MASTER

Improvements on the order picking process at Sligro Food Group N.V.

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Improvements on the order picking process at Sligro Food Group N.V.

by

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Master of Science
in Operations Management and Logistics

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Abstract

This master thesis describes how the order picking process at Sligro Food Group N.V. can be improved by updating the order- and delivery schedule for its stores and the algorithm that is used to create batches that have to be picked in the distribution center. The order- and delivery schedule is updated to ensure that stores with similar ordering patterns are picked at the same time. Due to the unique order picking system it is possible to find the optimal composition of the batches. Implementing the new batching algorithm requires difficult software changes but leads to substantial expected cost savings. Updating only the order- and delivery schedule is easier to implement and also leads to cost savings, but these are difficult to quantify.
Preface

This report is the result of the master thesis project I have performed at Sligro Food Group. It is the last part that I need to complete to obtain my master’s degree in Operations Management and Logistics. I hope you enjoy reading this report as much as I enjoyed executing the project. First, I want to express my gratitude to some people that have helped and supported me during this project and during my student life.

First of all I would like start with thanking my mentor Rob Broekmeulen. His input has been very valuable and has really helped to complete the project. He was always available on short notice and the feedback I received was always motivating me to further improve the project. I would also like to thank my second supervisor Zumbul Atan for her input and the helpful critics on the research proposal and the concept report. This has really helped to improve the report.

Also I would like to thank Sligro Food Group for giving me the opportunity to execute this project and my colleagues for making my time at Sligro a pleasant one. Particularly I want to thank the employees of the Logistics and Process Management team at Sligro: Eric-Jan van Houtum, Arent Buijs, Peti Vilier and Edwin Dobbelsteen for their valuable input and helpful critics. Furthermore I would like to thank Sligro Food Group for giving me the opportunity to actually implement the changes I have proposed in this project.

Lastly I would like to thank my friends, family and fellow students for their continuous support. With the end of this project my life as a student also comes to an end. I am especially grateful that I have been given the opportunity to study a semester in South Korea, this has really broadened my view of the world. While this period of my life surely was an interesting and exciting one, I am excited to see what the next one will bring.

Luc Schilders

Veghel, May 2015
Management summary
A Dutch version of the management summary can be found in Appendix A.

Introduction
This report is the result of a master’s thesis project that is conducted at Sligro Food Group N.V. in Veghel, a company that operates in both the Dutch food retail and food service industries. Order picking is an important and labor intensive part of the handling process at the central distribution center. A few years ago paperless order picking was introduced within Sligro to improve the order picking processes within the organization. This means that nowadays a computer system rather than a sheet of paper tells the people in the distribution center which products have to be collected. This has led to a decrease in the number of mistakes and an increase in productivity and insight in the process. A batch of two orders is collected at the same time to reduce the average throughput time of the orders. This batch is created by a batching algorithm that awards points based on the number of similarities between orders. A similarity exist when both orders contain order lines that are located in the same section in the distribution center.

The order- and delivery schedule consists of the days that product groups are allowed to generate an order advice and the times a truck should be loaded, called dock times. This schedule influences the order picking process because it determines the days at which product groups can be ordered and the days and times at which orders are picked. The dock times determine the times at which trucks are loaded and which orders can be together in a batch. This is because the batching algorithm only considers orders from the same dock time when creating a batch. A well aligned schedule can ensure efficient operations at both the central distribution center (CDC) and the stores. The frequency of order moments has been determined in a previous project at Sligro but the alignment of these moments hasn’t received much attention.

This led Sligro to believe that there is still room for improvement in the order picking process. Currently it is not known what the improvement potential is that can be obtained by realigning the order- and delivery schedule. Furthermore it is not clear how the schedule should be changed to utilize this potential. This has led to the following research question:

*How should the order- and delivery schedule be rearranged and how should the batching algorithm be changed in order to improve the batch order picking process at the central distribution center?*

In this project only one distribution center (WYG) is analyzed. The same logic and analysis can be applied to the other distribution centers of the CDC because orders are collected in the same way throughout the CDC.

Analysis current situation
Improvement of the order picking process is measured by picker productivity, which means that the time needed to pick an order is reduced. In this project the sum of navigation time and picking time is the objective. Reducing this time increases productivity. Navigation time is defined as the time between when an order picker confirms a product has been picked and when he confirms that he is at the location of the next order line. This time can be short when the picking cart can stay in the same place for picking the next order line, or longer when this it has
to be moved. Picking time is defined as the time that runs from when the picker confirms he is at the right location until the picker confirms he has placed the products on the pallet.

Analysis of the current situation of the weeks 2 to 13 of 2014 (60 days, 3102 orders) in the WYG DC shows that there is a significant difference in productivity between employees. Some employees pick 600 products per hour while others pick as much as 1400 products per hour. From the analysis of the order picking characteristics shown below in Figure 1 the following five things can be concluded:

- First, the average number of products in a batch increases when more aisles have to be visited.
- Second, the number of order lines increases when more aisles need to be visited, up to a certain extent.
- Third, the number of products per order line declines when more aisles are visited.
- Fourth, more order lines per hour get picked when more aisles are visited.
- Fifth, when products in a batch are spread over more aisles, the number of picked products per hour decreases.

These effects are all straightforward and no unexpected relations were found.

Furthermore it becomes clear that the current situation differs from the situation as it has been defined. A large part of the batches that actually have been created contain orders from different dock times (34%) or only one order (5%). In theory, this number should be very low, which means that the rules of the batching algorithm are often violated, for reasons such as priority orders or imperfections of the people who release the orders.

The average number of batching points is rather constant per weekday and per week in the analyzed period. The workload however does fluctuate per weekday and per hour of the day, which can be explained by the current unbalanced layout of the order- and delivery schedule. A yearly pattern in demand can be seen for every DC. In the first three months of the year demand is at its lowest of the year. After this a period with holidays starts, that includes the summer. After the summer demand declines again. December is the last period of the year, with high demand due to Sinterklaas and Christmas.
Redesign
The research question states that both the order- and delivery schedule and the batching algorithm are suboptimal and should be redesigned. The order- and delivery schedule is suboptimal because it is not yet aligned and the current batching algorithm is not optimal because for the order picking conditions at Sligro the optimal algorithm can be used, but this is not the case. Finding stores with a similar ordering pattern and combining them in a dock time increase the performance of the batching algorithm and thus picker productivity. Because a batch at the CDC consists of a maximum of two orders, the optimal solution can be found within polynomial time using weighted matching.

Similar ordering patterns between stores are found by matching orders from an entire week. Dock times are created with a batching algorithm with a capacity of eight stores. The largest store in terms of number of order lines is selected first and the stores with most matching orders are added to the dock time. A new dock time is created when the dock time is full.

Creating new dock times this way leads to a 5.2% increase in similarities between orders for a control period when the current batching algorithm is used and another 6.5% increase in batching points when the weighted matching is used to find the maximum number of batching points compared to the situation as it was realized.

Changing the batching algorithm to the weighted matching algorithm means that also the objective function can be changed. A multiple linear regression model show that picking time can be predicted by the number of products in a batch while navigation time can be predicted by the number of order lines, the number of batching points and the number of aisles to be visited for that batch. This model is as follows:

\[
\text{Navigation time} = 4,428 + 0,270 \times \text{Order lines} - 0,064 \times \text{Points} + 1,597 \times \text{Aisle6} \\
+ 3,339 \times \text{Aisle8} + 4,252 \times \text{Aisle10}
\]

Changing the objective function of the weighted matching solution to this navigation time means that the time that is needed to pick the batches can be minimized. This optimization can be translated in cost savings directly because the savings are expressed in minutes.

The analysis shows that over 200 hours of navigation time can be saved in the WYG DC in half a year. Extrapolating this for the entire CDC leads to expected yearly cost savings of over €180.000. When only the dock times are changed, the expected cost savings are over €7.000. When also the product groups that can be ordered in these dock times are aligned, cost savings can increase, but it is unsure to which extent.

Implementation
Changing the dock times and the order moments of product groups merely consists of changing parameters in the system. Changing the batching algorithm to the weighted matching solution requires adaptations in the order releasing software Compass. Since this software is custom made for Sligro, implementing these changes is a realistic option.

The people responsible for these changes within Sligro should assess whether it is worthwhile to implement the changes proposed in the redesign. To minimize the risk, it is also possible to implement the redesign step by step, for example by changing the dock times and the order moments of product groups for a single distribution center first.
Conclusions and recommendations

The analysis of the current situation has shown that the workload distribution at the distribution centers is not equally divided amongst the dock times because of the unequal number of stores in each dock time. It has also become clear that several demand periods can be distinguished within a year and that these periods differ slightly for each distribution center. Furthermore it was shown that the productivity of the order pickers differs greatly. The performance of the batching algorithm is shown to be suboptimal. Also, it has become clear that in a large percent of the cases, the dock time restriction is violated because the majority of the batches (34%) consists of orders from stores of different dock times.

It has become clear that changing the batching algorithm to the weighted matching solution leads to a higher average number of batching points. The increase is about 6.5% for the analyzed period in the WYG DC. Furthermore, the redesign of the order- and delivery schedule leads to a more equally distributed number of batches per dock time. This can be explained by a more equal division of stores to the dock times in the new situation.

Aligning the product groups within a dock time helps to increase the average batching points even further. This ensures that potential similarities between stores can actually be utilized. Expected cost savings range between €7,000 when the dock times are updated and €180,000 when the optimal batching algorithm is used to minimize the expected navigation time.

It is recommended to further investigate:

- To which extent it is possible to align the product groups and update the dock times without hurting store operations.
- Whether it is worthwhile to implement changes to the batching algorithm.
- In what sequence/phases the proposed redesign should be implemented.

On an academic level, this project contributes to the literature by quantifying the improvements that can be achieved when the optimal weighted matching method as proposed by Gademann & Van de Velde (2005) is used instead of a sub-optimal algorithm. The difference between the seed-order, accompanying order selection algorithm currently in use at Sligro and the weighted matching solution has been presented in this research.

Limitations of this project are that the optimal weighted matching solution that is presented in this research is based on the biggest number of similarities between orders and the navigation time. Other methods are not considered. Also, the optimal solution is only compared with the current batching algorithm at Sligro and is only used for the specific warehouse conditions at the CDC. Comparing the weighted matching solution with heuristics for other warehouse conditions might provide useful insight in the performance of those heuristics.
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<th>Definition</th>
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</thead>
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<tr>
<td>ABS</td>
<td>Automatic ordering system</td>
</tr>
<tr>
<td>BS</td>
<td>Delivery service outlet</td>
</tr>
<tr>
<td>BUL</td>
<td>Distribution center for bulky products, part of the CDC</td>
</tr>
<tr>
<td>CDC</td>
<td>Central distribution center, located in Veghel</td>
</tr>
<tr>
<td>CPS</td>
<td>Case pack size</td>
</tr>
<tr>
<td>DE</td>
<td>Demand expectation</td>
</tr>
<tr>
<td>DIE</td>
<td>Distribution center for frozen products, part of the CDC</td>
</tr>
<tr>
<td>FD, FD2, FD3</td>
<td>Distribution centers for food products, part of the CDC</td>
</tr>
<tr>
<td>KND</td>
<td>Distribution center for non-food products, part of the CDC</td>
</tr>
<tr>
<td>MAX</td>
<td>Maximum quantity a store wants of a product</td>
</tr>
<tr>
<td>MIN</td>
<td>Minimum quantity a store wants of a product</td>
</tr>
<tr>
<td>OA</td>
<td>Order advice</td>
</tr>
<tr>
<td>RDC</td>
<td>Retail distribution centers, located in Kapelle and Putte</td>
</tr>
<tr>
<td>SFG</td>
<td>Sligro Food Group N.V.</td>
</tr>
<tr>
<td>SKU</td>
<td>Stock keeping unit</td>
</tr>
<tr>
<td>VRS</td>
<td>Distribution center for fresh products, part of the CDC</td>
</tr>
<tr>
<td>WYG</td>
<td>Distribution center for wine and distilled products, part of the CDC</td>
</tr>
<tr>
<td>ZB</td>
<td>Cash &amp; carry outlet</td>
</tr>
</tbody>
</table>
1. Introduction
This chapter serves as the introduction to the report on the Master thesis project performed at Sligro Food Group in partial fulfillment of the requirements for the degree of Master of Science in Operations Management and Logistics. In the first part of this chapter the organization structure will be described. The second part focuses on the part of the company where the project has been executed. The third section introduces the problem that is the subject of this project while the last section describes the outline of this document.

1.1. Sligro Food Group N.V.
Sligro Food Group N.V. started in 1935 as a wholesaler in margarine, fats and oils. Through organic growth and acquisitions it has grown to a company that encompasses food retail and foodservice selling directly and indirectly to the entire Dutch food and beverages market. In the Dutch food retail market, Sligro Food Group is represented with their 130 EMTÉ supermarkets, of which 30 are independently operated by franchisers. With these supermarkets Sligro is only a small player in the food retail industry, having a steady market share of 2.7% the last few years. The foodservice market is split into two parts: cash & carry and delivery-service. Sligro Food Group has 47 cash & carry outlets and 10 delivery-service outlets spread throughout The Netherlands. With a market share that has grown steadily to 21.2% in 2013, Sligro is the market leader in the foodservice industry. Next to this, also some specialized production facilities are part of the Sligro Food Group. The organization is managed from the central distribution center and head office in Veghel. Support functions are also located here. An overview of this organization structure can be found in Figure 2 below.

