MASTER

Intelligent carrier compilation to reduce handling operations in the retail supply chain

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Intelligent carrier compilation to reduce handling operations in the retail supply chain

by

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BSc Industrial Engineering and Management Science — TU/e 2010
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in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

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ABSTRACT

This master thesis describes how the assignment of products to carriers can be improved by taking the handling operations of both the distribution center and the retail store into account. In the research project, the situation of Albert Heijn is described and it is determined how the assignment of products to the carriers can be adjusted based on the current deliveries and the current number of carriers needed.

First, an assignment problem is formulated with as overall objective is minimizing the number of aisles visited in the store and in the distribution center. On an operational level, the assignment of SKUs to carriers can be adjusted; and on a tactical level, the slotting of SKUs to aisles in the distribution center can be adjusted.

A heuristic is designed to solve the problem on an operational level, and a simulation model is used to test how the importance of the store operations influences the results in relation to the distribution center operations.
MANAGEMENT SUMMARY
In this report, the results of the master thesis carried out at Albert Heijn are presented. Albert Heijn is the largest grocery retailer in the Netherlands and in this thesis project the handling operations in the retail supply chain of Albert Heijn are studied.

PROBLEM DESCRIPTION
The focus of this research project is to improve the assignment of products to carriers in the distribution center. In the current situation, carriers have to be sorted in the backroom of the store, because the products on the carriers are not loaded based on the location in the store they are placed. It is studied whether it is possible to improve the assignment of products to carriers in the distribution center, taking the handling operations in the store into account. It is assumed that the number of carriers used is the same as in the current situation and that only the assignment of products to the carriers is adjusted. Furthermore, it is assumed that the products are no longer sorted in the backroom of the store. In this project, the products are sorted during the replenishment process in the store.

The problem description results in the following research question:

Which factors influence the carrier compilation process in the distribution center and how can the carrier compilation process be adjusted to take the handling operations in the store into account when compiling carriers?

A conceptual model is developed which takes the relevant characteristics of the store process into account. In the operational model, the assignment of products to carriers is determined; and in the tactical model, the assignment of SKUs to aisles in the distribution center (DC) is determined.

RESULTS
A heuristic is developed, which assigns products to carriers based on: (1) the volume of the products, (2) the aisles the product is placed in the DC, and (3) the category of a product. It is assumed that when an aisle is visited in the DC everything from the same category is collected on the same carrier. Therefore clusters are formed with products from the same category which are situated in the same aisle of the DC. The first fit decreasing algorithm is used to determine whether it is possible to reduce the number of carriers used. The analysis showed that the number of carriers can be reduced with 13% when the clusters are assigned differently to the carriers, which indicates the possibility to change the assignment of products to carriers.

The simulation model tests the performance of the developed heuristic. The heuristic makes use of seed clusters, which determine which other clusters, are assigned to the same carrier. The objectives of the model are (1) to minimize the distance travelled in the DC, and (2) to minimize the distance travelled between the aisles in the store. The factors α and β, (where 0 ≤ α ≤ 1, and 0 ≤ β ≤ 1) influence respectively the distance a candidate cluster can be located from the seed cluster in the DC and in the store. The higher α and β are the smaller the allowed distance is. Four simulation scenarios are selected to show how α and β influence the results. One scenario shows the results when the distances travelled in the DC and those travelled in the store are not taken into account (α=0 and β=0). The assignment is thus based only on the volume of the clusters. The next scenario
(α=0 and β=1) shows the results when the distances travelled in the store are extremely important and only the same categories as the seed cluster can be loaded on the carrier. Also a scenario is tested in which the distances in the store are not taken into account and the products can only be collected within a limited distance of a few aisles from the seed aisle (α=0.2 and β=0). Finally, a scenario is included that emphasizes the clusters should be located close to each other both in the DC and in the store (α=0.05 and β=0.1).

In Table 1 the results of the simulation model are presented. The performance of the current order picking algorithm is put in the table with the results to indicate the performance of the current situation. It is possible to reduce the distance travelled between the aisles in the store, but this leads to an increase in the distance travelled in the DC.

**Table 1: Results simulation model for several settings of α and β for 53 deliveries**

<table>
<thead>
<tr>
<th>α</th>
<th>β</th>
<th>Number of carriers used</th>
<th>Average inter aisle distance per carrier (in m)</th>
<th>Average intra aisle distance per carrier (in m)</th>
<th>Average total distance travelled in DC per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
<th>Average distance travelled in store between aisles per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>683</td>
<td>473 m</td>
<td>289 m</td>
<td>762 m</td>
<td>+37%</td>
<td>86 m</td>
<td>+83%</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>780</td>
<td>476 m</td>
<td>270 m</td>
<td>746 m</td>
<td>+34%</td>
<td>32 m</td>
<td>-32%</td>
</tr>
<tr>
<td>0.2</td>
<td>0</td>
<td>777</td>
<td>277 m</td>
<td>205 m</td>
<td>482 m</td>
<td>-14%</td>
<td>74 m</td>
<td>+58%</td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>780</td>
<td>475 m</td>
<td>269 m</td>
<td>744 m</td>
<td>+33%</td>
<td>34 m</td>
<td>-28%</td>
</tr>
</tbody>
</table>

In Figure 1, a graph presents the average distance travelled between the aisles in the store per carrier for the described scenarios. The performance of the current order picking algorithm is plotted in the graph with the results to indicate the performance of the current situation. Furthermore, a lower bound is given which indicates the theoretical minimum distance that has to be travelled in the store. In this graph, 53 deliveries are shown. When the store is not taken into account during the assignment of products to the carriers (β=0), the average distance travelled in the store is high. When the distance travelled is taken into account (β≠0), it can be seen that the distance travelled between the aisles can be reduced with around 30% compared to the current situation.
In Figure 2 the average distance travelled in the DC per carrier is shown in a graph. The performance of the current order picking algorithm is plotted in the graph with the results to indicate the performance of the current situation. Furthermore, a lower bound is given which indicates the theoretical minimum distance that has to be travelled in the DC. The simulation results of the scenarios are given for 53 deliveries.
The results show that there are possibilities to reduce the distance travelled in the DC compared with the current situation. In scenario $\alpha=0.2$, $\beta=0$ the average distance travelled per carrier is reduced with 14%. The fact that in the simulation model only one pick zone is defined in combination with the alpha factor that causes that the aisles visited are located close to each other, leads to the fact that efficient pick orders can be composed. So no rest picks are performed and in this situation fewer carriers can be used than in the current situation. The other three scenarios tested lead on average to an increase of 35% of the distance travelled per carrier in the DC.

The distances travelled in the DC and store can be compared by determining the travel time at these two locations. The travel time in the DC can be determined by multiplying the distance travelled with the speed of the order picker and divide this by the average number of carriers collected at once. The travel time in the store is in the current situation related to the average sorting time per carrier. Based on the difference in travel distance with the current situation, the travel time is determined for the other scenarios. The costs of an order picker in the DC are twice the costs of an employee in the store at Albert Heijn, so the total relevant time is expressed in minutes of store employee time. The results in Table 2 show that it is possible to reduce the total time spent on travelling when the distances travelled between the aisles in the store are taken into account.

**Table 2: Relevant time spent on travelling with carrier**

| $\alpha$ | $\beta$ | # carriers used | DC | | Store | | Total relevant time (in min of store employee time) |
| --- | --- | --- | --- | --- | --- | --- |
| | | | Aver. tot. dist. travelled per carrier (in m) | Aver. time spent on travelling per carrier (in sec) | Difference with current situation (in %) | Aver. dist. travelled between aisles per carrier (in m) | Time spent on travelling per carrier (in min) | Difference with current situation (in %) | |
| Current situation | | | 780 | 558 m | 62 sec | 47 m | 7 min | 9 min |
| 0 | 0 | 683 | 762 m | 85 sec | +37% | 86 m | 13 min | +83% | 16 min |
| 0 | 1 | 780 | 746 m | 83 sec | +34% | 32 m | 5 min | -32% | 8 min |
| 0.2 | 0 | 777 | 482 m | 54 sec | -14% | 74 m | 11 min | +58% | 13 min |
| 0.05 | 0.1 | 780 | 744 m | 83 sec | +33% | 34 m | 5 min | -28% | 8 min |

**CONCLUSION**

The results of the simulation model show that it is possible to take both the distance travelled in the store and in the DC into account, when assigning products to carriers. Furthermore, the results show that it is possible to reduce the number of aisles visited in the store, but it is not possible to reduce the distance travelled in the DC at the same time. Based on the distances travelled, an estimation can be made of the travel time and costs. The results show that it is beneficial to take the location of the products in the store into account, when the carriers are compiled in the distribution center. This leads to an increase of the costs in the DC, but this is compensated by the costs savings in the store.
Additionally, the results show that it is possible to reduce the distance travelled in the DC, when one pick zone is defined as done in the simulation model. This way the carriers can be loaded more efficiently so no rest picks have to be performed anymore. The disadvantage is that in this scenario the distance travelled between the aisles in the store increases.

In this research only one store is studied, but the method of defining categories for SKUs in the same store aisle can be applied to multiple stores. Additionally, the described assignment method can be applied to the current slotting as well as an adjusted slotting.

Furthermore, a model is given that describes the assignment of SKUs to DC aisles. This can be used to improve the slotting, but the problem is difficult to solve. Therefore, it is suggested that this problem is solved by making use of a simple improvement heuristic. Nevertheless, more data from other stores is needed to design a slotting that improves the quality of the carrier compilation for the majority of the stores.

**Recommendations**

Before the assignment of products to the carrier is adjusted, it should be studied how changing the compilation of the carriers influences the store handling operations. It should be checked whether reducing the number of categories loaded on a carrier leads to a reduction of the travel time between the aisles in the store. Furthermore, it should be checked whether this effect is linear or not. When this is known a better estimation can be made of the travel time savings in the store.

The simulation model has shown that it is possible to reduce the distance travelled in the DC. This indicates the opportunity for Albert Heijn to investigate how dynamic pick zones can be used in their DC. This dynamic picking avoids the undesirable process of ‘rest picking’, because the pick zones have dynamic borders, and they can be adjusted based on the size of the order being picked.

In this research, only the data of one store is used to determine whether it is possible to reduce the distance travelled in the store and in the DC. It is important to gain more insight in how an increase in the travelled distance in the DC influences the picking efficiency and the existence of congestion in the DC. Furthermore, it should be studied whether a different assignment of products to carriers influences the batching possibilities and efficiency.

**Future research**

To improve the compilation of the carriers, it can be studied whether it is possible to adjust the moment a product arrives at the store. It should be tried to deliver only full carriers loaded with one category of products. In this case fewer aisles need to be visited in the store in total, since there are no carriers with multiple categories loaded on it.

In this research the exact location of products on a carrier is not taken into account, only the assignment of products to the carrier is. It is difficult to determine the exact location, because a carrier is a three dimensional space, every order picker loads the carrier differently, and every store employee unloads the carrier differently. It could be worthwhile to gain more insight in this process to determine to which extent the sequence the products are loaded on a carrier influences the sequence the products are unloaded from a carrier.
PREFACE

This report is the result of my graduation project that has been conducted at Ahold in completion of the Master Operations Management & Logistics at Eindhoven University of Technology. With the completion of this project, an end to my life as a student is there. Therefore, I would like to use this opportunity to thank some people who supported me during my graduation project and my studies.

First of all, I would like to thank my mentor, and first supervisor of the TU/e, Rob Broekmeulen. I would like to thank him for the time he had available to answer all my questions, and the new insights and advices he provided me with during my project. I would also like to thank my second supervisor of the TU/e, Dmitry Krushinsky, for his critical and useful comments on my report.

Secondly, I would like to thank all the people from Ahold who provided input for my research. Special thanks go to Caroline Fluit for her feedback during our regular meetings and her involvement in my project. She gave me guidance and support during my project, and helped me find the right people and the right information. Also many thanks go to Karel Jan van der Kaaden for his useful feedback during our meetings and his guidance. Next to them, I also would like to thank the people from the Value Chain Development team for their help, feedback, and small talk during the lunch breaks.

Last but not least, I would like to thank my family and friends. Special thanks for my parents for supporting me for the choices I made during my studies and being there when I needed them. Furthermore, I would like to thank my friends for being there during my graduation project and studies, and for providing me with welcome distractions, which made my student life altogether a great period in my life.

Linda Brands
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# List of Definitions and Abbreviations

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<th>Dutch</th>
<th>Explanation</th>
</tr>
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<tr>
<td>AH</td>
<td>Albert Heijn</td>
<td>Albert Heijn</td>
</tr>
<tr>
<td>Baarn II</td>
<td>Baarn II</td>
<td>Old store format of neighborhood grocery stores</td>
</tr>
<tr>
<td>DNAH</td>
<td>De Nieuwe Albert Heijn</td>
<td>Most recent store format of neighborhood grocery stores</td>
</tr>
<tr>
<td>DC</td>
<td>Distributiecentrum</td>
<td>Distribution center</td>
</tr>
<tr>
<td>LDC</td>
<td>Landelijk Distributie Centrum</td>
<td>National distribution center for the slow moving non-perishable products</td>
</tr>
<tr>
<td>LVC</td>
<td>Landelijk Vers Centrum</td>
<td>National distribution center for the slow moving perishable products</td>
</tr>
<tr>
<td>RDC</td>
<td>Regionaal Distributie Centrum</td>
<td>Regional distribution center for the fast moving products</td>
</tr>
<tr>
<td>WVA</td>
<td>Winkelvriendelijk Aanleveren</td>
<td>Concept for the compilation of a carrier that reduces the handling operations in the store</td>
</tr>
<tr>
<td>SKU</td>
<td>Stock Keeping Unit</td>
<td>An item of stock that is completely specified as to function, style, size, color, and, usually, location (Silver, Pyke, &amp; Peterson, 1998)</td>
</tr>
<tr>
<td>WMS</td>
<td>Warehouse Management System</td>
<td>System that controls the movement and storage of products within a warehouse</td>
</tr>
<tr>
<td>Replenishment zone</td>
<td>Vulpad</td>
<td>Specific area in store, often equal to an aisle in a specific store</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

In this chapter, firstly some general information about Albert Heijn is given, and subsequently the research background, the research questions and the scope of the research are described.

1.1 COMPANY DESCRIPTION

Albert Heijn B.V. is a grocery retailer in the Netherlands, and part of Koninklijke Ahold N.V., the holding organization. The market share of Albert Heijn was 33.7% in 2012 (ah.nl, onderzoeksbureau Nielsen), which makes Albert Heijn the leading food retailer in the Netherlands. Albert Heijn has a brand awareness of 99% in the Netherlands (ah.nl, TNS NIPO onderzoek).

1.1.1. STORE FORMATS

Albert Heijn operates four main store formats: the neighborhood grocery store, the larger Albert Heijn XL supermarket, the Albert Heijn to go convenience store, and the AH grocery webstore albert.nl (ah.nl). The neighborhood grocery store operates in two different store formats: ‘Baarn II’, and ‘DNAH’, which is the most recent store format. In Table 3 an overview is given about the characteristics of the three main store formats for the daily groceries.

Table 3: Overview of the characteristics of the main store formats for the daily groceries

<table>
<thead>
<tr>
<th>Store format</th>
<th>Number of stores</th>
<th>Average floor surface (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AH Baarn II</td>
<td>442</td>
<td>1.200</td>
</tr>
<tr>
<td>AH DNAH</td>
<td>340</td>
<td>1.559</td>
</tr>
<tr>
<td>AH XL</td>
<td>22</td>
<td>24.100</td>
</tr>
<tr>
<td>All stores</td>
<td>804</td>
<td>1.309</td>
</tr>
</tbody>
</table>

1.1.2. SUPPLY CHAIN STRUCTURE

To give more insight in the supply chain structure of Albert Heijn, firstly the processes in the distribution centers are described in more detail and secondly the processes at the stores.

1.1.2.1. Distribution centers

Albert Heijn has several distribution centers (DCs) located in the Netherlands. In Geldermalsen Albert Heijn has the Landelijk Distributie Centrum (LDC). The non-perishable slow movers are stored and picked at this location. In the Landelijk Vers Centrum (LVC), Albert Heijn stores and picks all the perishable slow movers. Furthermore, Albert Heijn has four Regionale Distributie Centrums (RDCs), and these RDCs are located in Zaandam, Pijnacker, Zwolle and Tilburg. At these locations, the fast moving non-perishable and perishable goods are stored and picked.
In Figure 3 the good flows between the distribution centers are shown.

Furthermore, Albert Heijn has a few external DCs: one category distribution center for cheese in Zeewolde, a non-food distribution center in Oosterhout; a distribution center for flowers in Bleiswijk; and a distribution center for frozen foods in Oosterhout.

