51.672** | **€ 6.409** | **€ -1** | **€ 71.022** |
| | **Percentage** | **4%** | **3%** | **10%** | **73%** | **9%** | **0%** | **100%** |

# Appendix H

Table 10: KPIs of alternative 1 and the sensitivity analyses on the inter-DC transport costs.

| KPIs | Alternative 1 | Inter-DC transport costs (75%) | Inter-DC transport costs (125%) |
|---|---|---|---|
| ***# Products per DC-type*** | | | |
| NDC | 10.374 | 10.319 | 10.383 |
| RDC | 2.751 | 2.807 | 2.743 |
| ***# Products per storage type*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (2322, 2876, 3190, 1986) | (2327, 2875, 3187, 1930) | (2329, 2861, 3190, 2003) |
| RDC Beilen (2x2m, 2m, 1m) | (382, 2290, 79) | (339, 2366, 102) | (386, 2288, 69) |
| RDC Breda (2x2m, 2m, 1m) | (96, 2396, 259) | (90, 2360, 357) | (96, 2406, 241) |
| RDC Veghel (2x2m, 2m, 1m) | (759, 1931, 61) | (743, 2006, 58) | (770, 1916, 57) |
| RDC Woerden (2x2m, 2m, 1m) | (341, 1727, 684) | (273, 1875, 659) | (355, 1693, 695) |
| ***Volume handled (m3)*** | | | |
| NDC Elst | 11.154 | 11.873 | 10.756 |
| RDC Beilen | 14.187 | 14.107 | 14.312 |
| RDC Breda | 8.058 | 8.007 | 8.114 |
| RDC Veghel | 15.158 | 15.050 | 15.293 |
| RDC Woerden | 12.508 | 12.027 | 12.590 |
| RDC Total | 49.911 | 49.191 | 50.309 |
| **Total** | **61.065** | **61.065** | **61.065** |
| ***Volume handled per storage type (m3)*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (7.932, 2.380, 751, 90) | (8.708, 2.338, 744, 84) | (7.544, 2.380, 740, 92) |
| RDC Beilen (2x2m, 2m, 1m) | (8.582, 5.595, 11) | (8.238, 5.850, 20) | (8.656, 5.647, 9) |
| RDC Breda (2x2m, 2m, 1m) | (2.716, 5.272, 70) | (2.658, 5.247, 102) | (2.721, 5.327, 67) |
| RDC Veghel (2x2m, 2m, 1m) | (11.146, 4.010, 2) | (11.049, 3.997, 3) | (11.250, 4.041, 2) |
| RDC Woerden (2x2m, 2m, 1m) | (6.343, 5.154, 1.011) | (5.828, 5.699, 500) | (6.472, 5.043, 1.074) |
| ***# Products changed in DC-type*** | | | |
| RDC --> NDC | - | 118 | 74 |
| NDC --> RDC | - | 172 | 64 |
| **Total** | **-** | **290** | **138** |
| ***# Products changed in storage type*** | | | |
| NDC Elst | - | 153 | 161 |
| RDC Beilen | - | 50 | 3 |
| RDC Breda | - | 34 | 14 |
| RDC Veghel | - | 2 | 2 |
| RDC Woerden | - | 129 | 49 |
| **Total** | **-** | **368** | **229** |

Table 11: KPIs of alternative 1 and the sensitivity analyses on the inbound transport costs.