<table>
<thead>
<tr>
<th>Central distribution center and head office Veghel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Food retail</strong></td>
</tr>
<tr>
<td>EMTÉ</td>
</tr>
<tr>
<td>130 own and franchised supermarkets</td>
</tr>
<tr>
<td>2 distribution centers</td>
</tr>
</tbody>
</table>

**Sligro Fresh Partners & Production**
Specialized production facilities for convenience products (CuliVers), fish (SmitVis), and patisserie (Maison Niels de Veye) and participating interest in four fresh food associates

Figure 2 - Organizational structure Sligro Food Group N.V.

Net sales increased in 2013 to almost 2.5 billion euros while net profit decreased with 1 million to 68 million euros compared to 2012. The division of the net sales between the different parts of the organization can be found below in Figure 3.
1.2. Warehouse operations

The flow of goods to and from the different outlets go via Sligro’s various distribution centers. There are two retail distribution centers (RDC’s) that supply the retail stores and a central distribution center (CDC) that supplies the foodservice outlets and the retail distribution centers. The central distribution center is divided into several specialized distribution centers, with each one dedicated to products with specific characteristics. Goods can in some cases also flow from the cash & carry wholesale outlets (ZB’s) to the delivery-service (BS’s) outlets or directly from a supplier to a retail store or delivery-service outlet. There are also a lot more specific flows between specific outlets, but the most important ones and the ones relevant for this project are depicted below in Figure 4. The thickness of the arrows is no indication for the volume of that flow.

Figure 3 - Division of sales between parts of the organization (Source: Annual report SFG 2013).

Figure 4 - Flow of goods.
As can be seen in Figure 4 above, there are a lot of flows between the different parts of the organization. In total, the CDC handles over 175 million products each year. Handling costs at the distribution centers and the outlets make up for a large share of the total costs, which means that reducing these costs has a significant impact. That is the reason why Sligro Food Group is always trying to improve these handling processes at the CDC.

1.3. Problem introduction
Order picking is an important and labor intensive part of the handling process at the CDC. A few years ago paperless order picking was introduced within Sligro to improve the order picking processes within the organization. This means that nowadays a computer system rather than a sheet of paper tells the people in the distribution center which products have to be collected. This has led to a decrease in the number of mistakes and an increase in productivity and insight in the process.

The order- and delivery schedule consists of the days that product groups are allowed to generate an order advice and the times a truck should be loaded, called dock times. This schedule influences the order picking process because it determines the days at which product groups can be ordered, the times at which orders are picked and the times that trucks are loaded. A well aligned schedule can ensure efficient operations at both the central distribution center and the stores. The frequency of order moments has been determined in a previous project at Sligro but the alignment of these moments hasn’t received much attention.

This led Sligro to believe that there is still room for improvement in the order picking process. Currently it is not known what the improvement potential is that can be obtained by realigning the order- and delivery schedule. Furthermore it is not clear how the schedule should be changed to utilize this potential.

1.4. Report outline
In this chapter the Master Thesis project that has been executed at Sligro Food Group in Veghel was introduced. The project has followed the model presented by Van Aken et al. (2012) based on the regulative cycle by Van Strien (1997). The rest of this document is structured as follows. The second chapter provides a more detailed description of the problem that is the subject of this project. In the third chapter a summary of the literature that is relevant for the problem at hand is presented. This summary provides an overview of what has already been done in this field of research and what contribution this project can make to the literature. Hereafter the current situation is analyzed, which forms the basis of the rest of the project. In chapter five the redesign is presented, alongside with its impact on the different systems and KPI’s. The expected benefits due to the redesign are also calculated in this chapter. Chapter six discusses how the proposed redesign can be implemented while also indicating points of attention regarding the implementation. General conclusions and recommendations towards Sligro form the last part of this report.
2. Problem definition
In this chapter of the report, the problem will be defined. First, the problem context will be given. The scope of the project is determined in the second section. This will form the basis for the problem statement which will be stated and explained next. The last part of this chapter consists of the research questions.

2.1. Problem context
This project was initiated because the productivity of the order pickers has only increased moderately since the paperless order picking system called PickArts was put in use at the CDC. This led Sligro to believe that there is still room for improvement in the order picking process at the distribution centers. An improvement in this process can have a large impact on the costs because warehousing is an important and labor intensive function within the Sligro Food Group.

The order pickers operate a vehicle in the distribution centers that can hold two pallets and each pallet holds one customer order. PickArts creates and releases batches of two orders using a batching algorithm so that the vehicles collect one batch at a time.

As stated before, all stores order and receive product groups according to a fixed order and delivery schedule. The stores have a big influence on which days they can order and receive certain product categories. Good reasons exist for these preferences, like not wanting to have a big delivery during peak days or desiring delivery of product groups that are located next to each other in the store on the same day. Also some less good reasons might exist, like someone not wanting to work on a certain day of the week.

The dock times are also part of the order and delivery schedule. Dock times determine when trucks are loaded to replenish the stores. These have grown so historically or have been set to store preferences. The assignment of stores to dock times has an influence on the order picking process at the CDC because the batching algorithm only considers orders from stores within the same dock time, meaning that the results of the batching procedure depend on the dock times. At the moment this is not taken into consideration.

This has resulted in an order and delivery schedule that is optimized in the direction of the stores, meaning that on the other hand concessions were made at the distribution centers. Since the order picking process is influenced by the order and delivery schedule, redesigning it while taking into account the handling at the central distribution center can lead to more efficient order picking. Because more than 175 million products are handled at the CDC annually, a small increase in productivity can lead to significant savings.

The batching algorithm might perform better when stores are assigned to dock times according to their order composition and when the order moments of product groups for these stores are synchronized. Higher scores are expected have a direct impact on the order picking process, since this would reduce the distance and thus the time that is needed to collect all items. Currently it is not known whether stores exist that have similar order compositions within product groups. Sligro wants to gain insight into how the order and delivery schedule can be adapted in such a way that stores with similar order compositions are grouped together while taking into account restrictions like keeping the workload balanced at the distribution centers and the transportation planning.
Currently, the batching algorithm selects a seed order based on the expected time needed to pick all items in it. The accompanying order is selected based on the number of identical picking sections and picking aisles. This algorithm does not produce optimal results and it is not known what the improvement would be when another algorithm is used.

2.2. Scope
This section describes the scope of the project. The scope is used to delineate the research area and to ensure that the project on the one hand can be completed within the set time frame but on the other hand that the project is still large enough to have a significant impact.

As described previously, various order picking methods are being used within Sligro. The focus in this project is on the PickArts system because this method is used for collecting most products and this system allows the batching of orders. Other methods are left out of this research because they would either make the project too big and complex or they are not suitable for order batching (e.g. full pallet distribution and put to light).

Even though the PickArts system is used to pick orders in both the RDC’s and the CDC, this project only focuses on the CDC because this is where the project was initiated. More specifically, the analysis for this project only focuses on the wine (WYG) distribution center for simplicity reasons. When this is successful, the same logic can be applied to the other distribution centers in the future.

The order batching algorithm is in the scope of the project. Many different batching algorithms exist and it is interesting to compare the current performance of the algorithm with the optimal solution.

The order frequency of the product groups for all stores has been determined in a previous project by minimizing the number of order lines, taking into account the shelf life of products and the shelf capacity in the stores. This parameter is taken as a given and out of scope of this project.

2.3. Problem statement
Taking into account the problem context and the scope as described in the previous sections, the problem statement is formulated as follows:

*The problem is that batch order picking at the central distribution center is not performed in the most efficient way due to the current layout of the order and delivery schedule and due to the chosen batching algorithm.*

The problem statement forms the basis for the research questions, which will be presented in the next section. The rest of this project will focus on finding a solution for the statement presented here.

2.4. Research questions
In this section, the research questions for the project will be presented and discussed. As explained in the problem definition section, the problem is that the batch order picking process at the central distribution center is currently not performed in the most efficient way due to the layout of the order and delivery schedule and due to the chosen batching algorithm, taking into account the scope of the project. The research question that is created from this problem is formulated as follows:
How should the order- and delivery schedule be rearranged and how should the batching algorithm be changed in order to improve the batch order picking process at the central distribution center?

The order- and delivery schedule consists of the information on which days stores can order a product group and the dock times for each store for each distribution center. The batching algorithm that is currently in use does not produce the optimal solution, while the current situation can accommodate an algorithm that can calculate the optimal solution. This will be explained in the next chapter. However, the applicability of another batching algorithm depends on its complexity, ease of implementation, improvement potential and possible side effects.

To help answer the main research question, four sub-research questions have been formulated. These questions are presented below.

1. What is the current situation and performance of the order and releasing processes at the central distribution center?

To determine a baseline for the project, the as-is situation should be analyzed first. The first sub question is therefore focused on the current situation and performance of the order releasing and picking processes at the central distribution center.

2. What are the effects of rearranging the order- and delivery schedule and changing the batching algorithm?

The second sub question considers the effects of rearranging the order- and delivery schedule and the effects of changing the batching algorithm. The actual redesign is also part of this question.

3. What are the expected benefits of implementing the proposed redesign?

In the third sub question the expected cost savings due to the redesign are calculated. Furthermore, the expected effects on the workload at the CDC and the stores and other effects due to the changes are measured.

4. How can the changes in the order- and delivery schedule and batching algorithm be implemented?

The fourth sub question regards the implementation of the proposed redesign. It is checked whether it is feasible and worthwhile to implement the proposed changes and also which systems need to be changed. Furthermore this question answers how often the redesign should be revisited.

When all these sub-question are answered, the answer to the main research question can also be given. The rest of this report follows the structure of these research questions, the chapters are in the same order.
3. Literature review

In this chapter a brief overview will be presented on specific parts of warehouse operations. It is a summary of the literature study (Schilders, 2014) that was performed in advance of this project. Tompkins et al. (2010) show that the typical distribution of costs as a percentage of the warehouse operating expense can be divided over four categories: order picking (55%), shipping (20%), storage (15%) and receiving (10%). The first part of this chapter will focus on order batching, which is part of the order picking process and which is a popular strategy that is often used in warehouses to reduce the mean throughput time per order (Van den Berg, 1999).

A batch can be defined as a collection of orders that get collected at the same time. Many algorithms and heuristics can be found in the literature that create such batches. The second part of this chapter will focus on the periodic vehicle and the periodic inventory routing problem. These types of problems combine warehouse operations with the vehicle routing problem. In the last part of the literature review the contribution of this project to the literature is explained.

3.1. Order batching

Order batching has received a lot of attention in academic literature. Because the batching problem is NP-hard in most situations, many heuristics and algorithms have been developed that can be used under different circumstances. The warehouse layout, capacity of the picking vehicle, traversal strategy, storage strategy and many more variables are changed to check the performance of the algorithm under certain circumstances.

All research that has been studied in this literature review shows that there are improvement possibilities with respect to the more simple or random methods. The problem with most of the complex batching methods is that for large size problems the computation time is quite long. Furthermore, it is difficult to compare the batching methods because different parameter settings are used in each publication.

The batching method that is currently in use at Sligro first selects a seed order: the largest order in terms of products and order lines to be picked. Next, it selects the order with the largest number of similar picking locations and aisles and finally it creates a batch. A very similar algorithm has been studied by Ho & Tseng (2006). These authors compare nine different selection rules and ten different similarity rules and find out that under their assumptions smallest-value-based seed selection rules perform better than greatest-value-based seed algorithms. Furthermore, the smallest-value-based seed selection rules perform best with smallest additional number of picking location rules while greatest-value-based seed selection rules perform best with greatest number of identical locations/aisles rules. This means that the batching method used at Sligro performs worse than the best solution method that is included in this study.

A finding that is important for this project is described in Gademann & Van de Velde (2005). These authors prove that when a batch consists of a maximum of two orders, the order batching is not NP-hard so that the optimal solution can be found using weighted matching within polynomial time. Because the picking vehicles with the PickArts system can only accommodate two orders, the optimal solution can be calculated for the situation at Sligro for this order picking system.
3.2. Periodic vehicle and inventory routing

A large amount of literature has been published on both the periodic vehicle routing problem and the periodic inventory routing problem. Since these problems exist in a wide range of industries, a lot of variations have been introduced. Most papers present a linear programming model and heuristics to come to a solution for the specific situation. Cost savings are often several percentage points, translating in big cost savings due to the high costs involved with distribution. The literature that is relevant for this project, is quite scarce. The retail industry with a warehouse and multiple stores has received quite some attention, but the operations in the warehouse are often left out of the scope of the research.

Only few articles have been published that extend the inventory routing problem by taking the workload at the distribution center into account. Gaur & Fisher (2004) describe a periodic inventory routing problem at a supermarket chain in their research. This supermarket chain periodically updates their delivery schedule and vehicle routing to deal with demand variation. The retail stores are replenished from the distribution center several times per week. Once the delivery schedule with delivery times has been determined, it stays the same for the period. The demand at the retail stores is dynamic, as it can vary over time. Some of the trucks that are used to replenish the stores are owned by the supermarket chain, but most trucks are leased. Workload at the distribution center has to be balanced to ensure that capacity constraints are met. First, clusters of stores are made based on their geographical location. From these clusters the routes are determined. After this the trucks are assigned to the routes and the workload at the DC is balanced. The authors assume a single product, because it is sent from one distribution center. Their goal is to minimize the total transportation costs. They model this problem by representing it with a graph consisting of nodes and edges. The nodes represent the delivery days and the edges represent successive deliveries. By finding the shortest path in the graph, the total costs associated with the edges are minimized. This method led to 4% savings in distribution costs compared to the current situation.