Cross docking takes place at the RDC for the goods from the LDC, the LVC, and some product categories that are picked externally. Every RDC supplies around 210 retail stores. The product categories of frozen foods, bakery products, and newspapers and magazines are delivered directly to the stores.

1.1.2.2. Stores
The stores receive several flows of products a few times a week, or daily in separate deliveries. For the perishable and non-perishable deliveries, it is possible that these are delivered more than once per day.
The products arrive to the store on carriers. In this research, the carriers that are studied are roll cages. These roll cages have a fixed volume and a weight limit. The case packs are directly loaded on the carrier when picked in the DC. The products on the carriers first need to be sorted per replenishment zone. A replenishment zone is in general similar to the products from one aisle in a specific store, and these replenishment zones differ between stores. The products are reloaded on other carriers before the items can be stacked on the shelves. This is done to make the shelf stacking process more efficient. It prevents too much relocation of the carriers in the store when stacking the shelves. This way the store employees do not have to move too often between different aisles.

1.2. RESEARCH BACKGROUND

In the current situation, unnecessary handling operations are performed in the store, because the carriers with the replenishment orders from the distribution center need to be sorted in the backroom of the store. The products on the carriers are not grouped on the carrier to make the shelf stacking process efficient in the store. The products are reloaded onto other carriers, and sorted per replenishment zone, to perform the shelf stacking process in the store more efficiently.

The sorting and reloading activity in the backroom can be partially prevented by loading the carriers from the distribution center in such way that they can be replenished directly in the store, and can be stacked on the shelves efficiently. At Albert Heijn this is called ‘Winkelvriendelijk Aanleveren’ (‘WVA’), or ‘store friendly delivery’. ‘WVA’ can be seen as a concept for the compilation of a carrier that reduces the handling operations in the store by compiling the carriers differently within the constraint that every carrier is stacked properly, is full, is safe to unload, and is easy to move.

In the current situation, the distribution centers do not deliver ‘WVA’ to the stores for several reasons. These reasons are summarized in the cause and effect diagram in Figure 4.
Figure 4: Cause and effect diagram

- Shelf plan is designed by the commercial department
- Shelf plans differ between stores because of physical layout and other characteristics
- Replenishment zones are defined by store manager
- Replenishment zones are not defined as efficient as possible
- Replenishment zones differ a lot between stores
- Orders cannot be picked 'WVA' by current WMS
- No sorting process in DC before transportation
- Orders are not delivered 'WVA' at stores
- Additional sorting per replenishment zone has to be done in backroom store
- Additional handling cost in the store
- Backrooms are often relatively small, which makes sorting more difficult
- Sorting in backroom store is not executed as efficiently as possible

Order compilation by WMS

Sloting criteria based on characteristics of SKUs

Restrictions for order picking operations in DC

Order picking method

Allocation of SKUs to DC based on fast/slow movers
Based on the cause and effect diagram we conclude that there are several reasons why orders are not delivered ‘WVA’ to the stores. On the one hand, the fact that all stores differ makes it impossible in the current situation to collect the orders ‘WVA’ in the DC. On the other hand, there are several restrictions in the distribution center operations and design which make it difficult to collect the orders ‘WVA’.

Albert Heijn would like to gain more insight in the factors that influence the compilation of a carrier, and how they could improve the compilation of the carriers in the distribution center. They also want to know how this influences the supply chain.

1.3. **RESEARCH QUESTIONS**
The main research question can be defined as:

**Which factors influence the carrier compilation process in the distribution center, and how can the carrier compilation process be adjusted to take the handling operations in the store into account when compiling carriers?**

To answer this research question several sub questions are defined.

1. What should a qualitatively good ‘WVA’ carrier look like?
2. Which factors influence the carrier compilation process in the distribution center?
3. How should the store handling operations be included in the carrier compilation process in the distribution center?
4. Which solution directions are available to improve the compilation of a carrier, and how do these solutions perform?

1.4. **SCOPE**
In this section the scope of the research is described, as well as the limitations related to these scoping choices.

In this research, we assumed that the products on the carriers are no longer sorted per replenishment zone in the backroom of the store. This means that the carriers are brought directly into the store after the delivery. Therefore, the shelf stacking process will change a little, because the products on the carrier are not necessarily for the same replenishment zone. It is possible that a carrier contains products for other replenishment zones. So this can result in the situation that the store employee has to move the carrier within the store several times, and also has to walk more when the products on the carrier are not loaded perfectly sorted.

In this research, one store is used as a standard store. This is done to identify which of the other factors, other than the differences between the stores, influence the quality of the carrier compilation. The planogram and assortment of this standard store is used as the input for the research. Also, the data of the deliveries to this store is used as input of the research. The choice to use only one store as input for the research leads to several limitations. Firstly, the batching of orders between different stores in the distribution center cannot be taken into account. Therefore, the advantages of batching orders to reduce the travel distance in the DC cannot be determined. Furthermore, it is difficult to design a new slotting for the DC, because the data of only one store is
known to use as input for this slotting. For the same reason, it is also not possible to determine whether congestion occurs in the DC during the order picking.

In this research, the regular flow of non-perishable products picked at the RDC and LDC is studied. In this research, one RDC and the LDC will be studied, because all the SKUs that are picked at Albert Heijn and delivered to a store come from one of these locations.

We assume that the creation of the replenishment orders is independent of the carrier compilation. The current store orders are used as a testbed to improve the compilation of the carrier. This means that the current store orders stay the same, and there will be no changes in the distribution of orders over the week. The same products need to be picked, transported, and stacked on the shelves for every replenishment.

In this research, the number of carriers used for a delivery is not adjusted. This assumption is made because the assignment of products to carriers for a delivery is improved, and the goal is not to save costs by reducing the number of carriers used for a delivery.

In this research, the operations at the distribution center and its design are studied. It is not tested whether the allocation of SKUs to a distribution center based on slow/fast moving is done properly, so it is assumed that this is done well. The choice is made not to change the allocation of SKUs, because this negatively influences order picking efficiency in both DCs, and it leads to an increase in the number of carriers that have to be transported between the LDC and RDC.

We assume that the current physical size of the DCs cannot be adjusted, only the size and the number of the pick zones in the DCs.

The restrictions concerning safety, and stackability may not be overruled, when the compilation of the carriers is changed. This means that carriers cannot be top heavy. The meaning of top heavy is that the density of the products picked on a carrier may not increase too much, because then the top becomes heavier than the bottom of the carrier, which places the gravity point of the carrier higher, which makes it more unstable. Furthermore, the weight and volume limit of a carrier cannot be exceeded, and products should be stacked in such a way that they do not get damaged.

1.5. Outline Report

In this section, the outline of the report is summarized. In this first chapter a company description, the research background, the research questions, and the scope of the research are given. Subsequently, a short literature review about the grocery retail supply chain, and the handling operations in this supply chain is given. In Chapter 3, the deliveries to the stores, the processes in the DC and store, and the design of the DC are analyzed. Based on the analyses, a conceptual model is developed in Chapter 4. This conceptual model describes the anticipation developed. This chapter also describes, based on the conceptual model, an operational model about the assignment of SKUs to carriers, and a tactical model about the slotting of SKUs in the DC. In Chapter 5, the heuristic to solve the operational model is described and a simulation model is used to test this heuristic. In Chapter 6, the results of the simulation model are described. Finally, in Chapter 7 the conclusions, recommendations and future research directions are given.
2. LITERATURE REVIEW

In this chapter a literature review is given, to give more insight about the characteristics of the grocery retail supply chain and its handling operations.

2.1. GROCERY RETAIL SUPPLY CHAIN

For grocery retailers, an efficient supply chain is very important to be profitable. The profit margins are low, on average 2% (Hoofdbedrijfschap Detailhandel, 2011), so excellent service and performance at the lowest cost are needed to be successful in the market (De Koster & Neuteboom, 2000). Grocery retail concerns relatively low-valued articles, which has as a result that the costs of transportation and handling are much higher than the cost of inventory (Van der Vlist & Broekmeulen, 2006).

When the cost structure of the retail supply chain is considered, it can be seen that handing costs are a substantial part of the total supply chain cost. In Figure 5 (Broekmeulen et al., 2004) the operational logistical cost in the retail supply chain for non-perishables are shown. It can be seen that the majority of the costs are handling costs, and the largest part of the handling costs are allocated to the store.

![Figure 5: Operational logistical cost in the retail supply chain for non-perishables (Broekmeulen et al., 2004)](image)

2.2. HANDLING OPERATIONS IN THE RETAIL SUPPLY CHAIN

In the retail supply chain, handling operations occur in the distribution center and in the store. The following sections describe the handling operations at these two locations in the supply chain for Albert Heijn.

2.2.1. DISTRIBUTION CENTER HANDLING OPERATIONS

In Figure 6 the typical functional areas and flows within distribution centers are described (Tompkins et al., 2003).
Order picking, the process of retrieving products from storage (or buffer areas) in response to a specific customer request, is the most labor-intensive operation in distribution centers with manual systems, and a very capital-intensive operation in distribution centers with automated systems (Tompkins et al., 2003). Multiple order picking methods are often used in distribution centers, because of the different characteristics of the SKUs. In Figure 7 a classification of the order picking methods is made (De Koster, 2008).

### Figure 6: Typical functional areas and flows within distribution centers (Tompkins et al., 2003)

![Diagram of typical functional areas and flows in distribution centers](image)

**Figure 6: Typical functional areas and flows within distribution centers (Tompkins et al., 2003)**

Order picking, the process of retrieving products from storage (or buffer areas) in response to a specific customer request, is the most labor-intensive operation in distribution centers with manual systems, and a very capital-intensive operation in distribution centers with automated systems (Tompkins et al., 2003). Multiple order picking methods are often used in distribution centers, because of the different characteristics of the SKUs. In Figure 7 a classification of the order picking methods is made (De Koster, 2008).

### 2.2.1.1. Retail distribution center

A retail distribution center typically supplies products to retail stores. The supply of retail stores involves high-volume distribution; the customer orders will typically be large and may be similar. In general, the most time of an order-picker is spent on travelling, and it is the largest component of
labor. Bartholdi & Hackman (2011) state that travel time is waste, because it costs labor hours, but does not add value. Therefore, travelling must be reduced. In contrary to a ‘typical’ distribution center, in a retail distribution center each order-picker is likely to make many picks per unit of distance travelled. All order-pickers are also likely to follow a common path, such as along an aisle or flow rack (Bartholdi & Hackman, 2011). So this means that the distribution of the order picker’s time is different, and travel time becomes less important. The challenge in such order-picking is to keep the work flowing smoothly by eliminating bottlenecks (Bartholdi & Hackman, 2011).

In retail distribution centers in the Netherlands, mainly picker-to-parts order picking systems are used, and this is also the case at Albert Heijn. So this type of order picking system is explained in more detail in the following section.

2.2.1.2. Picker-to-parts order picking systems

In picker-to-parts systems, the order pickers walk or drive along the aisles to pick items (De Koster, 2008). There are two types of picker-to-parts systems: low-level picking, and high-level picking. In low-level order picking systems, items are picked from picking locations (e.g. racks, gravity flow racks and bins) while travelling along the aisles. High-level order picking systems, also called man-on-board order picking systems, employ high storage racks in which picking locations are visited by pickers on board an order-picking truck (Dallari et al., 2008).

There are several organizational variants of picker-to-parts systems. Picking can be done by article (batch picking) or by order (discrete picking or single-order-picking). In the case of batch picking, multiple customer orders (the batch) are picked simultaneously by an order picker. Many in-between variants exist, such as picking multiple orders followed by immediate sorting (on the pick cart) by the order picker (sort-while-pick), or the sorting takes place after the pick process has finished (pick-and-sort) (De Koster et al., 2007). To apply sort-while-pick, the order-picking vehicle must be equipped with separate containers for individual orders (Van den Berg & Zijm, 1999). Another variant is zoning, which means that a logical storage area is split into multiple parts, each with different order pickers. Depending on the picking strategy, zoning may be further classified into two types: progressive zoning and synchronized zoning, depending on whether orders picked in a zone are passed to other zones for completion, or are picked in parallel (De Koster et al., 2007). Wave picking is a popular strategy if batching and zoning are both applied. All the order pickers start picking in their respective zones at the same time. Only after all pickers have completed their tour, the next wave starts (Van den Berg & Zijm, 1999).

2.2.2. STORE HANDLING OPERATIONS

Not much research is done in the field of store handling operations. Only some recent research can be found about the shelf stacking process. The shelf-stacking process starts after the incoming products are moved into the store and are taken to the shelves. The focus is on products that are replenished in pre-packed form, but presented to the final consumer in individual units.

In 2009 a study about the shelf stacking process was published by Van Zelst et al. Firstly a conceptual model for the shelf stacking activities in the retail store is made, and after this the model is validated using data collected at two retail companies in the grocery sector. A motion and time study is used to collect the data. For each SKU the time needed by a store clerk for stacking the items on the shelf
is measured for a delivery (i.e. an order line in the store). The total stacking time (TST) for an order line is separated into several sub activities. This way the elements are as short as can be accurately timed and constant elements can be separated from the variable elements.

A regression model was used to reveal the impact of the most important drivers for shelf stacking efficiency, measured by the TST per consumer unit. The results show that the presented model for the stacking time was, unlike reported in the literature so far, non-linear in consumer units. It can be concluded from the model that the case pack size, the number of case packs stacked simultaneously, the filling regime, and the working pace of the employees are the most important drivers for stacking efficiency (Van Zelst et al., 2009).

Another research done by Curșeu et al. (2009) describes also the shelf stacking process in grocery retail stores. The model is based on the same data set, but the difference is that Van Zelst et al. (2009) focus on the consumer unit level, and Curșeu et al. (2009) focus on the order line level in determining the total stacking time. The total stacking time per order line (TST) is divided into seven subtasks, and after this, the key variables that can influence the execution time of each subtask are identified. This research concentrates on order line-related (number of case packs (CP) and number of consumer units (CU) per order line) and product-related characteristics (product category) as the key drivers of time variation of the shelf-stacking process. Curșeu et al. (2009) also develop a model, depending only on the number of case packs and the number of consumer units that estimates the total stacking time per order line.
3. **Analysis**

In this chapter the current situation at Albert Heijn is described. Firstly, the deliveries to the stores are analyzed in more detail. After this, the handling operations in the store and in the distribution center are described. Finally, the rationales behind the slotting of the distribution center are studied, and a regression analysis is used to test whether the criteria used for the slotting can be observed.

3.1. **Analysis of deliveries to the store**

Firstly, the grouping of products in the assortment is described; after that, the transportation methods of the products; and finally some numbers are given about the deliveries collected in the DC.

3.1.1. **Assortment**

The biggest part of the assortment is ordered at Albert Heijn, and is picked at the national or regional distribution centers. Only a few products arrive via external distributors. This is the case for non-food products, flowers, frozen foods, newspapers & magazines, bread, and cheese.

The biggest part of the assortment cannot be ordered in consumer units, this is only the case for some products at the LDC. In the current situation, mainly the fast movers are allocated to the RDCs, and the slow movers are allocated to the LDC. The majority of the products are ordered per case pack, or a fixed number of products have to be ordered, and these products are placed in a crate.

The order sizes are determined in such a way that products that are ordered can be replenished directly on the shelves, and almost nothing has to be kept in the backroom. In addition, the shelf life and the demand of a product are used to determine the right order amount to prevent too much loss due to exceeding the best before date.

The assortment is grouped on several levels. Firstly, products are grouped in assortment groups (used for the Baarn II store format), or in modules (used for the DNAH store format). The grouping of SKUs in assortment groups or modules is based on the similarity of products. The commercial department uses these assortment groups and modules to make the planogram. Every assortment group or module gets some predetermined amount of space in the store layout. It should be taken into account that the assortment groups and modules do not contain the same SKUs in each store, and are grouped differently. In general, several assortment group or modules are placed in a store aisle. Secondly, products are also grouped in family groups. A family group is a collection of assortment groups. The grouping of the family groups is done by the RDC, based on the characteristics of the assortment groups. For example, all the beverages are placed together in the RDC, to deliver these together on a carrier to facilitate this for the store. Nevertheless, this is not beneficial for all the assortment groups, because many assortment groups within family groups are not located near each other in the store. Family grouping is only used in the RDC. Finally, products are grouped in perishable and non-perishable products, based on whether products need to be preserved cooled or not. The perishable and non-perishable products are delivered separately to the stores.