| KPIs | Alternative 1 | Inbound transport costs (75%) | Inbound transport costs (125%) |
|---|---|---|---|
| ***# Products per DC-type*** | | | |
| NDC | 10.374 | 10.390 | 10.360 |
| RDC | 2.751 | 2.735 | 2.765 |
| ***# Products per storage type*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (2322, 2876, 3190, 1986) | (2306, 2908, 3190, 1986) | (2336, 2855, 3168, 2001) |
| RDC Beilen (2x2m, 2m, 1m) | (382, 2290, 79) | (392, 2277, 66) | (376, 2296, 94) |
| RDC Breda (2x2m, 2m, 1m) | (96, 2396, 259) | (100, 2401, 234) | (96, 2384, 286) |
| RDC Veghel (2x2m, 2m, 1m) | (759, 1931, 61) | (769, 1910, 56) | (742, 1958, 65) |
| RDC Woerden (2x2m, 2m, 1m) | (341, 1727, 684) | (348, 1721, 666) | (330, 1744, 691) |
| ***Volume handled (m3)*** | | | |
| NDC Elst | 11.154 | 10.724 | 11.627 |
| RDC Beilen | 14.187 | 14.321 | 14.055 |
| RDC Breda | 8.058 | 8.117 | 7.980 |
| RDC Veghel | 15.158 | 15.302 | 15.007 |
| RDC Woerden | 12.508 | 12.600 | 12.396 |
| RDC Total | 49.911 | 50.340 | 49.437 |
| **Total** | **61.065** | **61.065** | **61.065** |
| ***Volume handled per storage type (m3)*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (7.932, 2.380, 751, 90) | (7.477, 2.444, 713, 90) | (8.412, 2.346, 777, 93) |
| RDC Beilen (2x2m, 2m, 1m) | (8.582, 5.595, 11) | (8.698, 5.616, 7) | (8.529, 5.513, 14) |
| RDC Breda (2x2m, 2m, 1m) | (2.716, 5.272, 70) | (2.756, 5.297, 65) | (2.712, 5.192, 76) |
| RDC Veghel (2x2m, 2m, 1m) | (11.146, 4.010, 2) | (11.251, 4.049, 2) | (11.046, 3.958, 3) |
| RDC Woerden (2x2m, 2m, 1m) | (6.343, 5.154, 1.011) | (6.461, 5.120, 1.019) | (6.253, 5.152, 990) |
| ***# Products changed in DC-type*** | | | |
| RDC --> NDC | - | 89 | 97 |
| NDC --> RDC | - | 72 | 110 |
| **Total** | **-** | **161** | **207** |
| ***# Products changed in storage type*** | | | |
| NDC Elst | - | 323 | 289 |
| RDC Beilen | - | 12 | 8 |
| RDC Breda | - | 28 | 27 |
| RDC Veghel | - | 3 | 4 |
| RDC Woerden | - | 33 | 26 |
| **Total** | **-** | **399** | **354** |

Table 12: KPIs of alternative 1 and the sensitivity analyses on the handling costs.

| KPIs | Alternative 1 | Handling costs (75%) | Handling costs (125%) |
|---|---|---|---|
| ***# Products per DC-type*** | | | |
| NDC | 10.374 | 10.363 | 10.343 |
| RDC | 2.751 | 2.762 | 2.783 |
| ***# Products per storage type*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (2322, 2876, 3190, 1986) | (2344, 2829, 3190, 1999) | (2303, 2922, 3190, 1928) |
| RDC Beilen (2x2m, 2m, 1m) | (382, 2290, 79) | (373, 2306, 83) | (351, 2353, 79) |
| RDC Breda (2x2m, 2m, 1m) | (96, 2396, 259) | (88, 2410, 265) | (88, 2390, 305) |
| RDC Veghel (2x2m, 2m, 1m) | (759, 1931, 61) | (756, 1948, 58) | (760, 1973, 50) |
| RDC Woerden (2x2m, 2m, 1m) | (341, 1727, 684) | (344, 1707, 712) | (283, 1869, 631) |
| ***Volume handled (m3)*** | | | |
| NDC Elst | 11.154 | 11.147 | 11.347 |
| RDC Beilen | 14.187 | 14.187 | 14.251 |
| RDC Breda | 8.058 | 8.060 | 8.092 |
| RDC Veghel | 15.158 | 15.163 | 15.221 |
| RDC Woerden | 12.508 | 12.508 | 12.155 |
| RDC Total | 49.911 | 49.918 | 49.718 |
| **Total** | **61.065** | **61.065** | **61.065** |
| ***Volume handled per storage type (m3)*** | | | |
| NDC Elst (2m, 1m, flowrack, shelfrack) | (7.932, 2.380, 751, 90) | (7.961, 2.319, 775, 93) | (8.143, 2.406, 716, 83) |
| RDC Beilen (2x2m, 2m, 1m) | (8.582, 5.595, 11) | (8.512, 5.664, 12) | (8.321, 5.915, 14) |
| RDC Breda (2x2m, 2m, 1m) | (2.716, 5.272, 70) | (2.641, 5.341, 77) | (2.641, 5.358, 93) |
| RDC Veghel (2x2m, 2m, 1m) | (11.146, 4.010, 2) | (11.129, 4.032, 2) | (11.149, 4.069, 3) |
| RDC Woerden (2x2m, 2m, 1m) | (6.343, 5.154, 1.011) | (6.367, 5.064, 1.077) | (5.900, 5.744, 511) |
| ***# Products changed in DC-type*** | | | |
| RDC --> NDC | - | 26 | 23 |
| NDC --> RDC | - | 36 | 53 |
| **Total** | **-** | **62** | **76** |
| ***# Products changed in storage type*** | | | |
| NDC Elst | - | 236 | 253 |
| RDC Beilen | - | 12 | 44 |
| RDC Breda | - | 54 | 62 |
| RDC Veghel | - | 5 | 3 |
| RDC Woerden | - | 40 | 114 |
| **Total** | **-** | **347** | **476** |