Ronen & Goodhart (2008) also introduce a system that considers the connection between the operations in the distribution center and the planning of the vehicle routing. This system is used to create a planning for replenishing retail stores. Store requirements, transportation capacity and workload constraints at the distribution center are taken into account in order to create a vehicle route planning at minimal costs. The environment of this system can be described as follows: retail stores are supplied by the distribution center and each store is supplied by trucks from the distribution center a fixed number of times each week. This frequency can change during the year because of peaks in demand. Several stores can be replenished on one route and routes can vary during the week due to variations in demand. Deliveries are made from Monday through Saturday, some stores requesting delivery before a certain time. Different truck sizes are used to replenish the stores. Order picking at the distribution center is done in batches and the limited capacity requires workload balancing at the DC. The authors approach this problem by first clustering the stores based on their geographical locations. Next, delivery days are assigned to stores using a capacitated assignment model such that the workload at the distribution center is balanced and capacity constraints are met. In the last step vehicle routes are created for each day that products are shipped. This model is compared with a manual planning of the vehicle routes, resulting in 1 to 5% cost reduction. The computation time is about ten minutes, which is a lot faster than manually calculating a solution.
The articles published by Gaur & Fisher and Ronen & Goodhart match the situation at Sligro quite well. The difference is that Sligro wants to incorporate the order picking process into the problem while the mentioned articles simplify this to a single product. No literature has been published yet that takes the warehouse operations in more detail into account, like product groups, the order picking process or order characteristics at the distribution center.

3.3. Contribution to the literature

The optimal solution that can be found when the batch consists of two orders has received little academic attention. All research that has been discussed in this chapter assumes that a batch consists of more than two orders, excluding the possibility of using weighted matching to find the optimal solution. This project will contribute to the literature by quantifying the improvements that can be achieved when the optimal method is used instead of a sub-optimal algorithm. However, since only the specific situation at Sligro will be considered, the generalizability will be limited.

Changing the order and delivery schedule will also have an effect on the transportation planning towards the stores. This so-called inventory routing problem has been studied thoroughly in the literature. Few articles however take into account the operations at the distribution center, which is relevant for this project. Furthermore, in these relevant papers the operations at the warehouse are limited to the capacity of loading trucks per time interval, simplifying the warehouse operations to a single homogenous product. No literature has been published yet on the relation with order picking at the warehouse. As stated in the beginning of this chapter, this makes up a big part of the total costs at the warehouse. This project will contribute to the literature by studying the effect on order picking performance by influencing the order- and delivery schedule.
4. **Analysis current situation**

In this section of the report, the current situation will be analyzed. On the one hand this is done to gain insight in the processes and on the other hand will analyzing the current situation help to determine a baseline for the rest of the project, allowing a comparison between the as-is situation and the proposed redesign.

4.1. **Layout order- and delivery schedule**

In this section the current layout of the order- and delivery schedule will be analyzed and discussed. The schedule consists of the dock times for each store for each distribution center and the order moments of each product group for each store. This schedule is quite large since Sligro’s assortment is divided over nearly 300 product groups. Almost 100 product groups are seasonal and therefore have no standard order days. Not all outlets have the same assortment due to the limited availability of space in small outlets. ZB’s have between 163 and 195 groups in their assortment while a total of 8514 product group - store combinations have been defined for the ZB’s. 275 of these combinations can be ordered five times a week, 62 four times, 924 three times, 4157 two times and 3096 combinations can be ordered once per week. When a group can be ordered five times a week, only one schedule is possible. For each of the other cases, five different schedules are currently in use. An overview of the combinations currently being used can be found below in Table 1 below.

<table>
<thead>
<tr>
<th>Order moments</th>
<th>mon, tue, wed, thu, fri</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 order moments</td>
<td>mon+wed, mon+thu, tue+thu, tue+fri, wed+fri</td>
</tr>
<tr>
<td>3 order moments</td>
<td>mon+wed+fri, tue+thu+fri, mon+tue+thu, mon+wed+thu, tue+wed+fri</td>
</tr>
<tr>
<td>4 order moments</td>
<td>all days excluding either: mon, tue, wed, thu, fri</td>
</tr>
</tbody>
</table>

Table 1 - Order moments during the week.

This means that the total number of possible schedules can be calculated as follows: \(1^{275} \times 5^{62} \times 4^{924} \times 3^{4157} \times 2^{3096}\). On Mondays 3099 groups are allowed to generate an order advice, on Tuesdays 3220, on Wednesdays 3169, on Thursdays 3101 and on Fridays 3216. The situation for each DC can be found in the table below on the left. It can be seen that the distribution is not as flat as the total for all distribution centers combined. The BS’s don’t compensate for this variation, when they are included roughly the same pattern can be found. This can be seen in Table 2 below, on the right.

<table>
<thead>
<tr>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUL</td>
<td>319</td>
<td>327</td>
<td>380</td>
<td>290</td>
</tr>
<tr>
<td>DIE</td>
<td>361</td>
<td>309</td>
<td>349</td>
<td>339</td>
</tr>
<tr>
<td>FD</td>
<td>537</td>
<td>633</td>
<td>550</td>
<td>579</td>
</tr>
<tr>
<td>FD2</td>
<td>493</td>
<td>506</td>
<td>427</td>
<td>439</td>
</tr>
<tr>
<td>FD3</td>
<td>178</td>
<td>186</td>
<td>197</td>
<td>194</td>
</tr>
<tr>
<td>KND</td>
<td>501</td>
<td>517</td>
<td>535</td>
<td>492</td>
</tr>
<tr>
<td>VRS</td>
<td>629</td>
<td>659</td>
<td>646</td>
<td>698</td>
</tr>
<tr>
<td>WYG</td>
<td>81</td>
<td>83</td>
<td>85</td>
<td>70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUL</td>
<td>421</td>
<td>411</td>
<td>487</td>
<td>414</td>
</tr>
<tr>
<td>DIE</td>
<td>466</td>
<td>439</td>
<td>451</td>
<td>457</td>
</tr>
<tr>
<td>FD</td>
<td>733</td>
<td>764</td>
<td>705</td>
<td>685</td>
</tr>
<tr>
<td>FD2</td>
<td>618</td>
<td>588</td>
<td>567</td>
<td>538</td>
</tr>
<tr>
<td>FD3</td>
<td>212</td>
<td>234</td>
<td>241</td>
<td>238</td>
</tr>
<tr>
<td>KND</td>
<td>538</td>
<td>744</td>
<td>623</td>
<td>612</td>
</tr>
<tr>
<td>VRS</td>
<td>868</td>
<td>844</td>
<td>870</td>
<td>934</td>
</tr>
<tr>
<td>WYG</td>
<td>101</td>
<td>106</td>
<td>109</td>
<td>91</td>
</tr>
</tbody>
</table>

Table 2 - Number of groups allowed to generate order advice for each weekday. Left: ZB, Right: ZB+BS.
The review period can be defined as the time between two order moments. It depends on the number of times a group is allowed to order each week, but also on the division of the order moments over the week. The review period partly determines the order advice since more products are needed to cover a longer period. For each distribution center, the review period differs slightly for each weekday. Groups in the KND DC generate 1,2 times a week on average, groups in the VRS DC 2,5 times and groups the rest in the distribution centers generate an order advice approximately 2 times per week for each store. Naturally, the review periods for the KND DC are therefore longer, while for the VRS DC they are shorter. Later on in this report the relation between the length of the review period and the order size will be analyzed.

When a store manually orders from product groups that are not generating an order advice that day, it is still being picked on that day when other groups in the same distribution center are generating an order advice. Otherwise the order is picked the next time a group in the corresponding DC generates an order advice.

Each store is loaded into a truck on a predefined time called a dock time.

The dock times are currently divided into two parts, one part for the morning and one for the afternoon. For each part three dock times exist, containing several stores. The order picking system PickArts is also divided into these dock times. This means that only orders that are released with the same dock time can be batched together. The division between morning and afternoon has been made because truck drivers usually drive two tours each day, one in the morning and one in the afternoon. Currently, the dock times are 8:00, 9:00, 10:00 in the morning and 14:00, 15:00, 16:00 in the afternoon. A dock time in the morning means that the truck will be loaded and delivered in the afternoon. A dock time in the afternoon means that the truck will be preloaded for delivery the next morning. Dock times are aligned between the distribution centers to ensure there is enough time to shuttle small orders or to ensure that the driver has enough time to load the truck at multiple locations if necessary.

In the current situation the number of stores in each dock time is not distributed equally. Some dock times contain more stores than others. It can be possible for a store to be assigned to multiple dock times when that store receives multiple deliveries on a day. The unequal division of stores in dock times doesn’t have to be a problem, since multiple small stores can generate the same volume as one large store. In the case that a dock time contains only a few stores, the options for the batching algorithm are limited, making it more difficult to create batches with high congruency between the orders. This might have a negative influence on the order picking productivity.

4.2. Picker productivity and order composition

The picker productivity measure is the subject of this research. The ultimate goal of this project is to increase the productivity. To be able to improve this KPI, it first has to be defined uniformly because it can be interpreted in multiple ways. Currently picker productivity is measured weekly for each area of each distribution center as the average number of products picked per hour, provided that the order picker has picked more than a certain amount of batches in that area in that week. The number of order lines in a batch, the number of aisles to be visited for the batch and other variables are disregarded in this measure, since it is believed that these are averaged out over the batches over the week.
The time that is needed to collect an order consists of loading, navigation, picking and unloading time. When an order picker accepts a batch the loading time starts. Loading time is defined as the time that is needed to load empty pallets on the picking cart. This time is rather constant for all batches because it independent of the composition of the batch. Navigation time is defined as the time between confirming a product has been picked and confirming that the order picker is at the location of the next order line. This time can be short when the picking cart can stay in the same place for picking the next order line, or longer when this it has to be moved. Picking time is defined as the time that runs from when the picker confirms he is at the right location until the picker confirms he has placed the products on the pallet. Unloading time runs from when the picker has confirmed he has picked the last order line until he has unloaded the pallets at the right place at the expedition area. This time is again roughly the same for all batches, for the same reason mentioned above.

The navigation time combined with the order picking time is called the collection time and taken as the objective for this project because the loading and unloading times are independent of the batch composition. Picker productivity is inversely proportional to the collection time because when productivity is higher, collection time is shorter. In this project the number of order lines, the number of aisles to be visited, the number of batching points and number of products in the batch will be taken into account when calculating collection time. The objective is to increase productivity by decreasing the expected collection time.

![Order picker characteristics](image)

**Figure 5 – Order picker characteristics in the WYG DC in the first three months of 2014.**

To check the current order picker characteristics, data from the WYG DC from the first twelve weeks of 2014 is analyzed. Employees that have less than five batches in the specified period are excluded from the analysis. As can be seen from Figure 5 above, the average number of products and the average number of order lines that get picked per hour differs greatly per employee. It can be seen that these two measures are correlated. Employees who pick more products per hour on average also pick more order lines per hour on average. On the other hand, the average number of visited aisles is slightly lower for employees who pick more products per hour. While the average number of products and order lines in a batch differs per employee,
there is no relation between productivity and average number of products or order lines in a batch.

Next, the influence of the number of aisles that have to be visited to collect a batch on order picking characteristics will be discussed. In Figure 6 below the following five variables can be found.

- First, the average number of products in a batch increases when more aisles have to be visited. This can be explained by the fact that batches with few products also have to visit only few aisles. So when more aisles have to be visited, more products are in the order. This relation holds to a certain extent because the volume that fits on a pallet is limited.

- Second, the number of order lines increases when more aisles need to be visited, up to a certain extent. The reason for this is that when a batch consists of only a few lines, the chance is big that these are spread over only few aisles. If they would be spread over many aisles it would mean there are large gaps between consecutive picks because orders are split in the order they are located in the warehouse. This leads to a batch containing more order lines when more aisles have to be visited. Because the number of products that fits on a pallet is limited, also the number of order lines is limited, meaning that the number of order lines stops increasing when more than 5 aisles have order lines.

- Third, the number of products per order line declines when more aisles are visited since the number of products in a batch doesn’t change as much as the number of order lines and since it stabilizes due to the capacity constraint.

- Fourth, more lines per hour get picked when more aisles are visited. Since the number of products per order line decreases when the number of aisles increases, it takes less time on average to pick an order line, increasing the number of lines that can get picked per hour.

- The fifth variable is the productivity. When products in a batch are spread over more aisles, the number of picked products per hour decreases. This is caused by the increased distance that needs to be covered and the decreased number of products per order line.

These effects are all straightforward and no unexpected relations were found.

Figure 6 – Order picker characteristics plotted against aisles to be visited in the WYG DC in weeks 2 to 13 of 2014.
When looking at the same data for individual employees, the same pattern that has been described above can be discovered, despite the differences in productivity between employees that have been observed earlier in this section.

The one way traffic rule in the distribution center has the effect that when an aisle is entered, the next one has to be traversed as well. This means that when the first order line of the batch lies in an uneven aisle, the previous even aisle has to be traversed as well. The same holds for when the last order line is in an even aisle, in this case the next uneven aisle has to be traversed to be able to return to the I/O point. Thus, always an even number of aisles needs to be traversed to collect a batch. When this is taken into account, also the same pattern described above can be observed.