In this research, the expression ‘category’ is used to refer to the grouping of modules in the same store aisle. In this research, this is based on the store plan of store 1204, because it represents a
medium store of store format DNAH (the newest store format), and has an average sales/m². Categories differ between stores, because store layouts differ. Therefore, categories are store specific. The concept ‘category’ is introduced in this research to indicate which modules can be merged to be handled together in the store without making the handling operations in the store less efficient.

3.1.2. Carriers
The store orders are transported on roll cages, roolly’s, or dolly’s. Rolly’s and dolly’s differ because of their size, and both are used to load crates on it. For the non-perishable goods, mainly roll cages are used, and the case packs are in general placed directly on them. Every carrier has a volume and weight limit to ensure safety for the employees. The volume limit of a carrier is 0.85 m³, and the weight limit is 400 kilograms. Therefore, this means that per store delivery, generally multiple carriers are delivered to the store.

Furthermore, the carriers should be stable and not top heavy. This means that the density of the products picked on a carrier may not increase too much, because then the top becomes heavier than the bottom of the carrier, which places the gravity point of the carrier higher, which makes it more unstable.

3.1.3. Characteristics of deliveries
In this section, the deliveries are studied in more detail, and numbers are given about the characteristics of the deliveries.

3.1.3.1. Number of carriers used
Based on the store data from week 50 2012 to week 16 2013 of store 1204: per delivery, on average 1.18 carriers are collected from a pick zone in the LDC, and 2.76 carriers are collected from a pick zone in the RDC. The probability that more than 1 carrier is collected from a pick zone in the LDC is 61.79%, and 71.9% in the RDC. The chance that more than 2 carriers are collected from a pick zone in the LDC is 8.85%, and 59.87% in the RDC. This shows that unless many more SKUs are placed in the LDC, the chance is very small that more than two carriers have to be collected from a pick zone for a delivery. In the RDC this chance is much higher.
Table 4 shows how many SKUs are placed within a category, and to which DC these SKUs are assigned.

Table 4: Characteristics of categories

<table>
<thead>
<tr>
<th>Category</th>
<th># of SKUs in LDC</th>
<th># of SKUs in RDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>635</td>
<td>51</td>
</tr>
<tr>
<td>2</td>
<td>928</td>
<td>134</td>
</tr>
<tr>
<td>3</td>
<td>1096</td>
<td>127</td>
</tr>
<tr>
<td>4</td>
<td>434</td>
<td>136</td>
</tr>
<tr>
<td>5</td>
<td>824</td>
<td>247</td>
</tr>
<tr>
<td>6</td>
<td>584</td>
<td>268</td>
</tr>
<tr>
<td>7</td>
<td>125</td>
<td>443</td>
</tr>
<tr>
<td>8</td>
<td>96</td>
<td>109</td>
</tr>
<tr>
<td>9</td>
<td>112</td>
<td>186</td>
</tr>
<tr>
<td>10</td>
<td>423</td>
<td>70</td>
</tr>
<tr>
<td>11</td>
<td>257</td>
<td>58</td>
</tr>
<tr>
<td>12</td>
<td>185</td>
<td>33</td>
</tr>
<tr>
<td>13</td>
<td>1521</td>
<td>53</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>15</td>
<td>114</td>
<td>13</td>
</tr>
<tr>
<td>16</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>21</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7363</strong></td>
<td><strong>1989</strong></td>
</tr>
</tbody>
</table>

Because there are more SKUs assigned to the LDC than to the RDC, and fewer carriers are collected from the LDC than from the RDC, it can be concluded that in general the slow movers are assigned to the LDC, and the fast movers to the RDC.

The orders of a week without public holidays are studied in more detail to gain more insight into the characteristics of the deliveries to the store. It is chosen to study a week, because then the week pattern in the sales can be observed. In Table 5 and Table 6, the results are shown.
Table 5: Analysis of orders of store 1204 in one week

<table>
<thead>
<tr>
<th>Day</th>
<th># carriers</th>
<th>Lower bound based on volume (in # carriers)</th>
<th>Lower bound based on weight (in # carriers)</th>
<th># categories</th>
<th># modules</th>
<th># SKUs</th>
<th># case packs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>23</td>
<td>20</td>
<td>13</td>
<td>16</td>
<td>50</td>
<td>440</td>
<td>598</td>
</tr>
<tr>
<td>Tuesday</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>15</td>
<td>48</td>
<td>226</td>
<td>250</td>
</tr>
<tr>
<td>Wednesday</td>
<td>14</td>
<td>12</td>
<td>8</td>
<td>17</td>
<td>49</td>
<td>182</td>
<td>310</td>
</tr>
<tr>
<td>Thursday</td>
<td>16</td>
<td>14</td>
<td>9</td>
<td>16</td>
<td>44</td>
<td>202</td>
<td>297</td>
</tr>
<tr>
<td>Friday morning</td>
<td>19</td>
<td>16</td>
<td>11</td>
<td>16</td>
<td>50</td>
<td>332</td>
<td>435</td>
</tr>
<tr>
<td>Friday afternoon</td>
<td>24</td>
<td>20</td>
<td>14</td>
<td>15</td>
<td>51</td>
<td>401</td>
<td>533</td>
</tr>
<tr>
<td>Saturday morning</td>
<td>32*</td>
<td>22</td>
<td>17</td>
<td>16</td>
<td>52</td>
<td>414</td>
<td>572</td>
</tr>
<tr>
<td>Saturday afternoon</td>
<td>22</td>
<td>19</td>
<td>15</td>
<td>17</td>
<td>55</td>
<td>583</td>
<td>710</td>
</tr>
<tr>
<td>Week average</td>
<td>20.25</td>
<td>16.63</td>
<td>11.88</td>
<td>16</td>
<td>49.88</td>
<td>347.5</td>
<td>463.125</td>
</tr>
</tbody>
</table>

*= Includes 12 smaller carriers with pre-packed multipacks soda (display dolly’s), in the remainder of the research these display dolly’s are excluded from the analysis

Table 6: Analysis of carriers of store 1204

<table>
<thead>
<tr>
<th>Averages per carrier</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average # categories per carrier</td>
<td>2.6</td>
</tr>
<tr>
<td>Average # modules per carrier</td>
<td>4.3</td>
</tr>
<tr>
<td>Average # SKUs per carrier</td>
<td>17.16</td>
</tr>
<tr>
<td>Average # case packs per carrier</td>
<td>22.87</td>
</tr>
</tbody>
</table>

3.1.3.2. Grouping of products on carrier

When the SKUs are studied, we conclude that for the majority of the SKUs (94%) only one or two case packs are ordered per replenishment. On average only 1.014 SKUs are placed on two or more carriers, so this means that similar SKUs are generally placed grouped together on the carriers.

On average 4.3 modules are placed on a carrier, and a module is placed on 1.44 different carriers. When looking at the average weight and volume of these modules in an order, it becomes clear that the average weight of a module is 67.9 kilograms and the average volume is 0.202 m$^3$. The weight has a standard deviation of 99.4 kilograms, and the volume has a standard deviation of 0.260 m$^3$. This indicates that in general a module fits easily on a carrier. When the sequence that products are loaded on the carrier is studied, it becomes clear that SKUs from the same module are not grouped together on the carrier.

At the category level, 2.6 different categories are placed on one carrier. For an order, a category is on average placed on 2.94 carriers. When looking at the weight and the volume of the categories in
an order, then on average a category weighs 232 kilograms, and has a volume of 0.648 m\(^3\). The weight has a standard deviation of 461 kilograms, and the volume has a standard deviation of 0.718 m\(^3\). This means that based on the weight there is a probability of 35.94% that more than one carrier is needed to load the assortment group on, and based on the volume this probability is equal to 38.97%. For these calculations the maximum weight and volume of a carrier is taken into account.

When more than one category is placed on a carrier, the carrier needs to be moved to another location in the store to perform the shelf stacking process most efficiently. The reason for this is that categories are based on the aisles in the store where the products are located. It is important that categories are also grouped together on the carrier, else the carrier has to be moved multiple times through the store when products from the same category are placed on the bottom and at top of the carrier.

3.1.4. Conclusion Analysis of Deliveries
The number of carriers collected within a pick zone in the LDC is on average equal to one carrier, and in the RDC this number is equal to three. This indicates that in the RDC there are possibilities to improve the assignment of products to the carriers. In the LDC this is more difficult because the products are placed on less carriers, therefore the research is focused on the RDC.

The analysis of the SKUs showed that only 1.014 SKUs are placed on two or more carriers, and in general only 1 or 2 case packs are ordered per delivery. This indicates that it is possible to assign an order line to a carrier instead of only single case packs.

The detailed analysis of the deliveries in the RDC showed that in the current situation, modules and categories are not grouped together on the same carrier. Modules and categories are often placed on multiple carriers. This means that more aisles have to be visited in the store to replenish the products. Furthermore it was found that the average volume or weight of a module is too small to load a full carrier. When categories are studied, this is more likely to be possible. It is desirable to have as few categories as possible on the carrier, because then the replenishment in the store can take place more efficiently.

3.2. Analysis of Operations in Store and Distribution Center
The handling operations in the store, and in the distribution center, are analyzed to determine how the assignment of products to carriers influences these processes. Firstly, the store operations are described, and then the distribution center operations.

3.2.1. Store Operations
Two important operations related to the assignment of products on a carrier take place in the store. Firstly, the current sorting operation in the backroom of the store is described, and subsequently the shelf stacking process in the store.

3.2.1.1. Sorting in the backroom of the store
The order is delivered to the store on several carriers, and is placed in the backroom of the store. In the current situation, the products on the carriers first have to be sorted per replenishment zone because of the fact that the carriers are not compiled the way that the shelf stacking process can take place efficiently in the store. In this research, the sorting process in the backroom of the store is
removed. The carriers are brought directly to the store for the replenishment process. So it is studied whether the assignment of the products to the carriers can be improved.

3.2.1.2. Shelf stacking process
The shelf stacking process in the store is done by moving the carriers into the store near the aisle where the upper products on the carrier should be replenished. The store employee unloads the carrier and stacks the products, which are located in that aisle, on the shelves. When there are no more products of the same aisle on top of the carrier, the carrier is moved to another aisle to continue the shelf stacking process there. The store employee returns the carrier to the backroom and disposes the waste, when he is finished.

In this research, only the assignment of the products to the carriers is studied, so the orders of a store stay the same. This means that the shelf stacking time does not change, only the time needed to travel between the aisles in the store.

3.2.2. Distribution center operations
The assignment of products to a carrier is determined in the distribution center. Therefore, the processes that influence this, and are executed in the distribution center, are described in this section.

3.2.2.1. Order processing
The replenishment department determines the store orders, and these are loaded in the WMS. The WMS splits and sorts the store order based on the zones where the products have to be picked, and the sequence the pick locations are visited. When the order picking list for a store is too long, and not all the products fit on the carrier, based on the weight and/or volume limit, the WMS splits the order, and makes separate order picking lists. The slotting of the pick zones is done in such way that when the pick locations are visited in the fixed sequence, the carriers are loaded safely and products are not damaged.

3.2.2.2. Order picking method
The hall with the products is called the picking area. The picking area is divided into several zones, and orders are picked per zone. At the RDC, the non-perishable items are picked per case pack, and humans do this order picking. Order pickers travel with a forklift with 5 carriers placed on it through the DC. The pick orders are sorted by the WMS in such way that the pick locations could be visited in the right sequence. Order pickers are routed through the DC by making use of the S-shape method or also called the traversal method. Only one-way entry of an aisle is allowed, and when aisles do not have picks, they are not visited. Full pallet pick is also performed at the RDC.

In the LDC, other order picking methods are also used. Because of the fact that the LDC contains the slow moving items, unit picking is also performed at the LDC, next to case picking. A part of the unit picking is done with the carrousel, an automated order picking method.

3.2.2.3. Order release process
When the order of a store is released, several pick orders are created for this order. Because of the fixed travel route through the DC, the SKUs that have to be picked are sorted in the sequence the pick locations are visited. The fact that a carrier has a weight and volume limit means that, for one
store in general, more than one carrier has to be collected within a pick zone in the RDC. In the LDC this number is on average equal to one carrier per pick zone. Based on the sequence the pick locations are visited (no locations can be skipped), and the weight and volume limit the pick orders of the carriers are compiled.

### 3.2.2.3.1. Batching

When the store orders are released, and translated in pick orders, they are placed in a buffer. Every store order, and therefore also every pick order, has a LTS (= latest time shipping) time, which defines in which time frame an order should be picked. All the pick orders in this buffer that have a LTS within the same time frame of half an hour can be released to the order pickers. An order picker can pick five carriers at a time, so the pick orders have to be batched. For the RDC this is done based on the minimum number of pick locations to be visited. For the LDC this is done based on the minimum number of aisles to be visited.

Every 30 seconds the batching is repeated for the products in the buffer. One reason for this is that the new orders that are released can be combined with the orders already waiting in the queue to make more efficient batching combinations. The second reason is that not always all five carriers are collected by the order picker, so a few carriers need to be assigned again to an order picker.

It is important that the store order release is not done too early, because the docking area has a limited capacity. Only a limited number of carriers can be placed there before they are picked up for transportation. When the store order release is done too late, the batching between the orders is not performed most efficiently.

### 3.2.2.3.2. Rest picking

A carrier is placed in the rest pick zone, when the volume of the last pick order of a pick zone is smaller than 55%. This means that the last carriers of every zone are merged together for every store, to reduce the number of carriers needed to transport the store order. These rest picks do not have to be collected strictly in one pick zone. The batching of these rest picks is done the same way as for the ‘normal’ carriers. The fact that on one carrier products from multiple pick zones are collected means that the quality of the stacking of products onto each other is not secured by the routing through the DC anymore.

### 3.2.2.4. Order accumulation and sorting

During the batch picking the orders are sorted while picking, because the order picker places only products for the same store on a carrier. So the carriers from the order picking operation are directly placed on the docking area, and do not need additional sorting in the DC. On the docking area they are grouped together per store.

### 3.2.3. Conclusion of Operations in the Store and Distribution Center

Quit splitting in the back room of the store leads to sorting in the store while stacking. This means that multiple aisles are visited in the store in between the shelf stacking process. To perform the replenishment process more efficiently, the assignment of products to the carriers should be adjusted. The actual shelf stacking process in the store is not influenced by the assignment of products to carriers, only the travel time between the aisles in the store.
In the distribution center pick orders are compiled by following a simple heuristic. Based on the route the order pickers travel through the DC, every pick location that contains a product for the delivery is visited. This has as a result that the pick frequency within an aisle is quite high. The disadvantage is that there are no smart combinations made when looking at weight and volume of the SKUs. When it is possible to skip a location in the compilation of the pick orders, there will be more freedom in the sequence products can be loaded on a carrier.

The fact that different pick orders from multiple stores are batched based on the same aisles that are visited (LDC) or based on the same pick locations that are visited (RDC) causes the overall travel distance to be minimized, because less distance has to be travelled compared to collecting orders per store separately. The batching strategy causes the distance travelled in the DC to be minimized.

The existence of multiple pick zones causes multiple half-full carriers at the end of a pick zone. To reduce the number of carriers rest picking is used. Rest picking can be seen as an undesirable process, because it picks products in different pick zones, and these products are placed on the same carrier. This means that the quality of the stacking of products onto each other is not secured by the routing through the DC, and the grouping of the categories on the carrier is also not based on the routing of the DC anymore.

3.3. **ANALYSIS OF DISTRIBUTION CENTER DESIGN**

In this chapter the factors that influence the location a SKU is placed in the DC is studied. Firstly, the reasons behind the current slotting of the RDC and LDC are studied, and the criteria that are used when new SKUs are slotted. Furthermore, a regression analysis is conducted to determine whether these criteria can actually be observed in the current slotting.

3.3.1. **SLOTTING**

Firstly, the storage assignment of SKUs in the DCs of Albert Heijn will be discussed, then the slotting criteria of the RDC will be studied more extensively, and subsequently the rationales behind the slotting of the LDC.

3.3.1.1. **Storage assignment**

Every SKU has one fixed storage location in the distribution centers of Albert Heijn. In the RDC it is sometimes possible that a SKU has more than one storage location, when the demand of the SKU is high. This is done to prevent blockage. The extra pick location is always located next to the other pick location. On average only 120 of 2300 SKUs have an extra pick location in the RDC, so it is assumed that this is not enough to influence the sequencing of the products on the carrier significantly, when these extra pick locations are located in another aisle or pick zone in the DC.

3.3.1.2. **Slotting criteria of RDC**

In the RDC, slotting criteria are developed to ensure that products arrive undamaged, and are transported safely to the stores. Also, some actions are undertaken to group products from the same family group. The sequence in which products are slotted in the DC determines the sequence products are loaded on the carrier. This is because of the fact that the current method of compiling carrier for orders by the WMS is based on the sequence the products are slotted in the DC. When the slotting criteria are studied in detail, then the following slotting sequence can be observed.
The most important criteria is that products cannot be crushed, so non-crushables are placed in the beginning of the pick zone, and crushables at the end. Within these groups, the products with a high density are placed earlier than the products with a lower density to create stable carriers, and to prevent damaged products. Finally, the height is taken into account by grouping SKUs from the same height to make the SKUs easier to stack on the carrier. Finally, products are grouped per family group when this is possible. The priorities are shown graphically in Figure 8. Next to the slotting criteria the pick productivity is an important criteria that is taken into account when determining the slotting. It is important that the flow in the DC is stable, and no blockage occurs.

3.3.1.2.1. Prevention of damage

Products cannot arrive damaged at the store. To prevent this there is determined which SKUs are crushable. Products get a yes/no indication whether they are crushable or not. Crushable products are slotted at the end of pick zones, to prevent that other products with a high density are placed on top of them. To get some insight into the characteristics of the SKUs that are ordered at the store, the store order data of one week of store 1204 is studied. From that analysis it can be concluded that 39% of the products ordered are crushable. It can also be observed that in almost every delivery every category contains both crushable and non-crushable products.
From Figure 9 it can be concluded that mainly the density of non-crushable items is higher than the density of crushable items, and there are relatively few crushable items with a very high density, which makes it possible to place these crushable items on other crushable items. It can be concluded that the crushability of SKUs influences the slotting of SKUs significantly.

3.3.1.3. **Slotting LDC**
In the LDC, the location of a SKU is mainly based on its stackability class. There are 12 different stackability classes defined, and the SKUs are assigned to a class based on the packaging of the case pack, and SKU characteristics. The stackability class is used to prevent that products arrive damaged at the store. A few stackability classes determine in which pick zone a SKU is placed. The location of SKUs in the DC is also dependent on where a suitable type of slotting location is available in the DC. Furthermore, products are spread through the DC based on the pick frequency to prevent blockage.

3.3.2. **Regression analysis**
The regression analysis is performed to find out which characteristics of the SKUs, and which characteristics of the order picking process identified in the previous sections, influence the location of a SKU in the DC significantly. The regression analysis is conducted for both the RDC and LDC. Only the RDC is discussed in the report, because it can be concluded in the analysis earlier in this chapter that there exist only possibilities to improve the assignment of products to carriers in the RDC.

3.3.2.1. **Objective**
The objective of the regression analysis is to find out whether the characteristics of a SKU are significantly related to the location of a SKU in the distribution center (DC). The location of SKUs in the DC is related to the sequence products are loaded on a carrier, therefore it is useful to do this analysis. Based on the analyses of the orders, the order picking process and the slotting performed earlier, hypotheses are made and these are stated in the next paragraph.
3.3.2.2. Hypotheses

In this paragraph the hypotheses made about the factors that influence the location of a SKU in the DC are given.

- **Stackability of SKUs**
  In the RDC, the stackability is based on the crushability of a SKU. It is hypothesized that when a SKU is crushable, it is placed at the end of the pick zone in the DC. Therefore, the crushability will have a significant, positive effect on the location a SKU is placed in the DC. The reason for this is that crushable items cannot be placed at the bottom of a carrier, because this brings the risk of damaged products. Therefore, these products are placed preferably at the end of a pick zone to force that these products are almost always picked latest. Crushability is also an important criteria from the slotting criteria of the RDC.

- **Density of SKUs**
  The higher the density of a SKU, the closer a SKU is placed at the start of a pick zone in the RDC, so the density has a significant negative effect on the location where a SKU is placed in the RDC. When SKUs with higher density are placed at the beginning of the pick zone, it is less risky that products on a carrier will be crushed. This is because of the fact that products with a higher density will be placed on the bottom of the carriers when order picking. This is after crushability an important criteria from the slotting criteria in the RDC. Three categories are defined for the density (high, medium, and low), and whether the products are crushable or not, they are placed for these two groups from high to low density.

- **Height of SKU**
  The height of a SKU does not have a significant influence on where a product is placed in the DC. This criteria is used in the slotting criteria after crushability and density in the RDC, and products should be grouped based on corresponding height. Because of the fact that the other two criteria are prioritized before this requirement, and it is not based on decreasing or increasing height, but similar height, there is assumed that the height does not significantly influence the location in the DC.

- **Sum of demand SKU**
  The sum of the demand of a SKU does not significantly influence the location a product is placed in the DC. To prevent blockage in the DC, products with a high demand are spread over the locations in the DC. When the SKUs are spread evenly over the locations in the DC, this characteristic of a SKU should not be a predictor of the location of a SKU in the DC.

- **Category of SKU**
  The category of a product does not have a significant influence where in the DC a SKU is placed. The RDC applies family grouping, but this is overshadowed by the other slotting criteria, and therefore will not have a major influence. In addition, the fact that family groups do not match with categories will reinforce this effect.

- **Pick zone of SKU**
  The pick zone of a SKU has a significant influence on where a SKU is placed in the DC. The fact that pick zones are fixed zones within the DC, and these zones have consecutive pick locations causes this.
3.3.2.3. Dataset
The dataset used for the analysis is based on the WMS order pick list of store 1204 in Houten. The data of week 50 2012 until week 16 in 2013 is used. The dataset contains the non-perishable items that are picked at the regional distribution center (RDC) in Zaandam. It is known for every order line in the dataset, on which carrier the SKU is placed, and what the ordered quantity is. Furthermore, the details about the order picking trip are known. Another data set with the product characteristics of the SKU, and the pick zone and the pick location in the DC the SKU is slotted, is also available. The regression analysis is therefore conducted on the SKUs which are ordered from week 50 2012 until week 16 2013 in store 1204, in total 2523 SKUs. A few product groups are excluded from the analysis, because they are picked separately. This is the case for crates of beer from the crate picking installation, rollly’s with soda, and displays with promotion products. In addition, the SKUs with an unknown pick location or unknown product characteristics are deleted from the dataset. This finally results in 1989 SKUs.

3.3.2.4. Design
Next to the variables mentioned in the hypotheses, also some other variables are added to find out whether there are other characteristics of the SKUs that may have an influence on the location in the DC they are placed. The dependent variable in this regression analysis is the relative location a SKU is placed in the DC. The total number of SKUs that are in the assortment of store 1204, and are placed in the RDC, is determined. The SKUs in the DC are sorted based on their location from start to end, and a rank number is assigned to them. Because of the fact the total number of SKUs in the DC is known, this number can be scaled standardized for every SKU to the interval [0;1]. As a result, all the SKUs in the assortment of store 1204 are assigned to a relative location in the DC. The formula used to calculate this can be found in Equation 1.

\[
\frac{\text{Rank of SKU in DC}}{\text{Total number of SKUs in DC}} = \text{Relative location of SKU in DC}
\]  

(1)

Some variables that are included in the model are transformed before they could be added. This is the case for the variable that indicates the category of a SKU, and the variable that indicates the pick zone of a SKU. Dummy variables are added to make it possible to create a linear model.

The stepwise regression method in SPSS is used to obtain the results. The possible independent variables are added in order of relevance (strength of the correlation), and the independent variables which are not significant are left out of the model.

3.3.2.5. Results
It can be concluded that the pick zone has a major influence on where a SKU is placed in the distribution center. To focus solely on the characteristics of the SKU, the regression analyses are repeated for the pick zones of the RDC, which contain enough SKUs to conduct a reliable analysis.

For the values added to the model the variance inflation factor (VIF) is measured. This measure indicates how much the variance of an estimated regression coefficient is increased because of linearity. The VIF is for one variable (PZh06) higher than 10, so this variable is deleted from the analysis. When this is done, the entered variables all have a VIF < 10 which means they can be included in the model. The adjusted $R^2$ of the model indicates the proportion of the variance that is
explained by the model. The adjusted $R^2$ of this model is equal to 99.4%, which is very good. In Table 7, the variables that are added to model are shown.

Table 7: Result regression analysis of RDC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
<th>Added to model?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRUSH</td>
<td>Crushability of SKU (yes=1, no=0)</td>
<td>Yes</td>
</tr>
<tr>
<td>C_WEIGHT</td>
<td>Weight of SKU (in kg)</td>
<td>Yes</td>
</tr>
<tr>
<td>C_DENSITY</td>
<td>Density of SKU (in kg/ m$^3$)</td>
<td>Yes</td>
</tr>
<tr>
<td>C_HEIGHT</td>
<td>Height of SKU (in m)</td>
<td>Yes</td>
</tr>
<tr>
<td>C_VOLUME</td>
<td>Volume of SKU (in m$^3$)</td>
<td>Yes</td>
</tr>
<tr>
<td>CAT</td>
<td>Category of SKU</td>
<td>Partly</td>
</tr>
<tr>
<td>PZ</td>
<td>Pick zone of SKU</td>
<td>Partly</td>
</tr>
</tbody>
</table>

The variables with their coefficients are given in Table 8, and the regression model with these variables is used to determine the relative location of a SKU in the DC (independent variable).

Table 8: Regression model with variables and coefficients of the RDC

<table>
<thead>
<tr>
<th>Variables</th>
<th>Unstandardized coefficient B</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>.960</td>
</tr>
<tr>
<td>PZ_H01</td>
<td>-.803</td>
</tr>
<tr>
<td>PZ_H02</td>
<td>-.565</td>
</tr>
<tr>
<td>CAT7</td>
<td>-.076</td>
</tr>
<tr>
<td>PZ_H03</td>
<td>-.418</td>
</tr>
<tr>
<td>PZ_H05</td>
<td>-.210</td>
</tr>
<tr>
<td>PZ_H04</td>
<td>-.352</td>
</tr>
<tr>
<td>C_DENSITY</td>
<td>-4.354E-005</td>
</tr>
<tr>
<td>CAT8</td>
<td>-.049</td>
</tr>
<tr>
<td>CAT4</td>
<td>-.081</td>
</tr>
<tr>
<td>CRUSH</td>
<td>.035</td>
</tr>
<tr>
<td>CAT9</td>
<td>-.081</td>
</tr>
<tr>
<td>CAT11</td>
<td>-.086</td>
</tr>
<tr>
<td>C_WEIGHT</td>
<td>-.003</td>
</tr>
<tr>
<td>C_VOLUME</td>
<td>.713</td>
</tr>
<tr>
<td>CAT13</td>
<td>.013</td>
</tr>
<tr>
<td>CAT1</td>
<td>.021</td>
</tr>
<tr>
<td>C_HEIGHT</td>
<td>-.045</td>
</tr>
<tr>
<td>CAT6</td>
<td>-.025</td>
</tr>
<tr>
<td>CAT5</td>
<td>-.016</td>
</tr>
<tr>
<td>CAT10</td>
<td>-.022</td>
</tr>
<tr>
<td>CAT15</td>
<td>-.033</td>
</tr>
</tbody>
</table>
When the results of the regression analysis are studied in detail, it becomes clear that the dummy variables of the pick zone have a major influence on where a SKU is placed in the distribution center. The hypothesis that the pick zone of a SKU determines where a SKU can be placed in the DC can be confirmed for nearly all the pick zones. To focus solely on the characteristics of the SKU, the regression analysis is repeated for the pick zones that contain enough SKUs to conduct a reliable analysis. The results from these analyses can be found in Table 9 for the pick zones of the RDC. It is taken into account that the VIF of the variables has to be smaller than 10. In appendix B, the regression models for the pick zones are shown.

Table 9: Results regression analyses of pick zones in RDC

<table>
<thead>
<tr>
<th>RDC Pick Zone</th>
<th>N</th>
<th>Adjusted R²</th>
<th>CRUSH</th>
<th>C_WEIGHT</th>
<th>C_DENSITY</th>
<th>C_HEIGHT</th>
<th>C_VOLUME</th>
<th>SUM_SKUS_PICKED</th>
<th>CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>H01</td>
<td>465</td>
<td>91%</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Partly</td>
<td></td>
</tr>
<tr>
<td>H02</td>
<td>477</td>
<td>89.4%</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Partly</td>
<td></td>
</tr>
<tr>
<td>H03</td>
<td>55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H04</td>
<td>39</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H05</td>
<td>483</td>
<td>89%</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Partly</td>
<td></td>
</tr>
<tr>
<td>H06</td>
<td>361</td>
<td>93.8%</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Partly</td>
<td></td>
</tr>
<tr>
<td>H07</td>
<td>109</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The crushability of a SKU has a positive significant relation with the relative location of a SKU in the DC in all the pick zones, and therefore the hypothesis is not rejected. This means that when the SKU is crushable it is more likely to be placed at the end of the pick zone; and when a SKU is not crushable it is more likely that it is placed at the beginning of the pick zone.

The weight of a SKU has a negative significant relation with the relative location in the pick zone. When a product is heavy, the chance is higher that it is placed at the beginning of a pick zone; to prevent that it damages products that are placed under this SKU. This hypothesis is not tested, but this relationship is significant in the analysis for all the pick zones.

The density of a SKU has in two pick zones a negative, significant relation with the relative location in the pick zone. In the other two pick zones this relationship is not significant. Therefore the hypothesis that the density has a significant relationship with the location of a SKU in the DC can only be accepted for two pick zones, and has to be rejected for two pick zones.

The hypothesis that the height of a product does not influence the relative location of a SKU in a pick zone is rejected for three pick zones, because this variable is proven to be significant when determining the relative location of a SKU in the DC. For one pick zone the height of a SKU does not have a significant relationship with the location of a SKU in the pick zone.

The volume of a SKU has a positive relation with the location in the pick zone. The higher the volume of the SKU is, the further to the end the product is placed in a pick zone. This hypothesis is not tested, but this relationship is significant in the analysis for three pick zones, and not significant for one pick zone.

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The hypothesis that the number of SKUs picked is not significantly related to the location a SKU is placed in the DC can be accepted for all the pick zones.

When the regression model of the whole DC is studied, then it can be found that many categories influence the location a SKU is placed in the DC. But when this is studied on pick zone level, only a part of the categories are significantly related to the location a SKU is placed in the pick zone. The categories that are significant vary between the pick zones. Therefore, the hypothesis that it does not influence the location a SKU is placed in the DC is partially rejected.

The results of the regression analysis of the LDC can be found in appendix A.

3.3.3. CONCLUSION DISTRIBUTION CENTER DESIGN

The criteria that are used for the slotting of SKUs in the DC are developed to secure that products arrive undamaged to the store, and the carriers are safe to move. The criteria are based on the characteristics of a SKU. It is not possible to group all the SKUs of the same categories in the slotting of the DC because the products within the categories all have different characteristics.

The regression analysis showed that not all the slotting criteria of the RDC can be observed in the sequencing of the SKUs in the RDC. Only the weight and the crushability were significant in all the pick zones. Furthermore it can be concluded that, for only a few categories, a significant relationship exists between the category of the SKU and the location a SKU is placed in the DC.
4. DESIGN

In the analysis phase the characteristics of the deliveries, the operations in the store and the distribution center, and the slotting of the distribution centers are studied. Based on the insights gained a conceptual model is developed, which is described first. Subsequently the detailed model derived from the conceptual model is described.

4.1. CONCEPTUAL MODEL

In this chapter, a conceptual model is developed for the situation of Albert Heijn. As a framework the distributed decision making (DDM) system (Schneeweiss, 2003) is used. Firstly, the cost components in the system are described; subsequently the current situation is described; and finally an anticipated base model is given.

4.1.1. COST COMPONENTS

In the supply chain of Ahold, several cost components can be identified which are related to the assignment of products to a carrier. It is described which costs, per supply chain stage, are related to the compilation of a carrier.

4.1.1.1. Store

In this research, the costs that occur in the store are related to the process of stacking the shelves, and all the tasks that have to be executed to perform this process efficiently. When the carriers are delivered to the store, the carriers are brought to the store, and the products are stacked on the shelves. The assignment of the products to the carriers does not influence the actual shelf stacking time (excluding the walking time), but it does influence the time that is needed to switch between the different aisles, which can be seen as the time needed to move the carrier between aisles, or to walk between aisles. So the travel time within the store is influenced by the assignment of products to a carrier, and therefore this influences the cost.

4.1.1.2. Transport

The transportation costs are mainly dependent on the number of carriers that have to be transported to the stores. In this research, the number of carriers that have to be transported is not changed, only the compilation of the carriers is changed. Therefore, the transportation costs are not taken into account.

4.1.1.3. Distribution center

In the distribution center the costs are based on how efficient the products are picked for the store orders. The assignment of the products to the carriers only influences the travel time in the distribution center, because the time needed to pick the SKUs stays the same. The fixed time needed per carrier for starting picking and stopping picking also stays the same. It is not taken into account that pick orders are batched, so the travel distance of an individual pick order is taken into account.