4.3. Performance batching algorithm

The current performance of the batching algorithm that computes which batches are created will be discussed in this section. To clarify the batching procedure that is currently in use, first a numerical example is presented below. In the example, four orders are available for batching. Each order contains one or more products that have to be picked for only one store. All batches can only consist of up to two batches. The overview of which product (defined by product number) and the quantities in the orders can be found below in Table 3.

<table>
<thead>
<tr>
<th>Order1</th>
<th>Order2</th>
<th>Order3</th>
<th>Order4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod.nr</td>
<td>Quantity</td>
<td>Prod.nr</td>
<td>Quantity</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
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<td>29</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The batchign algorithm follows the following four steps:

1. The algorithm first selects a seed order, which is combined with the order that has the biggest match. The seed order is selected based on the total expected collection time. For each area in each DC, the average time to collect an order line and a product has been determined. The

<table>
<thead>
<tr>
<th>Time needed (sec)</th>
<th>Line</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed value Lines</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Seed value Products</td>
<td>114</td>
<td>96</td>
</tr>
<tr>
<td>Seed value Lines</td>
<td>360</td>
<td>300</td>
</tr>
<tr>
<td>Seed value Products</td>
<td>342</td>
<td>288</td>
</tr>
<tr>
<td>Seed value Lines</td>
<td>702</td>
<td>588</td>
</tr>
</tbody>
</table>

Table 3 - Order composition and seed values.
total collection time of an order is calculated from this information. The biggest order in terms of total collection time that has been released but not assigned to a batch yet is selected as the seed order.

2. All other released but unassigned orders are considered for creating a batch. The accompanying order is selected based on the number of identical pick sections, the number of identical pairs of aisles and the number of additional pairs of aisles. Aisles are always combined in pairs of two, since all DC’s have one-way traffic, meaning that entering one aisle means you have to traverse it and the next one completely to reach the I/O point again. The first two criteria are rewarded with points (in this example 100) while the last one is punished (in this example -10). These points can differ per DC and per area.

3. The best accompanying order is selected and the batch is created.

4. The process repeats itself until all orders are assigned to a batch.

<table>
<thead>
<tr>
<th>Product</th>
<th>Aisle</th>
<th>Section</th>
<th>Rack</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>22</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>23</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>26</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>27</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>28</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>29</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4 - Product location list.

In the example, the time to pick an order line is set to 30 seconds, while the time to pick a product is set to 3 seconds. Order4 is in this case selected as the seed order, since it consists of 126 products and 14 order lines, giving it a seed selection value of 798. This information can all be found in Table 3 above. In the article list, the location of the products is described. An
overview of this can be found in Table 4. As stated, points are awarded when products are in the same pair of aisles and when products are in the same section. Points are deducted when an additional aisle pair has to be visited. A section is defined as two adjacent and opposite racks in this example, but can be different for other DC’s.

To calculate the congruency between orders, it is counted per order how many order lines are located in each pair of aisles and in each section. The similarities between the candidates and the seed order are then awarded with points. The order with the highest number of points is selected as the accompanying order, creating the batch. In the example, 8 order lines in the seed order Order4 are located in aisle pair 1, consisting of aisles 1 and 2 while 6 order lines are located in aisle pair 2, consisting of aisles 3 and 4. Candidate Order2 has 9 order lines in aisle pair 1 and 1 order lines located in aisle pair 2. For aisle pair 1, it will receive points for 8 matches while for aisle pair 2 it will receive points for 1 match, meaning it will receive (8+1)*100 points. The assignment of points for the sections follows the same logic. Order2 receives (2+1+1+2+1)*100 points for the matches in the sections. No additional pairs of aisles have to be visited so no points are deducted. An overview for all orders can be found below in Table 5.

<table>
<thead>
<tr>
<th>Order4 Order lines</th>
<th>Order1 Order lines</th>
<th>Order2 Order lines</th>
<th>Order3 Order lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aisle1 4</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Aisle2 4</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Aisle3 4</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Aisle4 2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AislePair1 8</td>
<td>7</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>AislePair2 6</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Section1-1 3</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Section1-2 1</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Section2-1 2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Section2-2 2</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Section3-1 2</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Section3-2 2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Section4-1 0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Section4-2 2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| Matches | 12+8 | 9+7 | 9+7 |

Table 5 - Order lines per aisle/section and matches with seed order

From Table 5 it is also easy to see that Order1 receives most points when Order4 is the seed order, meaning that these two orders will form a batch. When the process is repeated, Order2 will become the seed order. Since Order3 is the only unassigned order left, Order2 and Order3 will form a batch as well.

The calculation of the assignment of points to batches can also be captured in formula form, which is presented below.
Batch points = \[
\sum_{i=A_{\min}^{S}}^{A_{\max}^{S}} PA \times \min\{N_{SA,i}, N_{CA,i}\} + \sum_{i=1}^{m} PS \times \min\{N_{SS,i}, N_{CS,i}\} - \sum_{i=A_{\min}^{C}}^{A_{\max}^{C}} AA \times N_{CA,i} - 100 \times N_{CA,i}
\]

\(m = \text{number of sections}\)

\(PA/PS/AA = \text{points for matching aisle/section/additional aisle}\)

\(A_{\max}^{S} = \text{furthest aisle pair seed order}\)

\(A_{\min}^{S} = \text{closest aisle pair seed order}\)

\(A_{\max}^{C} = \text{furthest aisle pair candidate order}\)

\(A_{\min}^{C} = \text{closest aisle pair candidate order}\)

\(N_{SA,i} = \# \text{ of order lines in aisle pair } i \text{ for the seed order}\)

\(N_{CA,i} = \# \text{ of order lines in aisle pair } i \text{ for the candidate order}\)

\(N_{SS,i} = \# \text{ of order lines in section } i \text{ for the seed order}\)

\(N_{CS,i} = \# \text{ of order lines in section } i \text{ for the candidate order}\)

The first term of the formula calculates the points to be awarded for matches in the same aisle pairs. Only aisle pairs that are in range of the seed order are considered, otherwise points have to be deducted. The minimum of the number of order lines of the seed order and the number of order lines of the candidate order in the corresponding aisle is used to calculate the number of matches. The same procedure is followed in the second term, when the number of matches for each section is calculated. The last two terms deduct points for order lines in the candidate order that are not in range of the seed order.

With the formula that has been described above the current performance of the batching algorithm can be analyzed. Again, data from the WYG DC from the weeks 2 to 12 of 2014 has been used for the analysis. The first week is excluded because it contains a holiday. Only batches that have been picked on a single day are considered. In total 3102 orders have been released and picked in this period that meet these criteria, spread over 1591 batches. This means that 1511 batches consisted of two orders, while 80 or 5% of the batches contained only one order. This can be due to the number of order available for batching being uneven or due to a manually entered batch containing only one order. This is only desirable when the due date for that order is short and needs to be met, otherwise it is suboptimal to collect one order at a time because there can be no congruency and the capacity of the picking cart is not fully used.

Besides the batches that consist of only one order, 104 or 6.5% of the batches have zero congruency between the orders. This is the case when no similarities exist between the two orders in the batch. On average, a batch has more than 21 similarities. When batches without
points are left out of the calculation, a batch has more than 23 similarities on average. The distribution of the points per batch can be found in Figure 7 below.

![Distribution of points per batch](image)

**Figure 7 - Distribution of points per batch.**

As can be seen, the majority of the batches only have few points while the maximum number of similarities between two orders in this period was 97. No significant difference between the average points per order is found between weeks or weekdays, as can be seen in Figures 8 and 9 below.

![Average points per order per weekday](image)

**Figure 8 - Average points per order per day of the week.**

![Average batching points per order per week](image)

**Figure 9 - Average batching points per order per week.**

No distinction has been made between ZB’s and RDC/BS’s in this analysis, orders from both types of outlets have been included. Of the 80 batches with one order, 16 were from a ZB while 64 were from a BS/RDC. Of the 1511 batches consisting of two orders, 1080 had both orders from a ZB, 194 batches consisted of two BS orders while 237 batches consisted of both a ZB and a BS order. On average, the ZB-ZB batches have 27 similarities, the BS-BS batches have approximately 4 similarities and the ZB-BS batches have more than 12 similarities. This difference is caused by the unequal order characteristics between these batches.
When looking at which stores belong to the orders in the batches, it stands out that out of the 1591 batches, 304 or 19.1% of the batches consist of two orders and both orders are destined for the same store. These batches have a low congruency because the only similarities between the orders can be in the last aisle pair and section of the first order and the first aisle pair and section of the second order. Furthermore, 547 or 34.4% batches have been created that consist of two orders that belong to stores in different dock times. While this shouldn’t be possible in theory, this can happen in practice when batches are created manually or when batches haven’t been assigned to the correct dock time yet. The remaining 660 or 41.5% batches from this period contained two orders from different stores that are in the same dock time. The composition of the batches from this last group is the way batches are intended to be formed. In Figure 10 below the batch composition is displayed graphically.

<table>
<thead>
<tr>
<th>Batch composition</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>One order</td>
<td>80</td>
<td>5.0%</td>
</tr>
<tr>
<td>Two orders, same store</td>
<td>304</td>
<td>19.1%</td>
</tr>
<tr>
<td>Two orders, different dock time</td>
<td>547</td>
<td>34.4%</td>
</tr>
<tr>
<td>Two orders, same dock time</td>
<td>660</td>
<td>41.5%</td>
</tr>
</tbody>
</table>

Figure 10 - Different batch compositions WYG DC week 2 to 12 2014.

4.4. Relation between picker productivity and the batching algorithm

The relation between the batching algorithm and picker productivity is important for the rest of this project. Picker productivity has been said in chapter 4.2 to be inversely proportional to the collection time. The performance of the batching algorithm is measured in points awarded for similarities between the orders in a batch. For this project to be successful, it first needs to be checked whether the batching algorithm actually positively influences the collection time.

It has become clear in section 4.2 that there is a large difference in order picking characteristics between employees since the number of products that gets picked per hour ranges between 600 and 1500 products per hour. Also the number of order lines picked per hour is different per employee. Furthermore, the congruency between the orders in the batch, the number of order lines, the number of aisles to be visited and the number of products in a batch are variables that are expected to have a significant influence on the collection time and order picker productivity. These expectations are based on the results found in the previous sections and the expertise of the process managers at Sligro.

Generally, when a batch has more points it also means that the batch has more order lines, products and aisles to be visited. In a previous section it has been explained that these kind of batches lead to a longer collection time. To understand the influence of the number of points
on productivity and collection time, the other mentioned variables are kept constant when comparing productivity between batches.

Data from the WYG DC from weeks 2 to 13 is used for this analysis. Only batches that are picked on a single day by a single picker are considered and errors are removed. Because the data that is available is limited, all variables are recoded into small intervals to create scenarios that contain similar orders, only with different points assigned by the batching algorithm. The number of aisles that have to be visited are taken as they are because it contains only five options. The number of order lines are divided into intervals of 10 while the number of products to be picked are divided into intervals of 200. Because the batches in the dataset contain up to 140 order lines and 2000 products, the number of scenarios can be calculated as follows: $5 \times 14 \times 10 = 700$ scenarios.

Because there are 1590 useable orders, the number of cases per scenario can be small for non-common batch compositions. Therefore productivity of the batches with the lowest number of points are compared with the batches with the highest number of points for the scenarios. Only scenarios with at least ten cases are used in this analysis. Cases with less than half of the maximum points in that scenario are compared with cases that have more than half of the maximum points.

Out of the 54 scenarios that contain ten or more cases, batches with the most points have a higher productivity than batches with the least amount of points 26 times. In 15 of these cases the average number of order lines for the batches with most points is higher, implying that productivity increases due to better congruency between the orders. In the other 28 instances, the batches with least points have a higher productivity. In 23 of these instances this can be explained by the fact that the batches with less points also contained less order lines.

From these results it can be concluded that orders that have a similar amount of order lines, products and aisles to be visited but only a few points lead to a lower productivity than orders that have more points in most cases. This means that the desire of Sligro to redesign the order and delivery schedule in order to improve the batching procedure does indeed lead to increased productivity in most cases. Therefore it is useful to pursue the increase of congruency between orders in a batch. In chapter 5 of this report the relation between collection time and the mentioned variables in this section will be discussed in more detail.

4.5. Workload distribution at the CDC

The current workload distribution at the central distribution center will be defined and discussed in this section. This variable is important in the rest of this project because it should be constant to ensure efficient warehouse operations. A constant workload distribution helps to reduce unnecessary overtime and to increase due date accuracy.

The workload is measured with the number of orders that have to be collected on a given day for each distribution center. Because each pallet carries the products of one order and because each order is created such that the available volume of the pallets is used as much as possible. The average volume of products is assumed to be the same throughout the days. In Figure 11 below the number of orders picked per distribution center with PickArts per weekday can be found for weeks 2 to 12 in 2014.
It stands out that the number of picked orders varies between the different weekdays for some distribution centers while for others it is pretty constant. The same pattern emerges when the number of picked products is used for the analysis. In the next section, the total number of pallets sent from each truck loading location is analyzed. Besides PickArts, this also includes the other picking systems that are used in the distribution centers, leading to a more equal distribution between the days of the week.

4.6. Demand periods within a year
Because the decision on how to arrange the order- and delivery schedule is a periodic one, it is useful to know which periods exist in a year. When the outcome for said decision differs per period, Sligro might decide to change the schedule for each period. While this might have a positive impact on the order picking process, also other parts of the organization have to be taken into account. From the store and transportation planning perspective, it is not desirable to change the schedule too often, because it would mean that delivery times could change every time the schedule is updated. Another reason for adapting the order- and delivery schedule is when new stores are opened or existing stores start to perform differently. However, the effects of these events cannot be foreseen and are therefore left out of this analysis.