4.1.2. CURRENT SITUATION

In the previous section, the cost components that are influenced by the sequence products are loaded on the carrier are given. The cost components that are influenced are:

- Travel time between the different aisles in the store to replenish products (store cost)
- Travel distance that has to be covered to visit all the pick locations in the distribution center to load the products on the carriers (distribution center cost)

It can be concluded that the assignment of the products to the carriers influences two stages in the supply chain, namely the operations in the distribution center, and the operations in the store. In the current situation, the distribution center compiles the carriers, and these are transported to the stores. The distribution center determines how the carriers are compiled. Therefore, the relationship between the distribution center and the store can be seen as a hierarchical relationship. The distributed decision making system shown in Figure 10 is used to describe this.

![Distributed decision making framework](image_url)

**Figure 10: Distributed decision making framework (Schneeweiss, 2003)**

In the system two decision making units (DMU) are present. This is on the top-level the distribution center, and on the base-level the store. There exists a hierarchical relationship between these DMUs, because the DC has the control over the process of compiling the carriers. The store cannot influence this, and in the current situation, this leads to cost in the store when the products of the same carrier have to be stacked in many different aisles.

In the model of Schneeweiss (2003), an anticipated base model is used. This model anticipates on the reaction of the base-level. In the current situation, the DC compiles the carriers against minimum order picking cost in the distribution center. When the distribution center anticipates on the store, the store handling costs are taken into account on an aggregate level when determining the compilation of the carriers. In the anticipated base model, the detailed aspects of the problem are not studied, only the important aspects for the problem are taken into account on an aggregate level.
4.1.2.1. Current conceptual model

In the current situation, the assignment of products to a carrier is determined in the distribution center. This is done by following a simple heuristic. The DC is divided in a number of fixed pick zones. The fixed slotting of the DC is used, and carriers travel in a fixed route (s-shape) through the DC. Based on the store order, every pick location that should be visited is visited. When a carrier is full, based on volume or weight, a new carrier is used, until the end of the pick zone is reached. Because of the heuristic used in the current situation, the slotting greatly determines the sequence products are loaded on a carrier. The regression analysis showed that the location where a SKU is placed in the DC is, for only a few categories, significantly related to the category of a SKU, and that it is not the most important characteristic of a SKU to determine where a SKU should be placed in the slotting.

For the store, the carriers are not compiled optimally, because they indicate that before they can start with the shelf stacking process the products first have to be sorted per category, because the products are not logically grouped on the carrier. When in the current situation the carriers are not sorted, and replenished directly in the store, this leads to an inefficient shelf stacking process, because there has to be switched frequently between different aisles.

4.1.3. Anticipated base model

The anticipated base model describes the characteristics of the base model that are taken into account in by the top level. Firstly the anticipation of the model is described, and secondly the instruction of the model.

4.1.3.1. Anticipation

From the top-level an anticipated base-level is developed in which the characteristics of the base-level are taken into account. The anticipation can be regarded as the base-level’s bottom-up influence on the top-level (Schneeweiss, 2003).

When studying the current situation, the assignment of products to the carriers should be adjusted, and this is done on the operational level. There is a fixed number of carriers available to visit a certain number of aisles to collect products. These carriers all have the same fixed capacity, and this capacity cannot be exceeded. Furthermore, all the products should be collected by a carrier. The assignment of products to a carrier determines how many aisles should be visited in the store when stacking the shelves, and it also influences the distance that has to be travelled in the DC, because pick locations have to be visited in a certain sequence. On a tactical level, the slotting of the DC can be adjusted. The decision variables of the system are the assignment of products to a carrier, and the location a SKU is slotted in the DC.

4.1.3.2. Instruction

There are several decisions that can be made on an operational level to change the sequence products are loaded on the carrier in the DC in the current situation. When an option or several options are chosen to be implemented, this is called the instruction. The top-level makes a decision, which influences the base-level. The options available for the current systems are given below:
- Allow that pick locations do not have to be visited in a fixed sequence based on the routing through the DC. Pick locations can be skipped for example, and visited later when this improves the sequencing of products on the carrier.
- Assign products to carriers in parallel instead of sequential. This means that there exists a choice to which carrier a product can be assigned, when there is capacity available on these carriers.

On the tactical level, the slotting of the DC can be adjusted. The slotting is in general a fixed factor, which only is adjusted incidentally. When this is possible, the categories can be grouped together in the DC, by taking into account the constraints how products should be stacked onto each other to create safe carriers. Then less distance has to be travelled when you want to place them grouped together on the carrier, meaning the shelf stacking process can be carried out more efficiently.

These options can be seen as an instruction, and lead to a different compilation of the carrier for the store.

4.2. Detailed model
A detailed model is developed based on the conceptual model described in the previous section. In the detailed model, the anticipation described in the conceptual model is further elaborated. This is done separately for the model on the operational level and tactical level. Furthermore, the decision variables, the constraints, and the objective function are given. After this, the solution method of the models is described.

4.2.1. Objective model
In the anticipated model, the main effects caused by the anticipation are taken into account, to give some insight in how the anticipation performs. The conceptual model described in the previous section indicates that the store handling should be taken into account when loading the products of a delivery on the carriers in the DC. The assignment of products on a carrier, and the sequence products are loaded on a carrier, influences the replenishment process in the store. The problem can be seen as a multi-criteria decision making problem, because two objectives have to be optimized, namely minimizing the handling operations in the store, and minimizing the handling operations in the DC.

4.2.1.1. Handling in store
One objective of the model is to minimize the store handling. The store handling is based on the number of aisles visited in the store of the carriers of a delivery. The aisle level is studied, because the exact location of a SKU in the store planogram does not influence the travel time in the store. The grouping and sequencing of products on a carrier only influences the travel time between the different aisles, and not the travel time within the aisle, because the store employees always walk this distance because the carrier is placed on a fixed location in the store.

4.2.1.2. Handling in DC
In the anticipated model only the travel distance in the DC is taken into account, because this is only influenced by the assignment of products to the carriers. The time needed to collect the products
does not change, because the same products have to be picked per delivery, and the same number of pick locations has to be visited. The distance travelled in the DC consists of four elements:

- the distance between the I/O point and the first pick location
- the distance between the last pick location and the final destination of the carrier in the DC
- the distance travelled within the aisles (y distance)
- the distance travelled between the aisles (x distance)

Because of the fixed number of carriers, the first two elements can be neglected, because this total distance is not influenced largely by the assignment of products to a carrier.

The intra aisle distance (y distance) is for an order picking trip significantly larger than the inter aisle distance (x distance). The aisle length in this situation is equal to 63 meters, and the total length of the DC is 210 meters (the inter aisle distance is 5.5 meters). Because of the traversal order picking method, only one way traffic is possible in the aisles. When calculating the number of aisles visited, it should be taken into account that a picker must travel back to the other side of the DC when two even/odd numbered aisles are visited. To overcome this problem, two aisles are seen as one, and double length is given to these aisles. This means that the DC consists of 20 aisles with length 2 x 63 = 126 meters, and with an inter aisle distance of 11 meters.

Figure 11 illustrates the distances described previously. The intra aisle distance and inter aisle distance are indicated with the arrows. The circle represents the I/O point, and the transparent, red blocks indicate the adjusted aisles with the double length.

Figure 11: Illustration of distances travelled in the DC
These numbers show that minimizing the number of aisles visited leads to a much higher reduction in distance than minimizing the spreading of the aisles visited in the pick zone. So in the model only the number of aisles visited in taken into account to simplify the model.

Because of the traversal order picking method, it is not possible to travel back and forth in the aisles of the DC. The relatively long aisles cause that when an aisle is visited by a carrier, all the products that are slotted there and are assigned to that carrier, are collected in that sequence. It is possible to visit an aisle twice or more, but this leads to a large increase in the travel distance. This increase in travel distance compared with the advantage of the sequencing of the products is assumed to be neglected. Furthermore, the store employees do not have to stack the shelves in the exact sequence the products are loaded, because the carriers are three-dimensional, so there are several items available to be shelved. Therefore, in the model only the aisle a SKU is slotted is taken into account, and not the exact location. In the DC, the aisles visited are used as a measure for the travel distance.

4.2.2. Hierarchical Structure

On the operational level, the assignment of products to a carrier influences the number of aisles visited in the DC and the number of aisles visited in the store. On the tactical level, the number of aisles visited in the DC and in the store can be influenced by changing the slotting. These decisions cannot be made simultaneously, because the slotting is a fixed factor that cannot be adjusted for every delivery. A hierarchical relationship exists between these two decision variables. When the optimal assignment of products is determined on the operational level, the slotting is a fixed factor. When the optimal slotting is determined, it should be taken into account that this slotting should not be optimized for only one delivery of one store, but that it should be optimal for a longer period and for all stores, because it is very costly to adjust the slotting.

4.2.3. Operational Model

In this section the formulation of the operational model is given.

On the operational level it is decided for a delivery to which carrier \( j \) an order line of SKU \( i \) is assigned. The decision variable stated in Equation 2 is used in the operational model.

\[
x_{ij} \in \{0,1\} \quad \text{assignment of order line of SKU } i \text{ to carrier } j \tag{2}
\]

Furthermore, the variables in Equation 3 and 4 are used in the model to indicate whether an aisle in the store or in the DC is visited by carrier \( j \).

\[
y_{a,j}^{store} = \text{aisle } a \text{ in store visited by carrier } j \quad (y_{a,j}^{store} \in \{0,1\}) \tag{3}
\]

\[
y_{a,j}^{dc} = \text{aisle } a \text{ in DC visited by carrier } j \quad (y_{a,j}^{dc} \in \{0,1\}) \tag{4}
\]

It is chosen to take into account only the carrier the order line is placed on, and not the exact sequence, because the grouping of products from the same category on the same carrier influences the travel time in the store more than the sequencing of products on a carrier.

Equations 5 to 9 describe the constraints of the model concerning the assignment of order lines to carriers.
In Equation 5 it is stated that every order line of SKU i should be assigned to only one carrier.

\[ \forall i: \sum_j x_{ij} = 1 \]  \hspace{1cm} (5)

In Equation 6 and 7 it is stated that every carrier has a fixed capacity based on the volume and weight that can be loaded on it. Therefore, the sum volume and weight of the order lines assigned to a carrier cannot exceed this capacity.

\[ \forall j: \sum_i V_i x_{ij} \leq VC \]  \hspace{1cm} (6)

\[ \forall j: \sum_i W_i x_{ij} \leq WC \]  \hspace{1cm} (7)

Where,

\[ V_i = \text{volume of order line of SKU } i \]

\[ W_i = \text{weight of order line of SKU } i \]

\[ VC = \text{maximum volume capacity of a carrier} \]

\[ WC = \text{maximum weight capacity of a carrier} \]

In Equation 8, and 9 it is stated that the location of the SKUs in the store is fixed, and that the location of the SKUs in the DC is fixed. Aisle a in the store or in the DC is only visited by carrier j when the order line of SKU i, which is loaded on carrier j, has to be unloaded, or picked there.

\[ \forall a, j: \sum_i L_{ia}^{Store} x_{ij} \leq y_{aj}^{Store} \text{, where } y_{aj}^{Store} \in \{0,1\} \]  \hspace{1cm} (8)

\[ \forall a, j: \sum_i L_{ia}^{DC} x_{ij} \leq y_{aj}^{DC} \text{, where } y_{aj}^{DC} \in \{0,1\} \]  \hspace{1cm} (9)

Where,

\[ L_{ia}^{Store} = \text{SKU } i \text{ located in aisle } a \text{ in the store } (L_{ia}^{Store} \in \{0,1\}) \]

\[ L_{ia}^{DC} = \text{SKU } i \text{ slotted in aisle } a \text{ in the DC } (L_{ia}^{DC} \in \{0,1\}) \]

After describing the simplifications made in the model the objective function can be derived, and it is given in Equation 10.

\[ \text{minimize } \sum_j \sum_a y_{aj}^{DC} + \gamma \sum_j \sum_a y_{aj}^{Store} \]  \hspace{1cm} (10)

The objective function describes on the one hand that the number of aisles visited in the DC should be minimized, and at the other hand the number of aisles visited in the store should be minimized. Factors \( \gamma \) determines to which extent the store should be taken into account when minimizing the objective function, and this part of the objective function is the anticipation of the model. The objective function minimizes the penalty per delivery, for the slotted SKUs, with a given number of carriers, and given number of pick zones.
4.2.4. Tactical Model

In this section formulation of the tactical model is given. This tactical model is applied on the aisles with the non-crushable and crushable products separately. The analysis showed that it is most beneficial to slot the crushable products at the end of the pick zone in separate aisles, because these SKUs should be collected last on a carrier, and therefore these aisles should be visited last.

On the tactical level, it is decided in which aisle a SKU is slotted. The decision variable on the tactical level is stated in Equation 11.

\[ s_{ia} \in \{0,1\} \quad \text{slotting of SKU } i \text{ to aisle } a \]  

(11)

When the slotting of the SKUs is changed, the grouping and sequencing of SKUs can be influenced more easily. The simplification is made that the SKUs are slotted on aisle level in the DC, and not on pick location level, because it is assumed that when products are assigned to a carrier, and have to be picked from a certain aisle, the products are picked in one trip and there is no travelling back and forth within the aisle. In addition, it is assumed that the aisle is not visited multiple times, because the aisle length is relatively too large, to make this beneficial for the sequencing of products.

Equation 12 and 13 describe the constraints of the tactical model.

Equation 12 states that every SKU \( i \) is slotted in only one aisle of the DC.

\[ \forall i: \sum_a s_{ia} = 1 \]  

(12)

Equation 13 states that the size of the pick location needed for a SKU differs between the SKUs. The total space needed for all the SKUs within an aisle cannot exceed the space capacity of an aisle.

\[ \forall a: \sum_i S_i s_{ia} \leq C_a \]  

(13)

Where,

\( S_i = \) storage location space needed for SKU \( i \)

\( C_a = \) capacity of space in aisle \( a \)

After describing the simplifications made in the model, the objective function is shown in Equation 14.

\[ \text{minimize } \sum_i \sum_j \sum_k \sum_l D_{ab} F_{ij} s_{ia} s_{jb} \]  

(14)

Where,

\( s_{ia} = \) SKU \( i \) slotted in aisle \( a \)

\( s_{jb} = \) SKU \( s \) slotted in aisle \( b \)
\( D_{ab} = \) distance between aisle a of SKU i and aisle b of SKU j in DC, where \( D_{ab} \in \{0,1\} \) (1 if SKUs are in same aisle, else 0)

\( F_{ij} = \) importance SKU i and SKU j are located near to each other, where \( F_{ij} \in \{0,1\} \) (1 if SKUs are from same aisle in the store (same category), else 0)

The problem described is a quadratic assignment problem. It describes that for all the SKUs assigned to a location in the DC the distance between the aisles should be minimized when they are from the same category. When this is done within the given constraints, the objective function is minimized. A penalty is given to a slotted SKU when SKUs from the same category have to be collected in different aisles in the DC.
5. INTEGRATION

In this chapter, the heuristic that is used to solve the detailed operational model is described. It was chosen to use a heuristic to solve the problem, because the problem is too complex to solve it in a limited time. After the description of the heuristic, the simulation model to test the performance of the heuristic is given. Subsequently, solution directions to solve the tactical model are suggested.

5.1. HEURISTIC TO SOLVE OPERATIONAL MODEL

A heuristic is developed to solve the operational model. Firstly, several lower bounds of the model are given. Secondly, the heuristic is explained.

5.1.1. LOWER BOUNDS

Firstly, the theoretical lower bound of the number of carriers needed to transport the delivery to the store is determined. This is done to determine whether there exists enough freedom in the number of carriers available to change the assignment of products to carriers. Furthermore, the theoretical lower bounds for the distance travelled in the DC, and in the store are given, when only the locations to be visited are taken into account.

5.1.1.1. Number of carriers used

The current heuristic used for the assignment of products to carriers does not make smart combinations based on the weight and volume of SKUs to use the capacity of the carriers optimally. Therefore, first an analysis is done whether the number of carriers used can be reduced. This is done by solving a bin packing problem, by using a first fit decreasing policy. There is determined which arrangement of the products is most beneficial to use least carriers. This result is compared with the results of the current order picking algorithm, which is described in appendix C. It is determined that 1990 carriers are needed to transport all the products from the described dataset, when the current order picking algorithm is used. To determine whether it is possible to load the products from the dataset on less carriers, there is determined per delivery, whether the volume or the weight in carriers is larger. For the largest number of carriers, the SKUs are sorted descending based on decreasing weight, decreasing weight/volume, decreasing volume or decreasing volume/weight. Then the products are assigned to the carriers, and when a product does not fit on one of the carriers anymore, a new carrier is used. This is done until all the products of a certain delivery in the RDC are assigned to a carrier. For this analysis there is assumed there exist only one pick zone in the RDC.

When the total number of carriers is studied, it can be seen that it is in general most beneficial to sort the order lines based on decreasing volume. In that situation only 1727 carriers are needed. This is a decrease of 13% compared to the number of carriers needed for the current order picking algorithm. For some deliveries it is more beneficial to sort the order lines based on decreasing weight. When this is done for these deliveries 1722 carriers are needed to transport all the deliveries. This shows that sorting the order lines on decreasing volume is a good method to reduce the number of carriers needed. These carriers are loaded for 90.99% based on volume, and 70.89% based on weight.
When there is decided that a SKU is picked in a certain aisle in the DC, it is from the store perspective most beneficial to collect all the other SKUs from the same category in that aisle too. For the DC this does not lead to extra cost, because when an aisle is visited, it should be travelled entirely. Therefore, clusters are made per delivery for products from the same category, and from the same aisle in the DC. These clusters are assigned to carriers by making use of the first fit decreasing policy. The clusters are sorted based on decreasing volume, because this is effective on the order line level. When the first fit policy based on volume is applied on the clusters, the number of carriers needed is equal to 1727. This is the same number of carriers needed as at the order line level, so there exists enough freedom to assign the products on cluster level to the carriers.

5.1.1.2. Distance travelled in DC
The theoretical lower bound for the distance travelled in the DC can be determined by determining the minimum distance travelled, when all the products of a delivery are picked. The volume and weight of the products is not taken into account, so it is assumed that everything is collected at once. The formula used to determine the lower bound is described in Equation 15.

\[
\text{Lower bound} = N \times 126 \text{ m} + (L - 1) \times 11 \text{ m} \times 2 \tag{15}
\]

Where,

\[
N = \text{number of aisles to be visited}
\]
\[
L = \text{number of last aisle to be visited}
\]

5.1.1.3. Distance travelled in store
The theoretical lower bound of the distance travelled in the store can be determined by assuming that in the ideal situation only one category is loaded on a carrier. Then no aisle changes are needed in the store, and the lower bound for the distance travelled in the store is equal to zero. The volume and weight of the products, and the number of carriers available for a delivery are not taken into account when setting this lower bound.

5.1.2. Cluster formation
In the current situation, SKUs are assigned to carriers on product level, but in the heuristic the choice is made to assign the products grouped together based on their category and their aisle in the DC. This choice is made, because it is desirable that when an aisle is visited and a SKU from a category is picked, the other products from this category are picked on the same carrier. The results of the previous analysis showed that it is possible to assign all clusters to a carrier, so this solution can always be used when the proposed solution of the heuristic cannot assign all the clusters to the carriers.

5.1.3. Assignment of clusters to carriers
The idea of the developed heuristic is based on the heuristic of Fisher and Jaikumar (1981), which is used to solve a vehicle routing problem. The heuristic they developed starts with a set of ‘seed’ customers, which are used to initialize the clusters, and these are assigned to a vehicle. The remainder customers are added to a cluster by solving a generalized assignment problem. This is done by determining the cost of assigning each customer to each cluster, and after this the total
minimum cost are determined, when each customer is assigned to one cluster without exceeding the capacity of each cluster. After the clustering phase, the exact routing for each cluster is determined by solving a travelling salesman problem. The heuristic used in this research also makes use of the concept of ‘seed’ clusters to assign all the clusters to a carrier. Also, it assigns all the products to a carrier before the routing through the aisles is determined.

The input of the heuristic is the list with all clusters (aisle-category combinations), and their weight and volume. It is determined whether clusters exist which have a larger weight or volume than the maximum capacity of a carrier. For these cases, full or multiple full carriers are collected from the aisle with one category loaded on it. This way, a full carrier can be collected in one aisle in the DC, and can be unloaded in one aisle in the store, which is the most efficient. The remainder volume and weight of the cluster that still has to be collected is put back in the list with clusters, and the weight and volume of this cluster is adjusted based on this remainder.

Seed clusters are selected to assign the remaining clusters to the carriers. The aisle of the seed, and the category of the seed are used to determine which other clusters should be loaded on the same carrier. In addition, the volume is taken into account. The clusters of a delivery are sorted based on decreasing volume, and the first cluster that is not yet assigned to a carrier is selected as seed. The reason that the volume of a cluster is used as a criteria for the seed selection is to make it easier that all the large volume clusters can be assigned to a carrier.

The basic idea of the heuristic is solving a bin packing problem. This means that the clusters are sorted based on decreasing volume, and then they are assigned sequentially to a carrier until a cluster in the sequence does not fit on the carrier. Then a new carrier is added, and the remaining clusters can be placed on one of these two carriers. This process is continued until all clusters are assigned to a carrier. This first fit decreasing algorithm minimizes the number of carriers used.

In the heuristic, the carriers are not load totally sequential. As stated in the operational model, the distance between the clusters in the DC is taken into account when the clusters are assigned to a carrier. Furthermore, the distance travelled between the clusters in the store is also taken into account. After determining the seed cluster of a carrier, the formula stated in Equation 16 is used to determine which other clusters should be assigned to a carrier.

$$V = 1 - \left[ (\alpha A_{seed}^{DC} - A_{cluster}^{DC}) + \beta D_{seed,cluster}^{CAT} \right]$$ (16)

Where,

$$A_{seed}^{DC} = \text{aisle number in DC of seed}$$

$$A_{cluster}^{DC} = \text{aisle number in DC of clusters}$$

$$D_{seed,cluster}^{CAT} = \text{distance in store between location of category of seed in store and location of category of cluster in store}$$

The absolute difference between the DC aisle number of the cluster and the seed, and the distance in the store between the category of the seed and the category of the cluster are determined for every cluster. Based on the values assigned to alpha (\(\alpha\)) and beta (\(\beta\)) (where, 0 <= \(\alpha\) <= 1, and 0 <= \(\beta\) <= 1),
value V is calculated. The larger the values of alpha and beta, the more important it is the clusters are picked near the seed cluster in the DC and/or in the store. Value V of a cluster should be equal or larger than zero to be a candidate cluster for the carrier. This minimum is set to prevent that the clusters are assigned sequential to the carrier, and that the small volume clusters that correspond little with the aisle and category of the seed, are assigned to the carrier when this is not necessarily required. This minimum value V indicates that the sum of α times the absolute distance in aisles in the DC and β times the distance in the store between the seed cluster and the cluster, cannot be too large. Factors α and β influence the absolute distance a candidate clusters can be located from the seed cluster in the DC, and in the store. The higher the α and β, the smaller the allowed distance. The candidate clusters are first sorted based on decreasing volume, and then sorted based on decreasing value V. The candidate clusters are assigned to the carrier based on decreasing value V, and when the carrier reaches its maximum weight, maximum volume, or there are no candidate clusters available anymore, the assignment based on this seed cluster is finished. For all available carriers, the procedure described above is repeated.

When the values of α and β are chosen to be very low, the distance between the aisles in the DC, and the distance between the categories in the store do not influence the assignment of the clusters to the carriers that much. Then the assignment is mainly based on the volume of the clusters, and a sequential approach is used to assign the clusters to the carriers.

When there are still unassigned clusters left after the assignment round, this means that the values of α and β were set quite high, which complicates the assignment. The number of carriers used cannot be increased, so it is attempted to add the remaining clusters to the available carriers. This can be seen as a parallel approach, because the carriers are selected multiple times to add clusters to it. The carrier with the smallest volume loaded on it is selected, and, using the same procedure as for the seed selection, the cluster with the largest volume, and not assigned to a carrier, is selected. It is checked whether this cluster fits on the carrier, and when this is the case, the cluster becomes the new seed of the carrier. When the cluster does not fit, the carrier with the second smallest volume is selected, and so on. The same formula is used for the unassigned clusters of the delivery, and the value V is calculated. The candidate clusters with a value V ≥ 0 are sorted based on decreasing volume, and then on decreasing value V, and assigned to the carrier until the capacity limit is reached or until there are no longer any candidate clusters available. The carrier with the smallest volume loaded on it is selected again, and the same procedure is repeated until all the clusters are assigned to a carrier. The pseudo code of the heuristic is given in appendix D.

After all the clusters are assigned to a carrier, the distance travelled in the DC is determined by sorting the clusters on a carrier based on the aisle number. The aisles are visited in sequence, and based on the aisle length and inter aisle distance, the distance travelled per carrier in the DC can be determined. To determine the distance travelled in the store for a carrier, it is determined how many categories are loaded on the carrier. For every extra category loaded on the carrier, an extra distance travelled in the store of 25 meters is assigned to the carrier, because this is the average distance between the categories in the store.
5.2. SIMULATION MODEL
A simulation model is used to show the added value of the anticipation. The heuristic described in the previous section is implemented, and tested for the given deliveries of store 1204. The simulation model is run for several scenarios in which the importance of the store and the DC is adjusted (α and β factor). A few performance indicators are developed, which can be used to compare the current situation with the simulation results of the anticipated model. In the remainder of this paragraph the objective of the simulation model, the dataset used, and the output of the model are described.

5.2.1. OBJECTIVE
The objective of the simulation model is to show how adjustments in the assignment of SKUs to carriers influence the quality of the compilation of the carriers.

5.2.2. DATASET
For the simulation model an existing dataset is used with the order pick lists of store 1204 in Houten. It contains the non-perishable items that are picked at the regional distribution center (RDC) in Zaandam. As an input for the simulation model the products that are picked for every delivery at the store are used, and the characteristics of these SKUs. The slotting of the SKUs in the DC is adjusted slightly, because one pick zone is used in the simulation model, instead of multiple pick zones. Therefore, the crushable products are moved to the end of the DC. In appendix C a more detailed description is given of the dataset used. In appendix E the DC layout is shown, and also the assumptions made about the layout of the DC are given.

5.2.3. OUTPUT
The output of the simulation model shows the assignment of products to a carrier. Based on this assignment, and the known location of these SKUs in the DC and the store, the aisles visited are also known. Based on this information and the information about the DC sizes, the following performance indicators are used:

- Distance travelled in the DC
- Distance travelled between aisles in the store

5.3. SOLUTION DIRECTIONS FOR TACTICAL MODEL
In this section, solution directions are given to solve the tactical model. Firstly, some suggestions are given for heuristics to solve the quadratic assignment problem, and secondly some practical insights gained to improve the slotting are given.

5.3.1. SOLUTION QUADRATIC ASSIGNMENT PROBLEM
It is suggested to solve the quadratic assignment problem with a heuristic, because these types of problems are quite complex to solve. A construction heuristic can be used to come to a start solution, or the start solution can be the current slotting. By making use of local search, all the possible solutions are searched and local changes are applied to find the (locally) optimal solution. This heuristic is time consuming, but this is not a big problem, because the slotting is not changed that often, and it is still a quite efficient method to solve a quadratic assignment problem. A variant
of local search is the swap heuristic. In this heuristic, SKUs in the slotting are swapped to determine whether a better solution can be created.

5.3.2. PRACTICAL INSIGHTS TO IMPROVE THE SLOTTING
The practical insights gained during the development of the model are described in this section. Firstly adjusting the number of pick zones is discussed, secondly the slotting of non-crushable and crushable SKUs in the DC, and finally the grouping of categories in the DC.

5.3.2.1. Adjusting the number of pick zones
Adjusting the number of pick zones in the DC gives more freedom in the order picking operations. When the pick zones are larger, in general more carriers are collected from a pick zone, and this results in more freedom in assigning products to a carrier. Also the average loading of a carrier will be higher, when there are less pick zones, because there are less ‘last carriers of a pick zone’. This makes the undesirable process ‘rest picking’ unnecessary. The disadvantage of less pick zones is that the distance between the I/O point, and the first and the last pick location visited will increase. This disadvantage can be overcome by making use of dynamic pick zones. This means that an attempt is made to minimize the inter aisle distance between the first and last aisle visited.

5.3.2.2. Slotting of non-crushable and crushable SKUs
It is most beneficial to group the non-crushable SKUs in separate aisles in the beginning of the pick zone, and the crushable SKUs also in separate aisles at the end of the pick zone. Crushable products can only be picked when non-crushable products assigned to that carrier are already loaded. That is why it is most beneficial to place them at the end to prevent needing to travel back and forth in the DC.

5.3.2.3. Grouping of categories
It is desirable to minimize the number of aisles a category is slotted in, because this makes it easier to group the products per category on a carrier. The problem is that categories differ between stores, so designing a new slotting based on the layout and data of one store is not optimal for all the stores. Furthermore, the requirements concerning safety should still be satisfied when changing the slotting.
6. RESULTS & DISCUSSION

In this chapter, the results of the simulation model are presented and discussed. In addition, the influence of the factors alpha (α) and beta (β) is discussed. Factors α and β influence the distance a candidate cluster can be located from the seed cluster. Factor α influences the distance in the DC and factor β influences the distance in the store; and the higher α or β is, the smaller the allowed distance from the seed cluster is.

6.1. RESULTS

Several settings of the alpha and beta factor are tested in the simulation model. In Table 10, the results of the average distances travelled per carrier in the DC and the store are stated. These results are obtained by simulating seven deliveries. In addition, the average distances travelled in the DC and in the store in the current situation are given. Furthermore, the difference between the current situation and the scenarios tested is shown in Table 10.

Table 10: Results simulation model for several settings of α and β for seven deliveries

<table>
<thead>
<tr>
<th>α</th>
<th>β</th>
<th>Number of carriers used</th>
<th>Average inter aisle distance per carrier (in m)</th>
<th>Average intra aisle distance per carrier (in m)</th>
<th>Average total distance travelled in DC per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
<th>Average distance travelled in store between aisles per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>111</td>
<td>229 m</td>
<td>206 m</td>
<td>435 m</td>
<td>+76%</td>
<td>93 m</td>
<td>+84%</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>111</td>
<td>496 m</td>
<td>267 m</td>
<td>762 m</td>
<td>+75%</td>
<td>34 m</td>
<td>-32%</td>
</tr>
<tr>
<td>0</td>
<td>0.1</td>
<td>111</td>
<td>486 m</td>
<td>275 m</td>
<td>761 m</td>
<td>+75%</td>
<td>38 m</td>
<td>-24%</td>
</tr>
<tr>
<td>0</td>
<td>0.05</td>
<td>111</td>
<td>495 m</td>
<td>277 m</td>
<td>771 m</td>
<td>+77%</td>
<td>56 m</td>
<td>+11%</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>111</td>
<td>318 m</td>
<td>254 m</td>
<td>572 m</td>
<td>+31%</td>
<td>80 m</td>
<td>+58%</td>
</tr>
<tr>
<td>0.2</td>
<td>0</td>
<td>111</td>
<td>280 m</td>
<td>203 m</td>
<td>484 m</td>
<td>+11%</td>
<td>79 m</td>
<td>+57%</td>
</tr>
<tr>
<td>0.1</td>
<td>0</td>
<td>107</td>
<td>307 m</td>
<td>205 m</td>
<td>513 m</td>
<td>+18%</td>
<td>82 m</td>
<td>+63%</td>
</tr>
<tr>
<td>0.1</td>
<td>0.05</td>
<td>111</td>
<td>409 m</td>
<td>248 m</td>
<td>656 m</td>
<td>+51%</td>
<td>68 m</td>
<td>+35%</td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>111</td>
<td>501 m</td>
<td>267 m</td>
<td>768 m</td>
<td>+77%</td>
<td>37 m</td>
<td>-27%</td>
</tr>
</tbody>
</table>

Based on these results, four scenarios are studied in more detail. The choice is made to select four relatively extreme scenarios. The first selected scenario is α=0, β=0. In this scenario only the volume of the clusters is taken into account; i.e. neither the distance travelled in the DC nor the distance in the store is taken into account. Therefore, it is expected that in this scenarios the lowest number of carriers is needed. The second selected scenario is α=0, β=1. In this scenario, only the distance travelled in the store is taken into account. Furthermore, initially only products from the same category are placed on the same carrier. However, due to the limited number of carriers available, multiple categories need to be placed on the same carrier, so this happens next. In the third scenario, only the distance travelled in the DC is taken into account. The choice is made to select α=0.2, β=0, because specifically β=0 the lowest additional distance travelled in the DC. Finally, the
fourth scenario is selected to incorporate both the distances travelled in the DC and in the store. The choice is made to set alpha and beta to $\alpha=0.05$, $\beta=0.1$, because in this scenario a reduction in the distances travelled in the store is achieved compared to the current situation.