In this section data on the number of pallets shipped from each truck loading location is used to check whether a pattern in the demand can be found in terms of volume. That is why in this chapter the demand periods are only based on the pallet volume. While this doesn’t provide insight in the composition of orders during the year, it can help to determine a period to base the further analysis on.

When looking at the number of pallets shipped to the different stores during a year, a small pattern can be discovered. After high demand periods like Christmas, Easter, Ascension Day, Kingsday and Pentecost the number of pallets that is shipped decreases significantly. Throughout the year a three week cycle can be distinguished, resembling Sligro’s promotion leaflet cycle. Products from this leaflet are sent out the week before they are in the promotion, causing a peak in the pallets that are shipped every third week. For perishable products this is of course not the case, because sending three weeks of inventory at once would lead to too much
outdating. In Figure 12 below the number of pallets sent from each truck loading location is shown for each three week promotion cycle. This is done to remove the fluctuations due to promotion items being sent to the stores in the week before the discounts start.

![Number of pallets sent per period](image_url)

Figure 12 - Number of pallets sent each promotion cycle from the DC's in 2013.

What stands out is that during the first periods of the year the number of shipped pallets is at the lowest level of the year on average. After these months a period with a slightly higher demand begins, except for the Food distribution center. This is partly because the special days cause higher demand and partly because of the influence of the weather, because good weather also causes higher demand. After the summer, demand slightly decreases again. The last period that stands out is the last month of the year, leading up to Sinterklaas and Christmas. It has to be noted that in Figure 12 above, data from the grocery packs is removed. Grocery packs are sent as full truck loads from the Food distribution center, including them would pollute the graph below. The peaks in number of pallets sent from the Food DC in promotion cycle 12, 14 and 15 can be explained by Sinterklaas and Christmas products being sent to the stores. Excluding these products would flatten the Food pattern in these cycles, making it look more like the other distribution centers patterns. But because there is no data on how much pallets actually contain these products, it hasn’t been excluded in the graph above.

The situation described above includes all pallets sent from the CDC. When looking at the same data, but only for the ZB’s, the same three week promotion cycle can be distinguished. In Figure 13 below, the number of pallets sent to the ZB’s is depicted for the different distribution centers. The average demand of each three week cycle has been used instead of the demand per week to increase the readability of graph. The demand periods within a year are roughly the same. The Food DC has low demand in the first part of the year compared to the last part of the year, which can partly be explained by seasonal products. The rest of the distribution centers has the lowest demand period in the first part of the year, followed by a period of high demand during spring and summer. After this the number of pallets decreases again. The last few weeks of the year demand is the highest of the year. The length of these periods and differences in pallets per period differ slightly per DC. When the first twelve weeks of 2014 are analyzed, the same pattern can be discovered.
It is reasonable to assume that the loading level of the pallets stays the same during the year because orders are always split in the same volumes. Furthermore, it is assumed that the average volume of products does not differentiate during the year, implying that the situation described above is representative.

In this section, only the volume of each distribution center has been analyzed. The composition of the orders might differ during the year, which means that the congruency between store orders is possibly different for different periods in the year.

In compliance with the process managers at Sligro, it has been chosen to use data from the first three months of the year for the initial analysis. On the one hand because the graphs in this section have shown that the number of pallets sent from each distribution center is quite stable and on the other hand because the process managers believe that during this period the composition of the orders is also rather stable.
5. Redesign and expected cost benefits
In this part of the report the effects of changing the order- and delivery schedule and the batching algorithm are studied. In this chapter the redesign will also be presented. The last part of this chapter consists of the expected cost benefits due to the proposed redesign.

5.1. Effects on picker productivity
Changing the batching algorithm and the order- and delivery schedule will have an influence on the number of points that a batch has. In chapter 4 of this report it has become clear that the number of batching points influences the picker productivity. For batches with an equal number of order lines, products and aisles to be visited, productivity is higher when the number of points is higher. The rest of this chapter is divided in three parts. In the first part the influences on picker productivity are quantified by creating a linear regression with SPSS. The second part will study the effects of changing the batching algorithm on the picker productivity while the third part will study the effects of changing the order- and delivery schedule on productivity.

5.1.1. Predictors of picker productivity
In this section it is checked which variables have an influence on picker productivity. As stated in chapter 4.2, picker productivity is in this project defined as the sum of picking time and navigation time. Picking time and navigation time are also defined in chapter 4.2. The following analysis is based on these definitions. Inspection of data from weeks 2 to 13 from the WYG DC in Table 6 below shows that the picking time per product is rather stable, independent of the number of aisles that has to be visited. The picking time is divided by the number of product in a batch, and from the Table below it can be seen that it takes about 0,03 minutes to pick one product. This can be explained by the way the pick time is measured. This time starts when the order picker scans the rack where the product is located and ends when the order picker confirms on his vehicle that the product is on the right pallet. This time is independent of the number of aisles that has to be visited or the number of order lines in a batch because on average this time is the same for all products.

In Table 6 below it is also clear that when the navigation time is divided by the number of order lines in a batch, a rather stable pattern can be found as well. On average, it takes 0,38 minute of navigation time for each order line. The navigation time decreases when a stop is made for multiple order lines. This is the case when the algorithm awards batching points. When this is the case, the time to pick an order line is deducted.

<table>
<thead>
<tr>
<th>Aisles</th>
<th>NAV time</th>
<th>PICK time</th>
<th>Batch OL</th>
<th>Avg Prod</th>
<th>Avg Points</th>
<th>PICK/Product</th>
<th>NAV/Batch OL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11,04</td>
<td>24,26</td>
<td>26,85</td>
<td>782,55</td>
<td>15,12</td>
<td>0,031</td>
<td>0,411</td>
</tr>
<tr>
<td>4</td>
<td>14,87</td>
<td>26,18</td>
<td>41,35</td>
<td>937,83</td>
<td>20,32</td>
<td>0,028</td>
<td>0,360</td>
</tr>
<tr>
<td>6</td>
<td>20,92</td>
<td>30,35</td>
<td>62,13</td>
<td>962,21</td>
<td>28,62</td>
<td>0,032</td>
<td>0,337</td>
</tr>
<tr>
<td>8</td>
<td>22,82</td>
<td>29,30</td>
<td>56,22</td>
<td>904,64</td>
<td>19,04</td>
<td>0,032</td>
<td>0,406</td>
</tr>
<tr>
<td>10</td>
<td>23,43</td>
<td>29,09</td>
<td>58,30</td>
<td>904,34</td>
<td>18,50</td>
<td>0,032</td>
<td>0,402</td>
</tr>
</tbody>
</table>

Table 6 - Averages per aisle

It has to be noted that these numbers might be different for other distribution centers because products in the WYG DC are always picked per case. For other distribution centers this might not be the case.
To verify these findings, a model is created in SPSS. A multiple regression model for both the picking time and the navigation time is used because from Table 6 above it seems that productivity can be explained quite well by a few linear variables.

**Picking time**

From the data inspection it was presumed that the picking time is predicted by the number of products in a batch. The summary of the linear regression analysis is presented below in Table 7, the full analysis can be found in Appendix B.

### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>Durbin-Watson</th>
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<tr>
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<td>.569</td>
<td>7.63297</td>
<td>.569</td>
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<tr>
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<th>df2</th>
<th>Sig. F Change</th>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>.000</td>
<td>1.831</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Products
b. Dependent Variable: Picktime

Table 7 - Pick time model summary

From Table 7 above it can be seen that almost 57% of the variance can be explained by the model. From Table 8 below it can be seen that the number of products in a batch is a highly significant predictor for the pick time of a batch. Furthermore, it takes about 0.029 minute to pick one product, roughly the same as was found in Table 6.

### Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>95.0% Confidence Interval for B</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>t</td>
<td>Sig.</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>1.208</td>
<td>.604</td>
<td>2.000</td>
<td>.046</td>
<td>.024</td>
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<tr>
<td>Products</td>
<td>.029</td>
<td>.001</td>
<td>.754</td>
<td>45.242</td>
<td>.000</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Picktime

Table 8 - Coefficients pick time model

**Navigation time**

Another linear regression model is created for navigation time. As stated before, the number of order lines is presumed that the navigation time can be predicted by the number of order lines in a batch. Furthermore, the number of batching points and the number of aisles to be visited are also believed to have an influence. The summary of the linear regression can be found below while the full analysis can be found in Appendix C.
### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
<th>Durbin-Watson</th>
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<tr>
<td></td>
<td>.845a</td>
<td>.714</td>
<td>.713</td>
<td>5,12987</td>
<td>.714</td>
<td>773,748</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Aisles10, Points, Aisles8, Aisles6, BatchOL  
b. Dependent Variable: Navtime

Table 9 - Model summary navigation time model

From Table 9 above it can be seen that over 71% of the variance can be explained by the model. From Table 10 below it can be seen that the number of products in a batch and the number of batching points are highly significant predictors for navigation time. Furthermore, it can be seen that compared to two and four aisles, additional navigation time is needed when the number of aisles to be visited increases. No significant difference was found between when two and four aisles have to be visited.

### Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>95.0% Confidence Interval for B</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>t</td>
<td>Sig.</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>4,428</td>
<td>.272</td>
<td>16,252</td>
<td>.000</td>
<td>3,893</td>
</tr>
<tr>
<td>BatchOL</td>
<td>.270</td>
<td>.008</td>
<td>.885</td>
<td>34,730</td>
<td>.000</td>
</tr>
<tr>
<td>Points</td>
<td>-.064</td>
<td>.012</td>
<td>-.136</td>
<td>-5,570</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles6</td>
<td>1,597</td>
<td>.360</td>
<td>.072</td>
<td>4,436</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles8</td>
<td>3,339</td>
<td>.367</td>
<td>.152</td>
<td>9,108</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles10</td>
<td>4,252</td>
<td>.444</td>
<td>.154</td>
<td>9,581</td>
<td>.000</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Navtime

Table 10 - Coefficients navigation time model

The model from Table 10 above can be presented in formula form in the following way:

**Navigation time**  
\[ \text{Navigation time} = 4,428 + 0,270 \cdot \text{Order lines} - 0,064 \cdot \text{Points} + 1,597 \cdot \text{Aisle6} + 3,339 \cdot \text{Aisle8} + 4,252 \cdot \text{Aisle10} \]

The standardized coefficients in Table 10 show that the number of order lines has the biggest influence on the expected navigation time while the influence of the number of points is about the same as the influence of the number of aisles that has to be visited. A linear regression seems to be a good choice to predict productivity since the model looks quite robust.

### 5.1.2. Batching algorithm

In chapter 4 of this report the batching algorithm has been discussed. The algorithm first selects the biggest seed order in terms of expected collection time and subsequently it searches for the
order with the largest number of similarities. From the literature study it has become clear that when a batch consists of at most two orders, the optimal solution can be found by using weighted matching. The optimal solution maximizes the total number of points for the orders that have been released.

To study the effects of using the weighted matching solution instead of the current batching algorithm, orders from the WYG DC from the first thirteen weeks (except the first) in 2014 are used. The batches that actually have been created and picked will be analyzed first. Because it has become clear in chapter 4 of this document that a large part (34%) of the batches contains orders from different dock times and because orders in the same dock time are not always released together, the current algorithm will be simulated. This will then be compared with a simulation of the optimal solution.

The simulation of the current situation takes all orders from one day and creates batches following the steps of the algorithm. Also the situation where dock times are disregarded has been analyzed because it can be useful when the order- and delivery schedule is adapted. The optimal solution is calculated using weighted matching, meaning that the total number of batching points is maximized for each dock time. The situation where dock times are disregarded is also analyzed so it can be used when the order- and delivery schedule is changed.

An overview of the batches that have been picked and the results of the simulation can be found in Table 11 below. The full results of the simulation can be found in Appendix D. The average number of batching points per day that has been realized in the analyzed period is 462. The simulation of the current situation has resulted in an average of 506 batching points per day. The increase can be explained by the fact that in the simulation the ideal situation is considered. All batches contain orders from the same dock time, in contrast to the realized situation, where only 40% of the batches contains orders from the same dock time. This results in an average of almost 4 batches per day with only one order in the simulation, opposed to an average of 1 batch per day with one order in the realized situation. When dock times are disregarded, each day has 686 batching points in the current situation. Batches with only one order only exist in this situation when the total orders per day is odd.

<table>
<thead>
<tr>
<th>Averages</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Orders per day</td>
<td>43</td>
</tr>
<tr>
<td>Points per day realized</td>
<td>462</td>
</tr>
<tr>
<td>Points per batch</td>
<td>10</td>
</tr>
<tr>
<td>Total number of batches</td>
<td>22</td>
</tr>
<tr>
<td>Batches containing 1 order</td>
<td>1</td>
</tr>
<tr>
<td>Batches with orders from the same store</td>
<td>4</td>
</tr>
<tr>
<td>Batches with orders from the same dock time</td>
<td>12</td>
</tr>
<tr>
<td>Batches with orders from a different dock time</td>
<td>5</td>
</tr>
<tr>
<td>Points per day optimal algorithm without dock times</td>
<td>721</td>
</tr>
<tr>
<td>Points per day optimal algorithm</td>
<td>531</td>
</tr>
<tr>
<td>Points per day current algorithm without dock times</td>
<td>686</td>
</tr>
<tr>
<td>Points per day current algorithm</td>
<td>506</td>
</tr>
</tbody>
</table>

Table 11 - Average results simulations WYG DC weeks 2 to 13 of 2014

The optimal solution for the batching problem can be found when weighted matching is used. This idea is discussed in Gademann & Van de Velde (2005). The authors prove that when a
batch consists of up to two orders, the optimal solution can be found within polynomial time. In this case the weighted matching problem is designed in Excel as an LP-model which is solved using OpenSolver because the Excel Solver restricts the maximum number of variables per model to 500. The LP-model can be written down in formula form as follows:

\[
\text{Maximize} \quad \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ij} \cdot x_{ij} \\
\text{Subject to} \quad x_{ij} \in \{0,1\}, \sum_{j=1}^{i} x_{ij} + \sum_{j=i+1}^{n} x_{ji} = 1 \forall i,j \\
\text{Where} \quad P_{ij} = \text{points for order combination i,j},
\]

\[x_{ij} = \text{whether combination i,j is chosen and } n = \text{total number of orders}.\]

As can be seen in Table 11 on the previous page, the simulation of the weighted matching results in an average of 531 batching points per day when the dock time restriction is met. Because the number of orders in each dock time is the same in both the simulation of the current algorithm and the simulation of the weighted matching solution, the number of batches with only one order also stays the same. When dock times are disregarded, the average number of points per day is 721. It can easily be explained that introducing the dock times leads to a lower amount of points because the number of possible batch combinations decreases. However, it is not desirable to disregard dock times because they ensure that enough docks are available at all times to load trucks, that the expedition area doesn’t get overcrowded and that the workload at the distribution centers is balanced.

The summarized results in Table 11 show that there is quite a big difference between the current batching algorithm, the optimal solution and the way the batches actually have been picked. The simulation of the current situation leads to a 9.5% increase in batching points compared to the realized situation while the optimal solution shows a 4.9% increase in batching points with respect to the simulation of the current situation. In chapter 4 of this report and earlier in this chapter it has been shown that the number of batching points positively influences picker productivity. Since changing the batching algorithm leads to a change in the average number of batching points, it will also lead to a change in picker productivity.

From the results above it can be concluded that following the batching procedure can lead to a big increase in batching points because the simulation of the current situation leads to 9.5% more batching points compared to the realized situation. This can be explained by the fact that all batches of the same dock time are released together in the simulation and because no deviation from the procedure is allowed. Following these rules in a more strict way thus leads to an increased performance of the current algorithm.

It has to be noted that for the simulations, it was assumed that all orders in each dock time are released and available for batching at the same time. In practice this is not always the case because orders have to be split manually. This means that it can happen that not all orders for a dock time are released simultaneously when no batches are available for picking. To make sure that the order pickers are not idle Sligro chooses to release orders from a dock time in parts in this case.
5.1.3. Order- and delivery schedule
Changes to the order- and delivery schedule can be made in two different ways. First, the dock times can be changed for each store. Second, the days that a product group is allowed to generate can be adapted. Changing the dock times leads to a different set of orders that is considered when batches are created. Changing the days that a product group is allowed to order leads to a different order composition because the review period can change.

As has been shown in the previous section, introducing dock times leads to a lower average number of batching points than when no dock times are used. The way stores are assigned to these dock times has an influence on the batches that are considered. The current arrangement of the dock times leads to a 27% decrease in average batching points per day for the current algorithm compared to when no dock times would be set. For the weighted matching solution, the current arrangement of dock times leads to a 26% decrease compared to the situation with no dock times. Rearranging the dock times from the order- and delivery schedule will lead to differences in these numbers because other batch combinations are considered. When the days that a product group is allowed to generated is changed the order composition changes. Aligning these product groups between the stores with the same dock time can ensure that the number of batching points is maximized. When orders from stores with the same dock time consist of the same product groups, the chance of similarities is bigger than they consist of different groups. Because the 47 ZB’s need to be assigned to 6 different dock times, the number of options is very large. If each dock time should contain the same amount of stores, $47!/(8!^5*7!)$ possible combinations exist, making it impossible to check all possible options. When the other types of outlets are taking into account, the number of possibilities increases even further. That is why a heuristic has to be used to assign stores to dock times.

The days at which product groups generate an order advice are fixed every week and the dock times are the same every day. To check which stores should fit well together in a dock time, all batches that have been picked in the weeks 2 to 13 in 2014 are analyzed. The analyzed time period is one week in each case and dock times are disregarded so the optimal solution for the entire week can be found. After this it can be observed which orders from which stores are most common in a batch. Putting these stores together in the same dock time on the same day are expected to lead to a big number of similarities. As stated above, the assignment of stores to dock times has to be done using a heuristic because the number of possible combinations is very large.

5.2. Effects on batch composition and order releasing
This section address the effects of changing the order- and delivery schedule and the batching algorithm on the batch composition and on the order releasing procedure.

5.2.1. Order releasing
Changing the batching algorithm to the optimal solution requires all orders in the same dock time to be released at the same time for the best effect. The current batching algorithm only creates one batch at a time. When this batch is accepted by an order picker the algorithm creates a new batch. This means that when new orders are considered for batching when they are released. The proposed weighted matching solution maximized the total number of batching points for all orders that are considered, which implies that the best effect is achieved when all orders are released. If all batches for a dock time are created at the same time, priorities have to be assigned to ensure that order with a large expected collection time are picked first.
Changing the order- and delivery schedule alone doesn’t influence the order releasing procedure because the only thing that will change is which stores get batched together.

5.2.2. Batch composition
Implementing the new batching algorithm also means that it is not possible anymore to consider orders from the next dock time when the number of orders in a dock time is odd. The current batching algorithm considers all orders from the next dock time when this is the case to reduce the number of batches with only one order. The percentage of batches with orders from the same dock time will increase because of this change. Also, it will be more difficult to manually add batches because they are all created at the same time.

This last effect doesn’t have to be a problem because creating batches manually will lead to a lower total amount of batching points. When batches are created manually because they should be picked first, it is better to assign a higher priority. In Compass this is already possible. This makes sure that orders can be picked before their due date while still achieving the optimal number of points.

Changing the order- and delivery schedule influences the composition of the batches. As has been shown in the previous section, rearranging the dock times leads to a higher number of batching points on average. Orders in a batch have a higher number of similarities in this case. Furthermore, the stores that are in a batch together change because of newly arranged dock times. Changing the days that product groups are allowed to generate an order advice also leads to a different batch composition. Because the product groups are aligned within a dock time, it means that the number of stores that can order a product group at the same time increases.

5.3. Criteria and restrictions on rearranging the order- and delivery schedule
Criteria and restrictions exist on rearranging the order- and delivery schedule but it was chosen to find the best solution that is possible without looking to the restrictions. This way it is possible to see what the potential of changing the schedule is. The schedule can be updated to cope with transport restrictions and the process of aligning the product groups requires collaboration with all the stores.

5.4. Redesign of the order- and delivery schedule
In this section the redesign of the order- and delivery schedule is presented. But first the method that was used to come to this redesign and the assumptions that were made will be explained.

5.4.1. Method
Previously in this chapter it has become clear that using weighted matching instead of the current batching algorithm leads to an increase in the average batching points per order. The redesign of the order- and delivery schedule focuses on finding stores that have the most similarities between them. Data from the WYG DC from weeks 2 to 13 of 2014 is used for the analysis. To rule out the difference in ordering days of product groups, it is checked for each week which stores fit together the best. This way the order days of product groups and dock times are disregarded, meaning that the best matches for an entire week are used.

Instead of running the batching algorithm for each day like was done in the first section of this chapter, the batching algorithm runs for an entire week to check which stores are together in a batch most often and which stores acquire the most points because they are together in a batch.
This is done for each week in the analyzed period and with this information new dock times can be assigned to the stores. The assignment of stores to dock times is done using a batching algorithm and the dock times are set to have a total capacity of eight stores, meaning that seven dock times are created. The batching algorithm works as follows:

1. The store with the most similarities with other stores is selected and added to a dock time.
2. The store with the most similarities to any of the stores in the dock time is added to that dock time.
3. Step two is repeated until the dock time contains eight stores.
4. The stores that are assigned to a dock time are not considered in the process anymore.
5. Steps 1 - 4 are repeated until all stores are assigned to a dock time.

The new schedule of these seven dock times can then be compared to the old situation by checking the solution in a different period. Verifying the solution by applying the new dock times to another period is an indication for the robustness of the solution. However, since the product groups for the orders can’t be changed in the analysis, the new dock times might not have synchronized product groups yet. If this is the case, the similarities between the stores are not fully used.

5.4.2. Assumptions

In the creation process of the model several assumptions were made. First, it is assumed that stores are only assigned to one dock time. Currently it can happen that a store is assigned to a dock time in both the morning and the afternoon. When stores need two dock times, this can be changed afterwards.

Furthermore it is assumed that each dock time should contain the same number of stores, disregarding size. This can lead to unequal dock times in terms of orders that need to be picked, but can be solved when big stores are divided over two dock times afterwards.

Also, it is assumed that no restrictions exist regarding the division of stores in dock times. It might be that some stores should be in a dock time together because of transport planning benefits. The redesign tries to provide the best overview of stores assigned to dock times. When this is not feasible Sligro might try to mimic the redesign as best as possible.

5.4.3. Redesign

In this section the actual redesign is presented. Because the data that was analyzed is from weeks 2 to 13 of 2014 from the WYG DC, the resulting dock times are for this distribution center specifically. Because the process is modeled in Excel it is easy to create solutions for the other distribution centers. The results of applying the savings algorithm to this data can be found below in Table 12. Like stated before in this section, the dock times are created based on the weekly similarities between the stores using a savings algorithm. The current arrangement of the dock times for the WYG DC can be found in Appendix E.
Table 12 - Newly arranged dock times.

As can be seen from the Table above, the dock times are quite different from the current dock times. To compare the performance from both situation, data from another period from the same distribution center is used. Data from week 27 to 39 is used to check the performance of both the current layout of the dock times and the proposed layout. The performance is in this case again measured as the average number of batching points per day. The results of this analysis are shown below in Table 13. Full results can be found in Appendix F.

| Dock time 1 | 5040 | 5045 | 5013 | 5067 | 5065 | 5017 | 5063 | 5024 |
| Dock time 2 | 5014 | 5037 | 5027 | 5068 | 5082 | 5050 | 5030 | 5060 |
| Dock time 3 | 5010 | 5070 | 5047 | 5054 | 5057 | 5051 | 5055 | 5090 |
| Dock time 4 | 5012 | 5049 | 5052 | 5031 | 5042 | 5062 | 5041 | 5043 |
| Dock time 5 | 5021 | 5056 | 5087 | 5016 | 5022 | 5035 | 5034 | 5036 |
| Dock time 6 | 5019 | 5020 | 5005 | 5059 | 5061 | 5044 | 5053 | 5085 |
| Dock time 7 | 5032 | 5092 | 5039 | 5066 | 5026 | 5069 | 5033 | 5088 |

Table 13 - Old dock times versus new dock times.

As can be seen from Table 13 above, changing the dock times with the savings algorithm leads to a higher average of batching points per day in the control period. This conclusion holds when the current batching algorithm is used but also when the weighted matching solution is used. When the current algorithm is used the average number of batching points is 5.2% higher if the new dock times are used. If the optimal batching solution is used, this number is 3.5% higher. From the Table above it can also be observed that when the changes to both the order- and delivery schedule and the batching algorithm are considered, the average number of batching points is 10.3% higher.

It has to be noted again that in this analysis product groups haven’t been rearranged in order to match with the changed dock times. Aligning the product groups within the dock times on each day is an important step to fully utilize the similarities in the ordering patterns because only when multiple stores in a dock time can order the same groups on the same day, similarities in the batches can exist.

With the current layout of the order- and delivery schedule and the dock times, a product group can be ordered by more than one store in a dock time in 83% of the cases in the WYG DC. For the redesign, this percentage is 93%. Only when more than one store within a dock can order a certain product group, there is a potential for similarities between orders. This implies that it should be avoided that only one group within a dock time orders a certain product group. The more stores that are allowed to order a product group, the higher the chance is that similarities exist between the orders. Of course it should also be avoided that too many stores can order the product group because this will lead to congestions in the warehouse.

The WYG DC consists of only four product groups, which means that the percentage of groups that are only ordered by one store is quite low. For other distribution centers this percentage seems to be larger which implies that the potential for improvement is bigger.
The savings algorithm selects the stores that have the most similarities and creates dock times based on this. As stated in the previous paragraph, similarities can only be utilized when multiple stores within a dock time can order the same product groups. In Table 9 above this is not included. The increase in batching points can therefore be even larger when the product groups are aligned.

5.5. Redesign of the batching algorithm
This section covers the redesign of the batching algorithm. As stated before, the current batching algorithm is not optimal, while the system can accommodate the optimal solution using a weighted matching algorithm.

5.5.1. Changing the batching algorithm
Changing the algorithm requires changes to Compass software. The current algorithm needs to be replaced by a LP-model that calculates the weighted matching solution for each dock time. Because the current algorithm only calculates one batch in advance, there is no need to manage the releasing of batches to order pickers. The largest one is always created first and therefore also released and picked first.

Weighted matching calculates the optimal solution for all orders combined, meaning that all batches are created at once. A separate program should be created that ensures that the batch with the largest expected throughput time is released to the order pickers first. The results of changing the batching algorithm have been shown previously in this chapter.