Table 11: Results simulation model for several settings of $\alpha$ and $\beta$ for 53 deliveries

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>Number of carriers used</th>
<th>Average inter aisle distance per carrier (in m)</th>
<th>Average intra aisle distance per carrier (in m)</th>
<th>Average total distance travelled in DC per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
<th>Average distance travelled in store between aisles per carrier (in m)</th>
<th>Difference with current situation (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current situation</td>
<td>780</td>
<td>363 m</td>
<td>194 m</td>
<td>558 m</td>
<td>47 m</td>
<td>0</td>
<td>0</td>
<td>683</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>780</td>
<td>476 m</td>
<td>270 m</td>
<td>746 m</td>
<td>+34%</td>
<td>32 m</td>
<td>-32%</td>
</tr>
<tr>
<td>0.2</td>
<td>0</td>
<td>777</td>
<td>277 m</td>
<td>205 m</td>
<td>482 m</td>
<td>-14%</td>
<td>74 m</td>
<td>+58%</td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>780</td>
<td>475 m</td>
<td>269 m</td>
<td>744 m</td>
<td>+33%</td>
<td>34 m</td>
<td>-28%</td>
</tr>
</tbody>
</table>

Table 11 depicts the results of the analysis of 53 deliveries. The average distance travelled in the DC per carrier is largely increased in the current situation compared to the analysis of 7 deliveries. This can be explained by the fact that more deliveries are studied, and based on that a more reliable number is found for this average distance. Furthermore, it can be seen that the range of the intra aisle distances is smaller than the range of the inter aisle distances. This means that the inter aisle distance has a larger impact on the average total distance travelled than the intra aisle distance. So, it is more important whether an aisle is visited than which aisle is visited.

6.2. DISCUSSION OF THE RESULTS

The results show that it is not possible to minimize the distance travelled per carrier in the DC and in the store at the same time. This can be explained by the fact that the current order picking method focuses on minimizing the distance travelled in the DC. In the current situation as many products as possible are picked when an aisle is visited in the DC. The distance travelled in the store can only be improved when the distance travelled in the DC increases.
Figure 12: Average distance travelled between the aisles in the store per carrier in multiple scenarios

The average distance travelled in the store between the aisles per carrier is presented in Figure 12. This average distance is given per delivery for the scenarios shown in Table 11. When the distance travelled in the store is not taken into account ($\beta = 0$), the average distance travelled between the aisles in the store is high. The two scenarios that do take the distances between the aisles into account show that the number of aisles visited can be reduced on average with 30% compared to the current situation. The lower bound is set to zero, because in the ideal situation only one category is loaded on a carrier and no travelling is needed between the aisles in the store.
The average intra aisle distance travelled in the DC per carrier is displayed in Figure 13. This average distance is given per delivery for the scenarios shown in Table 11. It can be derived that the scenario with $\alpha=0.2$, and $\beta=0$ performs better than the current situation, if one looks at the intra aisle distance. Both scenarios that take the store into account ($\beta \neq 0$) perform worse than the current situation. The lower bound shows the total intra distance of all the aisles that have to be visited divided by the number of carriers used for a delivery.
In Figure 14 the average inter aisle distance travelled in the DC per carrier is presented. This average distance is given for the scenarios shown in Table 11. It can be seen that the inter aisle distance travelled per carrier in the scenario \( \alpha = 0.2, \beta = 0 \), is almost equal to the distance travelled in the current situation. For the other scenarios this distance is larger than the current situation. The lower bound shows the distance from the I/O point to the last aisle and back, divided by the number of carriers used for a delivery.
In Figure 15 the total average distance travelled in the DC per carrier is given. Scenario $\alpha=0.2$, $\beta=0$ shows that there are possibilities to reduce the distance travelled in the DC compared to the current situation. The fact that in the simulation model only one pick zone is defined in combination with the alpha factor that causes the visited aisles to be located close to each other, leads to the fact that efficient pick orders can be composed. So no rest picks are performed and fewer carriers can be used than in the current situation. The other three scenarios tested lead on average to an increase of 35% of the distance travelled per carrier in the DC.

6.2.1. Distance travelled versus travel time

The results of the simulation model show that it is not possible to decrease the distance travelled in the DC and in the store at the same time. The distances travelled in the DC and in the store cannot be compared one to one, because different amounts of time and costs are related to these distances travelled.

To determine the cost of the scenarios only the total relevant time spent in the DC and in the store is taken into account. This means that only the variable costs of the travel distance in the DC and the variable costs of travelling between the aisles in the store are determined. This leads to the total relevant time stated in Equation 17.

$$\text{Total relevant time} = TRT_{\text{STORE}} + \delta TRT_{\text{DC}}$$  \hspace{1cm} (17)

Where,

$TRT_{\text{STORE}} = \text{total relevant time spent in store}$
**TRT$_{DC}$** = total relevant time spent in DC

$\delta =$ weight factor of hourly labor costs difference between the store and the DC

First the travel time in the current situation is determined. For the distances travelled between the aisles in the store in the current situation, it is assumed that the time needed for this is equal to the time spent on sorting in the backroom of the store in the current situation, which is equal to 29.5 hours a week (Ahold data). The detailed analysis of this assumption is stated in appendix F. On average 250 carriers with non-perishable products arrive at the store, so on average 7 minutes is spent per carrier on travelling between the aisles in the current situation. The average speed of an order picker is 2 meters/second (Ahold data), and on average 4.5 carriers (Ahold data) are collected in one trip, therefore per carrier on average 62 seconds are spent on travelling through the DC in the current situation. These numbers are used to determine the time spent on travelling in the other scenarios, and the results are presented in Table 12. The costs of an order picker in the DC are twice the costs of an employee in the store at Albert Heijn, therefore $\delta=2$. The costs of the total relevant time are calculated by multiplying the total relevant time with the labor costs of a store employee.

<table>
<thead>
<tr>
<th>Table 12: Relevant time spent on travelling with carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Current situation</td>
</tr>
<tr>
<td>0 0</td>
</tr>
<tr>
<td>0 1</td>
</tr>
<tr>
<td>0.2 0</td>
</tr>
<tr>
<td>0.05 0.1</td>
</tr>
</tbody>
</table>

The results show that it is possible to reduce the total time spent on travelling when the distances travelled between the aisles in the store are taken into account.

**6.2.2. DISCUSSION OF $\alpha$ FACTOR AND $\beta$ FACTOR**

The $\alpha$ factor influences the importance of the distance between the seed cluster and a candidate cluster for that carrier. When the value of $\alpha$ is extremely large, only clusters from the same aisle in the DC as the seed cluster can be assigned to the carrier. The closer the value for $\alpha$ approaches zero, the more aisles are allowed to be visited by the carrier. These aisles are located near the seed aisle (in front of or behind), and therefore this can be seen as a dynamic pick zone which size is influenced by the value of $\alpha$. 

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The $\beta$ factor influences the importance of the distance between the different aisles that have to be visited in the store. When the value of $\beta$ is extremely large, only clusters from the same category (store aisle) as the seed cluster can be assigned to the carrier. When the value of $\beta$ approaches zero, more categories are allowed to be loaded on the carrier. This is based on the distance between the different categories in the store.

When both factors are set to a (very) large number, the number of clusters that can be assigned to the carrier is too small, because there are not enough clusters with a value $V$ larger or equal to zero. This results in the selection of many seeds to assign all the clusters to a carrier. However, the disadvantage of selecting many seeds is that the quality of the carriers decreases, because the seeds are chosen independently of the clusters already loaded on the carrier.

When both factors are set too small, the effect of loading products of a certain part of the DC on the same carrier, or loading products from a certain part of the store on the same carrier is not visible. Then the clusters are not distinctive enough, and too many clusters are available to be assigned to a carrier.

6.2.3. **Limitations of Model**

When it is required to define more seeds than the number of carriers available this influences the results. When an extra seed is selected for a carrier, this is based on the volume of the available potential cluster (the not assigned cluster with the largest volume). The aisle and category of the cluster are not taken into account. This can result in a carrier that has to visit some aisles in the beginning of the DC and some aisles at the other end of the DC. This holds also for the store. When the characteristics of the other clusters loaded on a carrier are also taken into account during the assignment, this can improve the performance of the heuristic. Furthermore, it is important that the values of $\alpha$ and $\beta$ are chosen carefully to achieve good results.

In the distribution center, batching of multiple pick orders is used to reduce the distance travelled in the DC. Pick orders are batched when they visit similar aisles or pick locations in the DC. Often this applies for pick orders of different stores, because in general carriers of one store do not visit the same aisles or pick locations. Due to the inclusion of only one store, it makes it impossible to include the effects of batching in the results.

Furthermore, the effects of increasing the distance travelled in the DC are not taken into account in the model. This means that it is possible that the picking efficiency reduces when more distance is travelled in the DC.
7. CONCLUSION & RECOMMENDATIONS

In this chapter the main conclusions of the research are presented. Subsequently recommendations for Albert Heijn are given and possible future research directions are stated.

7.1. CONCLUSION

A qualitatively good ‘WVA’ carrier takes the store handling operations into account when compiling the carrier in the DC. Next to this, the requirements concerning the safety and the stacking of the products on the carrier should be satisfied, and also the capacity limits of the carrier cannot be exceeded.

Changing the compilation of a carrier in the distribution center is not as easy as it sounds, because of several reasons. In the RDC mainly the crushability of products and the weight influences where a SKU is slotted in the distribution center. Furthermore, the relatively long aisles in the DC cause the desirability to visit an aisle only once per order picking trip, because the travelled distance otherwise increases too much. In addition, the one way entry of the aisles makes it difficult to visit pick locations in a different sequence.

It is possible to take the store handling into account when compiling a carrier. Categories can be defined on store level, and these categories contain the products that are located in the same store aisle. It is chosen to look at the store aisle level, because the shelf stacking process is also managed on aisle level. Furthermore, the distances between the different categories in the store can be determined. The assignment of products to the carriers can be adjusted by taking into account whether products are from the same category or located near each other in the store. This can be preferred over the location of a product in the DC. In this research, the number of carriers is assumed to be fixed, and within this given number of available carriers per delivery, the assignment is adjusted.

In this research only one store is studied, but the method of defining categories can be applied to multiple stores as well. The described assignment methodology can be applied on the current slotting, but also on an adjusted slotting.

The results of the simulation model have shown that it is possible to reduce the number of aisles visited in the store, but that it is not possible to reduce the distance travelled in the DC at the same time. The results also showed that it is possible to reduce the distance travelled in the DC, but this influences the number of aisles visited in the store negatively.

The travel distances in the DC and in the store can be expressed in travel time. When the labor costs per location are taken into account, the cost per carrier can be determined. The results show that it is beneficial to take the location of the products in the store into account, when the carriers are compiled in the distribution center. This leads to an increase of the costs in the DC, but this is compensated by the costs savings in the store.

Furthermore, a model is given that describes the assignment of SKUs to DC aisles. It can be used to improve the slotting, but the problem is difficult to solve. Therefore is suggested that this problem is
solved by using a simple improvement heuristic. Nevertheless more data of other stores is needed to design a slotting that improves the quality of the carrier compilation for the majority of the stores.

7.2. **RECOMMENDATIONS**

Before the assignment of products to the carrier is adjusted, it should be studied how changing the compilation of the carriers influences the store handling operations. It should be checked whether reducing the number of categories loaded on a carrier leads to a reduction of the travel time between the aisles in the store. Furthermore, it should be checked whether this effect is linear or not. When this is known a better estimation can be made of the travel time savings in the store.

The simulation model showed that it is possible to reduce the distance travelled in the DC. It could be an opportunity for Albert Heijn to study whether it is an option to use dynamic pick zones in their DC. This also avoids the undesirable process of ‘rest picking’, because the pick zones have dynamic borders and can be adjusted based on the size of the order picked.

In this research, only the data of one store is used to determine whether it is possible to reduce the distance travelled in the store and in the DC. It is important that more insight is gained in how an increase in the distance travelled in the DC influences the picking efficiency and the existence of congestion in the DC. Furthermore, it should be studied whether a different assignment of products to carriers influences the batching possibilities and efficiency.

Furthermore, multiple store layouts could be studied to determine whether similarities exist between the products placed in the store aisles. It could be studied whether it is possible to implement these similarities also in the slotting of the DC.

7.3. **FUTURE RESEARCH**

To improve the compilation of the carriers, it can be studied whether it is possible to adjust the moment a product order arrives at the store. A focus should be to deliver only full carriers loaded with one category. To do this, products can be delivered in advance when the shelf capacity is sufficient or product orders can be delayed when the safety stock allows this. It can also be studied whether it is possible to adjust the shelf capacity or the case pack size to realize this. When only full carriers with one category are delivered, fewer aisles have to be visited in the store, because there are no carriers with multiple categories loaded on it.

In this research, it is assumed that in the current situation the time needed for sorting in the backroom is equal to the time needed for sorting during the shelf stacking process. More empirical research related to store handling operations can be done to study in which situations it is more beneficial to sort the carriers before the shelf stacking process in the backroom of the store or to sort the products during the shelf stacking process.

In this research the exact location of products on a carrier is not taken into account, only the assignment of products to the carrier is considered. It is difficult to determine the exact location of products, because a carrier is a three dimensional space, every order picker loads the carrier differently, and every store employee unloads the carrier differently. It could be worthwhile to gain more insight in this process to determine to which extent the sequence the products are loaded on a carrier influences the sequence the products are unloaded from a carrier.
8. REFERENCES


Bartholdi, J., & Hackman, S. (2011). *Warehouse & distribution science* (0.95 ed.). Atlanta, USA: The Supply Chain and Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology.


9. APPENDICES

A. REGRESSION ANALYSIS LDC

Objective
The objective of the regression analysis is to find out whether the characteristics of a SKU are significantly related to the location of a SKU in the distribution center (DC). The location of SKUs in the DC is related to the sequence products are loaded on a carrier, therefore it is useful to do this analysis. Based on the analyses of the orders, the order picking process, and the slotting performed earlier, hypotheses are made, and these will be stated in the next paragraph.

Hypotheses
In this paragraph the hypotheses made about the factors that influence the location of a SKU in the DC are given.

- Stackability of SKUs
  In the LDC the stackability of SKUs is based on stackability classes SKUs are assigned to. Based on these stackability classes SKUs are assigned to a pick location in the LDC, so the hypothesis is made that the stackability class of a SKU in the LDC has a significant influence on the location a SKU is placed in the LDC.

- Density of SKUs
  In the LDC the density of a SKU is not specifically a criteria for the slotting of a SKU in the DC. Therefore there is hypothesized that the density of a SKU does not significantly influences where in the DC a SKU is placed.

- Height of SKU
  In the slotting of the LDC the height of a SKU is not taken into account, so there is hypothesized that it does not significantly have an influence on where a product is placed in the DC.

- Sum of demand SKU
  The sum of the demand of a SKU does not significantly influence where a product is placed in the DC. To prevent blockage in the DC, products with a high demand are spread over the locations in the DC. When the SKUs are spread evenly over the locations in the DC, this characteristic of a SKU should not be a predictor of the location of a SKU in the DC.

- Category of SKU
  In the LDC SKUs are not grouped based on assortment group, module, family group or category, so there is hypothesized that the category of a SKU does not significantly influence the location in the DC a SKU is placed.

- Pick zone of SKU
  The pick zone of a SKU has a significant influence on where a SKU is placed in the DC. This because of the fact that pick zones are fixed zones within the DC, and these zones have consecutive pick locations.

Dataset
The dataset used for the analysis is based on the WMS order pick list of store 1204 in Houten. The data of week 50 2012 until week 16 in 2013 is used. The dataset contains the non-perishable items
that are picked at the national distribution center (LDC) in Geldermalsen. For every order line in the dataset is known on which carrier the SKU is placed, what the ordered quantity is, and the details about the order picking are shown. Another data set with the product characteristics of the SKU, and the pick zone and the pick location in the DC the SKU is slotted, is also available. The regression analysis is therefore conducted on the SKUs which are ordered from week 50 2012 until week 16 2013 in store 1204, which is equal to 8121 SKUs at the LDC. A few product groups are excluded from the analysis, because they are picked separately. This is the case for tobacco, medicines, crates of beer from the crate picking installation, roly’s with soda, and displays with promotion products. Also the SKUs with an unknown pick location or unknown product characteristics are deleted from the dataset. This finally results in 7363 SKUs for the LDC which are used in the analysis.