5.5.2. Changing the objective function of the batching algorithm
The weighted matching solution optimizes an objective function, which can be set to any variable. In the previous section this objective function is kept the same as the current algorithm. The number of similarities between orders in a batch is maximized for all orders in every dock time.

It is also possible to set other variables as the objective function of the weighted matching algorithm. An example of this is the navigation time, for which a model has been created previously in this chapter. When this navigation time is set as the objective function of the weighted matching problem, it is easier to calculate expected cost savings. Results of the simulation with the navigation time objective function can be found below in Table 14.

<table>
<thead>
<tr>
<th>Period 2-13</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time realized</td>
<td>30249</td>
<td></td>
</tr>
<tr>
<td>Total time weighted matching, objective</td>
<td>24802</td>
<td></td>
</tr>
<tr>
<td>Total time realized estimation</td>
<td>29623</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 27-39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time realized</td>
</tr>
<tr>
<td>Total time weighted matching, objective time</td>
</tr>
<tr>
<td>Total time realized estimation</td>
</tr>
</tbody>
</table>

Table 14 - Estimated navigation time in minutes per period

As can be seen from Table 15 above, the difference between the weighted matching solution and the realized situation is quite large. Because the model fit of the regression model was quite high, the realized situation matches the expected realized situation quite well. More than 200 hours of navigation time can be saved in the analyzed periods combined due to the redesign.
5.6. Effects on workload at the CDC and the stores

In this section the effects of redesigning the batching algorithm and the order- and delivery schedule are presented. A requirement of this project is that the workload at the distribution center and the stores shouldn’t deteriorate because of the redesign.

5.6.1. Workload at the CDC

Changing the batching algorithm doesn’t have a big influence on the workload at the CDC. While adapting the algorithm will lead to an increase in batching points and thus to an increase in productivity, this effect will be the same for all stores. The number of batches that have to be picked at a certain time of the day stays the same.

Rearranging the dock times does have an influence on the order- and delivery schedule. Currently, the number of stores per dock time is not distributed equally. In Table 15 below the number of orders per dock time from the WYG DC is displayed for the weeks 26 to 39 of 2014 for the current situation and for the redesign. Also, the number of stores that is in that dock time is displayed.

<table>
<thead>
<tr>
<th>Dock time</th>
<th>Current</th>
<th>Redesign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stores</td>
<td>Orders</td>
</tr>
<tr>
<td>8:00</td>
<td>10</td>
<td>469</td>
</tr>
<tr>
<td>9:00</td>
<td>11</td>
<td>466</td>
</tr>
<tr>
<td>10:00</td>
<td>11</td>
<td>522</td>
</tr>
<tr>
<td>11:00</td>
<td>2</td>
<td>222</td>
</tr>
<tr>
<td>14:00</td>
<td>8</td>
<td>355</td>
</tr>
<tr>
<td>15:00</td>
<td>18</td>
<td>867</td>
</tr>
<tr>
<td>16:00</td>
<td>6</td>
<td>112</td>
</tr>
</tbody>
</table>

Table 15 - Stores and orders per dock time.

As can be seen from the Table above, the division of stores per dock time is much more equal in the new situation. It has to be noted that in the redesign no stores have been assigned to two dock times. Currently some stores have a dock time in both the morning and the afternoon. In the redesign it was assumed that stores only have one dock time. In the current situation a peak in orders can be found at 15:00 and at 10:00 due to the high number of stores in those dock times while the orders in the dock times 14:00 and 16:00 are quite low due to the low amount of stores in these dock times. It is clear that the unequal division of stores leads to an unequal division of orders in the dock times.

In the new situation the number of orders per dock time seems to be better distributed, with exception of the dock times of 8:00 and 9:00, even though the number of stores per dock time is more equal. Because the process of rearranging the dock times starts with the store with the most similarities, this is most likely a big store with a lot of orders. Since stores are added to a dock time based on the largest number of similarities, the large stores will be added to a dock time first. This problem can be solved by also adding these stores to dock times in the afternoon so orders from these large stores are spread between dock times. When weeks 2 to 13 of 2014 from the WYG DC are analyzed, the same pattern can be discovered.

It has to be noted that although the number of orders is unequally divided amongst the dock times in the current situation, it doesn’t necessarily mean that the productivity of the order pickers suffers from this. When all orders from a dock time are ready to be loaded into the truck, order pickers can move on to batches from the next dock time. Because the total number of batches is the same in both situations and because order pickers almost always have batches
available for picking, the difference between both situations are the times at which batches are ready. When the number of orders per dock time is more equally divided, the number of orders that is ready too early or too late is reduced, which leads to a less crowded expedition area.

When the product groups are updated within the dock times, the workload at the CDC is also affected. When the total number of groups that is allowed to generate an order advice in each dock time is kept the same, the total number of orders on a day will not change.

5.6.2. Workload at the stores
When the batching algorithm or the dock times are adapted without changing the days that product groups are allowed to generate an order advice, the workload at the stores stays exactly the same because they order the same products on the same days. The only thing that changes in this case is the time at which the stores get a truck delivery. Changing the days at which product groups generate an order advice does not necessarily have an influence on the workload at the stores either if the number of product groups is kept the same for each day.

5.7. Expected cost benefits
Previously in this chapter it has become clear that both changing the batching algorithm and changing the dock times have a positive influence on the average number of batching points. In this section the expected cost benefits due to these changes are presented. To do this the formula from the regression model is presented again here:

\[
\text{Navigation time} = 4,428 + 0,270 \cdot \text{Order lines} - 0,064 \cdot \text{Points} + 1,597 \cdot \text{Aisle6} \\
+ 3,339 \cdot \text{Aisle8} + 4,252 \cdot \text{Aisle10}
\]

5.7.1. Cost benefits from changing the dock times and the batching algorithm
As can be seen from the formula above, one batching point leads to a reduction of 0.064 minute of navigation time. Previously in this chapter it was found that changing the dock times can lead to an increase of 71 batching points per day on average in the WYG DC. Because the WYG DC is only responsible for 5%, the following cost reduction can be calculated for the entire distribution center:

\[
\text{Expected cost savings} = \frac{71 \cdot 0,064}{60 \cdot 250 \cdot €22}{0,05} = €8.331 \text{ per year.}
\]

When the batching algorithm is also adapted to the weighted matching solution, the cost savings per year can be calculated as follows:

\[
\text{Expected cost savings} = \frac{100 \cdot 0,064}{60 \cdot 250 \cdot €22}{0,05} = €11.733 \text{ per year.}
\]

In these calculations the alignment of product groups within dock times is disregarded for simplicity reasons. When stores are allowed to order product groups on other days, the order composition changes as well. To calculate the cost savings in this case, the demand for every product has to be simulated, which is out of the scope of this project. While for the WYG DC this alignment might not yield a lot of cost savings because it consists of only four product groups (2% of total), it is expected that other distribution centers can benefit a lot from aligning product groups because the number of product groups is much larger, increasing the potential benefits. The calculation of the expected cost savings is therefore conservative.
5.7.2. Cost benefits from changing objective function of the batching algorithm

The expected cost savings presented above are based on changing the dock times and changing the batching algorithm to the weighted matching solution, optimizing the number of batching points. While the current batching algorithm is based on the number of similarities between batches, the weighted matching solution can use any variable as an objective function.

From the model presented above to estimate the navigation time it becomes clear that besides the number of batching points, also the number of order lines and the number of aisles to be visited has an influence. When the navigation time is used as the objective function for the weighted matching model, the cost savings can be calculated directly. Picking time is left out of the objective function because in the previous section it has become clear that this can be calculated from the number of products in the batch. Because the number of products that has to be picked stays the same in every situation, it is left out of the objective function. These results from this analysis are presented below in Table 16.

<table>
<thead>
<tr>
<th>Period 2-13</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time realized</td>
<td>30249</td>
<td></td>
</tr>
<tr>
<td>Total time weighted matching</td>
<td>24802</td>
<td></td>
</tr>
<tr>
<td>Objective time estimation</td>
<td>29623</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period 27-39</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time realized</td>
<td>28515</td>
<td></td>
</tr>
<tr>
<td>Total time weighted matching</td>
<td>21084</td>
<td></td>
</tr>
<tr>
<td>Objective time estimation</td>
<td>28820</td>
<td></td>
</tr>
</tbody>
</table>

Table 16 - Estimated navigation time per period

As can be seen from Table 16 above, the difference between the weighted matching solution and the realized situation is quite large. Because the model fit of the regression model was quite high, the realized situation matches the expected realized situation quite well. The navigation time differs a bit per period, but when these savings are extrapolated for one year, the yearly cost savings for the WYG DC can be calculated as follows:

$$Expected \ cost \ savings = 2 \times \frac{(29.623 - 24.802 + 28.820 - 21.084)}{60} \times \€22 = \€9.209 \ per \ year.$$  

The results above show that when the weighted matching solution is used in combination with the navigation time objective, the expected cost savings are much larger than when only the number of batching points is used in the objective function. Furthermore, these cost savings are only based on the WYG DC, which consists of only 2% of the total number of product groups and 5% of the orders. Extrapolating these numbers would result in 20 * $9.209 = $184.180 of cost savings per year for all distribution centers combined when the batching algorithm is changed. This calculation is a conservative estimation because optimizing the dock times and aligning the product groups can increase these savings even further.

5.8. Conclusion

In this chapter the effects of redesigning the batching algorithm and the order- and delivery schedule have been investigated. It has become clear that changing the batching algorithm to the weighted matching solution leads to a higher average number of batching points. The increase is about 6.5% for the analyzed period in the WYG DC. For the control period this change is roughly the same (6.7%). This means that the current algorithm performs not that
much worse than the optimal solution. However, it has to be noted that for the optimal solution also the number of similarities between orders has been used as the objective. While it is also possible to choose another objective (e.g. smallest number of picking locations), this hasn’t been considered in this project.

It has also become clear in this chapter that the redesign of the order- and delivery schedule leads to a more equally distributed number of batches per dock time. This can be explained by a more equal division of stores to the dock times in the new situation.

Furthermore, updating the dock times in the order- and delivery schedule also leads to a higher average number of batching points. The redesign of the schedule is based on weeks 2 to 13 of 2014 in the WYG DC and is tested on weeks 27 to 39 of 2014 in the WYG DC. The redesign leads to an increase of 5.2% in batching points when the current batching algorithm is used and an increase of 3.5% when the weighted matching algorithm is used. When both the dock times and the algorithm are changed, this increase is 10.3%.

Aligning the product groups within a dock time helps to increase the average batching points even further. Avoiding that product groups are only ordered by one store within a dock time prevents that similarities between stores aren’t utilized.
6. Implementation

In this part of the report the implementation of the proposed redesign is discussed. The feasibility of changing the order- and delivery schedule and the batching algorithm is checked and all changes that need to be made to the current systems are treated. Again, this part will follow the structure of the research questions, answering the sub-questions in the same order.

6.1. Feasibility of implementing the proposed redesign

In this section the feasibility of changing the batching algorithm and the order- and delivery schedule is discussed. First, the changes that are required for implementing the redesign are presented. After this it will be checked whether it is feasible and worthwhile to implement the proposed changes. This will first be done for the batching algorithm and after that for the order- and delivery schedule.

6.1.1. Batching algorithm

In chapter 5 of this report it has become clear that changing the batching algorithm influences the average number of batching points per day. The optimal solution can be found for batches that consist of up to two orders, which is the case for the PickArts system currently that is currently in use in some parts of Sligro’s CDC. The simulation of the weighted matching problem for weeks 2 to 13 of 2014 could be solved to optimality in Excel within half a minute for each day.

The current batching algorithm creates orders one by one because new orders might enter the system due to the procedure that is currently used to split orders. Because the algorithm runs very fast order pickers don’t have to wait for the system to create new batches. Furthermore, this always ensures that the biggest batch is picked first because it is the only one that is created. This also makes it easier to create a batch manually when it has a high priority.

Implementing the weighted matching solution would require an adaption of the software in Compass. For the best results all orders with the same dock time have to be released simultaneously because the weighted matching solution creates all batches for one dock time at the same moment. Because Compass is custom made for Sligro, software changes can be requested when it is believed that they will have a positive impact on the order picking process. This means that it is feasible to implement the proposed changes to the batching algorithm. Compass has to be adapted to be able to solve LP-models for each dock time. Next to this, also an adaption should be made in order to make sure that the batch with the biggest expected collection time gets picked first since in this case multiple batches are ready for picking. This is to ensure that the set due dates are met.

Other systems don’t need to be adapted when the batching algorithm is changed. The ordering system works separately from Compass and the vehicles used for order picking only pick up batches, which stay the same when weighted matching is used to create them.

It has to be checked whether it is worthwhile to implement the proposed changes to the batching algorithm in Compass. The benefits in picker productivity that have been presented in the previous chapter have to outweigh the costs of adapting the software. Also some costs, although small, are involved because people that work with Compass have to be notified of the changes. Together with the expected costs to change the software the reduction in navigation time can be used by the people responsible at Sligro to decide whether the redesign of the batching algorithm is worth implementing.
6.1.2. Order- and delivery schedule

As stated before, changes to the order- and delivery schedule can be made in two different ways. First, dock times can be adapted for each store, which will have an effect on the delivery time of a store and the possible batching combinations that are available. Second, the days at which product groups are allowed to generate an order advice can be altered. This can lead to different order compositions because the review period might change.