**Design**

Next to the variables mentioned in the hypotheses, also some other variables are added to find out whether there are other characteristics of the SKUs that may have an influence on the location in the DC they are placed. The dependent variable in this regression analysis is the relative location a SKU is placed in the DC. The total number of SKUs that are in the assortment of store 1204, and are placed in the LDC is determined. The SKUs in the DC are sorted based on their location from start to end, and a rank number is assigned to them. Because of the fact the total number of SKUs in the DC is known, this number can be standardized for every SKU to a number between 0-1. As a result all the SKUs in the assortment of store 1204 are assigned to a relative location in the DC. The formula used to calculate this is stated in Equation 18:

\[
\frac{\text{Rank of SKU in DC}}{\text{Total number of SKUs in DC}} = \text{Relative location of SKU in DC} \tag{18}
\]

Some variables that are included in the model are transformed before they could be added. This is the case for the variable that indicates the category of a SKU, the variable that indicates the pick zone of a SKU, and the variable that indicates the stacking category of a SKU in the LDC. Dummy variables are added to make it possible to create a linear model.

The stepwise regression method in SPSS is used to obtain the results. The possible independent variables are added in order of relevance (strength of the correlation), and the independent variables which are not significant are left out of the model.

**Results**

There can be concluded that the pick zone has a major influence on where a SKU is placed in the distribution center. To focus solely on the characteristics of the SKU, the regression analyses are repeated for the pick zones of both DCs which contain enough SKUs to conduct a reliable analysis. For the values added to the model the variance inflation factor (VIF) is measured. This measure indicates how much the variance of an estimated regression coefficient is increased because of linearity. The VIFs for five variables representing the dummy variables for some pick zones are higher than 10, so one dummy variable is deleted from the analysis. When this is done, the entered variables all have a VIF < 10 which is a good sign. The R² of the model indicates the proportion of the variance that is explained by the model. The R² of this model is equal to 97.1%, which is very good. In Table 13 the variables that are added to model are shown.
Table 13: Result regression analysis of LDC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Short explanation</th>
<th>Added to model?</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_WEIGHT</td>
<td>Weight of SKU</td>
<td>Yes</td>
</tr>
<tr>
<td>C_DENSITY</td>
<td>Density of SKU</td>
<td>No</td>
</tr>
<tr>
<td>C_HEIGHT</td>
<td>Height of SKU</td>
<td>No</td>
</tr>
<tr>
<td>C_VOLUME</td>
<td>Volume of SKU</td>
<td>No</td>
</tr>
<tr>
<td>STPLKL</td>
<td>Stacking category of SKU</td>
<td>Partly</td>
</tr>
<tr>
<td>CAT</td>
<td>Category of SKU</td>
<td>Partly</td>
</tr>
<tr>
<td>PZ</td>
<td>Pick zone of SKU</td>
<td>Partly</td>
</tr>
</tbody>
</table>

Based on these variables the following model can be made:

Relative location of SKU in DC = 0.733 + PZh01 * -0.599 + PZh02 * -0.377 + PZh03 * -0.187 + PZh83 * 0.340 + PZh82 * 0.315 + STPLKL12 * 0.261 + PZh81 * 0.286 + CAT4 * -0.059 + STPLKL1 * -0.096 + STPLKL8 * 0.098 + STPLKL10 * 0.119 + STPLKL9a * 0.088 + PZh06 * 0.249 + C_WEIGHT * -0.003

When the results of the regression analysis are studied in detail, it becomes clear that the dummy variables of the pick zone have a major influence on where a SKU is placed in the distribution center. The hypothesis that the pick zone of a SKU determines where a SKU can be placed in the DC can be confirmed for merely all the pick zones. To focus solely on the characteristics of the SKU, the regression analysis is repeated for the pick zones which contain enough SKUs to conduct a reliable analysis. The results from these analyses can be found in Table 14 for the pick zones of the LDC. It is taken into account that the VIF of the variables has to be smaller than 10.

Table 14: Results regression analyses of pick zones in LDC

<table>
<thead>
<tr>
<th>LDC Pick Zone</th>
<th>N</th>
<th>Adjusted R²</th>
<th>C_WEIGHT</th>
<th>C_DENSITY</th>
<th>C_HEIGHT</th>
<th>C_VOLUME</th>
<th>SUM_SKUS_PICKED</th>
<th>STPLKL</th>
<th>CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>H01</td>
<td>1743</td>
<td>66.2%</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Partly</td>
<td>Partly</td>
</tr>
<tr>
<td>H02</td>
<td>1753</td>
<td>75.6%</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Partly</td>
<td>Partly</td>
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<tr>
<td>H03</td>
<td>1400</td>
<td>17.4%</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Partly</td>
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<tr>
<td>H04</td>
<td>1796</td>
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<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Partly</td>
<td>Partly</td>
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<tr>
<td>H91</td>
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<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The regression analyses show there is a significant relation between the weight of a SKU and the relative location a SKU is placed in the DC for all the pick zones.

The hypothesis that the density of a SKU does not influence the relative location of a SKU in the DC is accepted, because this variable is not significant in the regression analysis for all the pick zones.

The hypothesis that the height of a product does not influence the relative location of a SKU in the DC is confirmed for two pick zones, because this variable is proven not to be significant when
determining the relative location of a SKU in the DC. For the other two pick zones this hypothesis is rejected, because the variable is significant for these pick zones.

The variable of the volume of the SKU is significant for two pick zones, and not significant for two pick zones. Therefore the hypothesis that the volume of a SKU has a positive relation with the location in the DC is accepted for two pick zones, and rejected for two pick zones.

For a part of the stacking categories of the SKUs the relative location they would be placed in the slotting of the DC differs significantly. For all pick zones a part of the stacking categories determine where a SKU is placed in the DC, and therefore this hypothesis can be confirmed.

The hypothesis that the number of SKUs picked is not significantly related to the location a SKU is placed in the DC can be accepted for all the pick zones.

For a part of the categories the relative location they would be placed in the slotting of the DC differs significantly, so the hypothesis that the category of a SKU does not influence the location in the DC it is placed is rejected. This is the case for all the pick zones.

**Conclusion regression analysis**

In the LDC only the weight and a few of the stackability class are in all the pick zones significantly related to the location a SKU is placed in the DC. Only for a few categories there exists a significant relation between the category of the SKU and the location a SKU is placed in the DC.

**Regression models pick zones LDC**

**LDC h01**

Relative location of SKU in DC = 0.231 + STPLKL1 * -0.197 + STPLKL4 * -0.078 + STPLKL13 * -0.275 + STPLKL8 * -0.202 + STPLKL7 * -0.172 + STPLKL2 * -0.136 + STPLKL2g * -0.125 + STPLKL1g * -0.208 + STPLKL3 * -0.132 + STPLKL3g * -0.096 + STPLKL6 * -0.121 + STPLKL138 * -0.247 + CAT13 * -0.013 + STPLKL11a * -0.211 + C_VOLUME * 2.381 + STPLKL4g * -0.059 + C_WEIGHT * -0.003 + CAT7 * 0.023 + CAT8 * 0.027 + CAT10 * 0.014

**LDC h02**

Relative location of SKU in DC = 0.367 + CAT4 * -0.074 + STPLKL10 * 0.115 + STPLKL9a * 0.089 + STPLKL6 * 0.061 + CAT10 * -0.034 + CAT7 * -0.033 + STPLKL4 * 0.017 + C_WEIGHT * -0.002 + STPLKL3 * -0.019 + C_HEIGHT * -0.070 + STPLKL7 * 0.036 + CAT 5 * 0.010 + STPLKL6g * 0.065 + STPLKL8 * 0.087

**LDC h03**

Relative location of SKU in DC = 0.568 + STPLKL7 * 0.037 + C_WEIGHT * -0.004 + STPLKL8 * 0.048 + STPLKL3g * -0.045 + CAT4 * 0.040 + CAT16 * -0.085 + STPLKL2g * -0.045 + STPLKL3 * -0.053 + STPLKL4g * 0.090 + STPLKL6g * -0.036

**LDC h04**

Relative location of SKU in DC = 0.771 + STPLKL8 * 0.091 + C_WEIGHT * -0.006 + STPLKL7 * 0.028 + CAT9 * 0.027 + CAT5 * -0.016 + C_HEIGHT * -0.134 + STPLKL7g * 0.085 + C_VOLUME * 0.644
B. REGRESSION ANALYSES PICK ZONES

RDC h01

Relative location of SKU in DC = 0.129 + CRUSH * 0.043 + CAT7 * -0.049 + C_DENSITY * -5.198E-005 + CAT13 * 0.037 + CAT12 * 0.047 + C_WEIGHT * -0.002 + CAT5 * 0.008

RDC h02

Relative location of SKU in DC = 0.373 + C_DENSITY * -3.382E-005 + CAT7 * -0.097 + CAT8 * -0.055 + CRUSH * 0.036 + CAT5 * -0.084 + C_WEIGHT * -0.003 + C_HEIGHT * 0.080 + CAT1 * 0.014 + C_VOLUME * 0.713

RDC h05

Relative location of SKU in DC = 0.728 + CAT7 * -0.037 + CRUSH * 0.044 + C_HEIGHT * -0.208 + C_VOLUME * 2.392 + C_WEIGHT * -0.006 + SumNoSKUsPicked * -4.514E-005

RDC h06

Relative location of SKU in DC = 0.871 + CAT4 * -0.026 + CAT11 * -0.017 + CRUSH * 0.028 + C_VOLUME * 1.018 + C_WEIGHT * -0.004 + CAT12 * 0.041 + C_HEIGHT * -0.039
C. DATASET SIMULATION MODEL

DATASET
In the research the orders from week 50 2012 until week 16 2013 are used. The original file consists of 67761 order lines, but only 52518 order lines are used in the analysis, because of several reasons. The first reason is that only the products not in promotion are studied. Also the display dollies with sodas are not part of the research, because they are not part of the ‘standard’ order picking zones. Finally, also the SKUs with no information about the characteristics of the SKU are filtered out.

The number of carriers used in this period is equal to 2652 for the RDC, when the carriers with only promotional items and the display dollies are filtered out. These 2652 carriers are not totally filled, because the order lines with SKUs with no SKU characteristics are filtered out. Based on volume these carriers are loaded for 59.26% and based on weight they are loaded for 46.17% on average.

CURRENT ORDER PICKING ALGORITHM
The current order picking algorithm is used on the dataset that is described in the previous section. The same slotting, and pick zones as in the current situation are used. The results show that for the given data set 1990 carriers are needed to load all the products on. This is a decrease of 25% compared to the number of 2652 carriers. Furthermore, based on volume the carriers are loaded for 65.37%, and based on weight for 52.69%. The difference between the number of carriers can be explained by the fact that these 2652 carriers were not totally full, because of the promotional items and SKUs without SKU characteristics on the carriers, which were not included in the dataset. The number of carriers available per delivery is based on the results of this analysis.
D. PSEUDO CODE HEURISTIC OPERATIONAL MODEL

NoLD - number of carriers
NoClusters - number of clusters
AisleNo - aisle number
VolClu - volume of cluster
WeiClu - weight of cluster
CarNo - number of carrier
CumVol - volume of carrier
CumWei - weight of carrier
CatD_{cluster, seed} – distance between category of cluster and category of seed in the store
CapVol – maximum volume that can be loaded on a carrier
CapWei – maximum weight that can be loaded on a carrier
α – importance of DC
β – importance of store

INPUT: NoLD, NoClusters, α, β
INITIALIZE: CarNo: = 0, CapVol := 0.85, CapWei := 400

FOR each cluster i
  Sort clusters based on increasing AisleNo, decreasing VolCl
  FOR each cluster j
    IF cluster j is not assigned to a carrier AND NoLD > 0 THEN
      NoLD = NoLD -1
      NoClusters=NoClusters – 1
      CarNo := CarNo + 1
      CarNo := carrier
      Cluster j := seed
      seed := carrier
      cluster jVolClu := carrierCumVol
cluster $j_{\text{WeiClu}} := \text{carrier}_{\text{CumWei}}$

EXIT FOR

END IF

END FOR

FOR each cluster $k$

IF cluster $k$ is not assigned to a carrier THEN

Calculate $V = 1 - (\alpha (\text{Abs}(\text{cluster}_{AisleNo} - \text{seed}_{AisleNo})) + \beta \text{CatD}_{\text{cluster}_{k, \text{seed}}})$

END IF

END FOR

Sort clusters based on decreasing $V$

FOR each cluster $n$

IF cluster $n_{\text{VolClu}} + \text{carrier}_{\text{CumVol}} \leq \text{CapVol}$ AND cluster $n_{\text{WeiClu}} + \text{carrier}_{\text{CumWei}} \leq \text{CapWei}$ AND cluster $n$ is not assigned to a carrier AND $V \geq 0$ THEN

$\text{NoClusters} = \text{NoClusters} - 1$

cluster $n := \text{carrier}$

cluster $n_{\text{VolClu}} := \text{carrier}_{\text{CumVol}}$

cluster $n_{\text{WeiClu}} := \text{carrier}_{\text{CumWei}}$

END IF

END FOR

IF NoLD=0 THEN

EXIT FOR

END IF

END FOR

FOR each carrier $m$

Sort clusters increasing $\text{carrier}_{\text{CumVol}}$

Select carrier with smallest volume loaded on it

Sort clusters based on increasing $\text{AisleNo}$, decreasing $\text{VolCl}$

FOR each cluster $i$

IF cluster $i_{\text{VolClu}} + \text{carrier}_{\text{CumVol}} \leq \text{CapVol}$ AND cluster $i_{\text{WeiClu}} + \text{carrier}_{\text{CumWei}} \leq \text{CapWei}$ AND cluster $i$ is not assigned to a carrier THEN


NoClusters = NoClusters - 1
cluster i := seed
cluster i := carrier m
cluster _VolClu := carrier m_CumVol
cluster _WeiClu := carrier m_CumWei

EXIT FOR
ELSE
Go to next carrier
END IF
END FOR
FOR each cluster k
IF cluster k is not assigned to a carrier THEN

Calculate V = 1 – (α (Abs(|cluster k_AisleNo – seed_AisleNo|) + β CatD_{cluster k, seed})

END IF
END FOR
Sort sheet based on decreasing V, and increasing delivery
FOR each cluster n
IF cluster n_VolClu + carrier m_CumVol <= CapVol AND cluster n_WeiClu + carrier m_CumWei <= CapWei AND cluster n is not assigned to a carrier m AND V >= 0 THEN

NoClusters = NoClusters - 1
cluster n := carrier m
cluster n_VolClu := carrier m_CumVol
cluster n_WeiClu := carrier m_CumWei

END IF
END FOR
END FOR
E. LAYOUT DC

Assumptions DC:

- All aisles have equal length
- The I/O point is located at the beginning of the DC, and the order picking trip ends also at this point
- When an even numbered aisle is visited, the next odd numbered aisle also has to be visited, therefore is assumed these two aisles are one aisle

Figure 16: Layout of RDC
F. VALIDATION OF TRAVEL TIME IN STORE IN CURRENT SITUATION

Store 1204 has 29.5 hours per week available for the non-perishable deliveries to perform the sorting process in the backroom of the store. To check whether it is realistic that this time is also used for the time needed to sort the products in the store during the shelf stacking process, the orders of week 50 2012 to week 16 2013 are studied in more detail. The sequence the products are loaded on a carrier is studied, and for every carrier is determined how many times the carrier should be moved between the aisles to perform the shelf stacking most efficient. Furthermore, the number of times a single SKU is brought to another aisle is determined. This choice is made when it is not efficient to move the entire carrier. An estimation of 90 seconds is made for the fixed time to move a carrier to another location in the store, and an estimation of 25 seconds is made for the fixed extra walking time for a single SKU. The first available SKUs on a carrier are studied and it is determined how many SKUs are from another aisle the carrier is located in. Based on this observation is decided, whether it is more beneficial to move the carrier or to walk to the other aisle. For every week the total stacking time (calculated based on the model of Curseu et al. (2009)), the total walking time for single SKUs, the total movement time with a carrier, and the total travel time in the store is determined, and the results are shown in Table 15. The average total travel time in the store is equal to 29.1 hours, which corresponds with the norm time of 29.5 hours for the sorting process in the backroom of the store.

Table 15: Analysis of shelf stacking time and travelling time in the store

<table>
<thead>
<tr>
<th>Week</th>
<th>Total stacking time (hours)</th>
<th>Total walking time for single SKUs (hours)</th>
<th>Total aisle change time with carrier (hours)</th>
<th>Total travel time in store (hours)</th>
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<tbody>
<tr>
<td>50</td>
<td>90.5</td>
<td>18.7</td>
<td>10.5</td>
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<td>Week average</td>
<td><strong>93.6</strong></td>
<td><strong>18.6</strong></td>
<td><strong>10.5</strong></td>
<td><strong>29.1</strong></td>
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