No software needs to be altered to implement changes to the order- and delivery schedule. Only the parameters in these software systems need to be adapted. Changing these parameters influences the days at which stores receive certain product groups and the times at which stores receive a truck delivery. This means that the proposed changes to the order- and delivery schedule are feasible to implement.

The overview of product groups that are allowed to generate an order advice on each weekday is more than 8500 lines long. Changing the lines has to be done partially by hand and is therefore quite labor intensive. This makes it undesirable to change the schedule of ordering days of product groups on a frequent basis. Furthermore this means that stores receive different product groups on different days. Stores might need to adjust their personnel planning because specific people are specialized in stocking the shelves for certain product groups.

It is not possible yet to automatically assign dock times to released orders yet. Every released order starts with the same dock time which has to be set to the right dock time manually. When the dock times are updated, the people that release the orders have to get used to the new situation. Currently they know by heart which stores are assigned to each dock time, changing them will require them to get used to the new situation again. Updating Compass so it can assign dock times automatically is therefore desirable because it would prevent that batches are being made with the general dock time and it would not have to get used to the new situation when the dock times are changed.

Changes to dock times in the afternoon don’t affect the stores delivery schedule because these truck loads are preloaded for delivery the next morning. These trucks are loaded at their dock time in the afternoon, stay overnight at the CDC and are delivered the next early morning. So stores can keep the same delivery time for these deliveries. Changes to the morning dock times do have an influence on the delivery times to the stores because they are sent from the CDC at the same day they are loaded into the truck.

Whether it is worthwhile to implement the proposed redesign is a different question. This means that stores will receive product groups on different days. In accordance with people at the stores it has to be checked whether the benefits of changing the order- and delivery schedule outweigh possible inconveniences at the stores because the personnel planning needs to be adapted. Sligro might choose to implement changes to the dock times in the afternoon first, because this doesn’t affect the operations at the stores or the transportation planning. Results of this implementation can be used to decide whether the rest of the changes should be implemented as well. It might also not be feasible to implement the proposed dock time changes due to transportation restriction. In this case it can be interesting to mimic the proposed redesign as best as possible.

Sligro might also choose to change the days that product groups are allowed to other within the dock times first. This can help to make sure that multiple stores within a dock time order the same product groups at the same day without changing the dock times.
At the beginning of this project it wasn’t clear what systems would be affected by the redesign, which is why the research question was included that would discuss whether other systems besides Compass would have to be changed to implement the changes. Now it has become clear that this is not the case. The only changes that need to be made to implement the redesign are the changes to Compass that have been discussed in this section and the changes to the parameters in the order- and delivery schedule.

6.2. How often should the redesign be revisited?

In chapter 5 of this report it has become clear that there are differences in terms of volume sent to the stores during the year. That is why the first period of the year was chosen for the analysis. The decision to change the batching algorithm has to be made only once because it doesn’t depend on the order composition but the decision to update the order- and delivery schedule is a periodic one. During the year a combination of stores in a dock time might perform differently because the stores experience seasonality of demand in a different way. This can be a reason for revisiting the decision on the order- and delivery schedule. On the other hand is changing the schedule on a frequent basis not desirable for the stores because their operations depend on the arrangement of the schedule. It also requires quite some labor to update days at which stores can order certain product groups.

The cost benefits from increased productivity will be discussed in the next part of this report. On the basis of this and with keeping in mind the previously mentioned disadvantages the process managers at Sligro can determine how often the redesign should be revisited in consultation with the stores.

6.3. Conclusion

In this chapter the requirements of implementing the proposed redesign have been presented. It has become clear that it is feasible to implement the changes to the batching algorithm because Compass is custom made for Sligro, meaning that software changes can be requested. The proposed weighted matching solution can be formulated as an LP-model which can find the optimal solution in a very short time. The changes to the order- and delivery schedule only consist of adaptations to system parameters. While it requires some time to update these parameters, it is feasible to do so.

Conclusions from the expected cost benefits can be used to decide whether it is worthwhile to implement the proposed redesign. Because the actual cost benefits can only be observed when the changes are implemented, Sligro can decide to implement the changes step by step. This can be done because adjusting the dock times in the afternoon is fairly riskless because stores don’t notice these changes and for order pickers it doesn’t matter to which stores the orders belong. This can also be achieved by changing the dock times and order moments of product groups for a single distribution center first and see how it works out. However, the people that release the orders have to get used to this new situation. Sligro might also choose to change the order moments of product groups first without changing the dock times.
7. Conclusions and recommendations

In this chapter the general conclusions that can be drawn from the project will be presented. Also recommendations towards Sligro are made in this chapter. Hereafter the academic relevance of this research is explained and the chapter is concluded with the limitations and suggestions for future research.

7.1. General conclusions

In this section the general conclusions that can be drawn from this research will be presented. The answers to the research questions will also be presented.

7.1.1. Current situation

The analysis of the current situation has shown that the workload distribution at the distribution centers is not equally divided amongst the dock times because of the unequal number of stores in each dock time. It has also become clear that several demand periods can be distinguished within a year and that these periods differ slightly for each distribution center. Furthermore it was shown that the productivity of the order pickers differs greatly. The performance of the batching algorithm is shown to be suboptimal. Also, it has become clear that in a large percent of the cases, the dock time restriction is violated because the majority of the batches consists of orders from stores of different dock times.

7.1.2. Redesign

It has become clear that changing the batching algorithm to the weighted matching solution leads to a higher average number of batching points. The increase is about 6.5% for the analyzed period in the WYG DC. For the control period this change is roughly the same (6.7%). This means that the current algorithm performs not that much worse than the optimal solution.

It has also become clear in this chapter that the redesign of the order- and delivery schedule leads to a more equally distributed number of batches per dock time. This can be explained by a more equal division of stores to the dock times in the new situation.

Furthermore, updating the dock times in the order- and delivery schedule also leads to a higher average number of batching points. The redesign of the schedule is based on weeks 2 to 12 of 2014 in the WYG DC and is tested on weeks 26 to 39 of 2014 in the WYG DC. The redesign leads to an increase of 5.2% in batching points when the current batching algorithm is used and an increase of 3.5% when the weighted matching algorithm is used. When both the dock times and the algorithm are changed, this increase is 10.3%.

Aligning the product groups within a dock time helps to increase the average batching points even further. Avoiding that product groups are only ordered by one store within a dock time prevents that similarities between stores aren’t utilized.

The cost benefits have been calculated for the WYG DC. Both the lower bound of the expected cost savings and the upper bound of the expected cost savings have been presented. The analysis was based on the WYG DC for simplicity reasons. However, this DC consists of only 2% of the product groups and 5% of the orders. The expectation is that for other distribution centers this benefit is higher because more order pickers work in these distribution centers and because the other DC’s have more product groups.
7.1.3. Implementation
It has become clear that it is feasible to implement the changes to the batching algorithm because Compass is custom made for Sligro, meaning that software changes can be requested. The proposed weighted matching solution can be formulated as an LP-model which can find the optimal solution in a very short time. The changes to the order- and delivery schedule only consist of adaptations to system parameters. While it requires some time to update these parameters, it is feasible to do so.

Conclusions from the expected cost benefits can be used to decide whether it is worthwhile to implement the proposed redesign. Because the actual cost benefits can only be observed when the changes are implemented, Sligro can decide to implement the changes step by step.

7.2. Recommendations
This section contains recommendations towards Sligro Food Group N.V. As has become clear from the analysis in this report, the current layout of the order- and delivery schedule and the batching algorithm cause a non-optimal order picking process at the central distribution center. This project has shown that cost savings are possible when the batching algorithm is changed, when the dock times are changed and when product groups are aligned between stores in the same dock times. Therefore it is recommended to investigate:

- To which extent it is possible to align the product groups and update the dock times without hurting store operations.
- Whether it is worthwhile to implement changes to the batching algorithm.
- In what sequence/phases the proposed redesign should be implement

7.3. Academic relevance
In the literature review it was pointed out that a lot of research has been conducted already on order batching and the periodic inventory routing problem.

First, this project contributes to the literature by quantifying the improvements that can be achieved when the optimal method is used instead of a sub-optimal algorithm. The difference between the seed-order, accompanying order selection algorithm currently in use at Sligro and the weighted matching solution has been presented in this research.

Furthermore, the literature on periodic inventory routing has been extended by including the operations at the distribution center into the problem instead of simplifying the warehouse operations to a single homogenous product. The increase in productivity has been studied while smoothening the workload at the distribution centers.

7.4. Limitations and future research
This section shows some limitations of the project and suggested areas that are suitable for future research.

- The optimal solution that is presented in this research is based on the biggest number of similarities between orders and the navigation time. Other methods are not considered.
- The optimal solution is only compared with the current batching algorithm at Sligro and is only used for the specific warehouse conditions at the CDC. Comparing the optimal solution with heuristics for different warehouse conditions might provide useful insight in the performance of those heuristics.
References


Gademann, N., & van de Velde, S. (2005). Order batching to minimize total travel time in a parallel-aisle warehouse. *IIE transactions, 37*(1), 63-75. DOI: 10.1080/07408170590516917


Appendix A: Management samenvatting

Introductie

Dit rapport is het resultaat van het een master thesis project dat is uitgevoerd bij Sligro Food Group N.V. in Veghel, een bedrijf dat in zowel de Nederlands food retail als de food service industrieën actief is. Orderverzameling is een belangrijk en arbeidsintensief deel van het handling proces in het centraal distributiecentrum. Een aantal jaar geleden is papierloos order verzamelen geïntroduceerd binnen Sligro. Dit betekent dat tegenwoordig een computersysteem in plaats van een vel papier de verzamelaars vertelt welke producten verzameld moeten worden. Dit heeft tot een afname van het aantal fouten en een toenemende productiviteit en inzicht in het proces geleid. Een batch van twee orders wordt in een keer verzameld om de gemiddelde doorlooptijd van de orders te verlagen. Deze batch wordt gemaakt door een batching algoritme dat punten toekent op basis van het aantal overeenkomsten tussen orders.

Het bestel- en afleveringschema bestaat uit de dagen dat product groepen besteld mogen worden en de laatste datum van de vrachtwagen, docktijd genoemd. Dit schema beïnvloedt het order verzamelschema omdat het bepaalt op welke dagen product groepen besteld mogen worden, de tijden dat orders verzameld worden en de tijden dat vrachtwagens geladen worden. Een goed afgestemd schema zorgt voor efficiënte processen op het centraal distributiecentrum en in de winkels. De frequentie van bestelmomenten is in een vorig onderzoek bepaald maar hierbij heeft de afstemming van bestelmomenten weinig aandacht gekregen.

Dit heeft ertoe geleid dat Sligro verwacht dat er nog ruimte is voor verbetering in het order verzamelschema. Op het moment is het niet bekend wat het verbeterpotentieel is dat behaald kan worden door het bestel- en afleveringschema opnieuw in te delen. Daarnaast is het niet duidelijk hoe het schema aangepast moet worden om dit potentieel te kunnen benutten. Dit heeft tot de volgende onderzoeksvraag geleid:

_Hoe moet het bestel- en afleveringschema worden ingedeeld en hoe moet het batching algoritme worden aangepast zodat het batch order verzamel proces op het centraal distributie centrum verbeterd kan worden?_

In dit project is slechts een distributiecentrum (WYG) geanalyseerd. Dezelfde logica en analyse kan echter worden toegepast op de andere distributiecentra van het CDC.

Analyse huidige situatie

Verbetering van het order verzamelschema kan worden gemeten door productiviteit van de verzamelaars. In dit project is productiviteit gedefinieerd als de som van navigatietijd en picktijd. Navigatietijd is gedefinieerd als de tijd tussen bevestigen dat een product is verzameld en de bevestiging dat de verzamelaar de locatie van de volgende orderregel is. Deze tijd kan kort zijn als het pickvoertuig op dezelfde plaats kan blijven staan voor de volgende orderregel, of langer als het voertuig moet worden verplaatst. Picktijd is gedefinieerd als de tijd die loopt van wanneer een verzamelaar bevestigd dat hij op de goede locatie is tot de verzamelaar bevestigd dat de producten op de pallet op het voertuig staan.

Analyse van de huidige situatie van de weken 2 tot 13 in het WYG DC laat zien dat er een significant verschil is tussen de productiviteit tussen verzamelaars. Sommigen verzamelen gemiddeld 600 producten per uur terwijl anderen 1400 producten per uur verzamelen. Uit de analyse van de productiviteit KPI die hieronder in Figuur 14 te zien is, kunnen de volgende vijf dingen worden geconcludeerd:
1. Het aantal producten in een batch neemt toe wanneer meer gangen moeten worden bezocht.
2. Het aantal orderregels neemt toe wanneer meer gangen moeten worden bezocht, tot op zekere hoogte.
3. Het aantal producten per orderregel neemt af wanneer meer gangen moeten worden bezocht.
4. Per uur worden meer orderregels verzameld als meer gangen moeten worden bezocht.
5. Wanneer het aantal producten in een batch verspreid is over meer gangen, daalt het aantal producten dat per uur verzameld wordt.

![Productiviteit per gang](image)

**Figure 14 - Productiviteit per gang voor WYG DC weken 2 tot 13**

Verder wordt uit de analyse van de huidige situatie duidelijk dat een groot deel van de batches die verzameld zijn bestaat uit orders met een verschillende docktijd of slechts een order. Dit betekent dat de regels van het batching algoritme vaak overtreden worden, voor redenen zoals spoed orders. Het gemiddeld aantal batch punten is redelijk constant per dag en per week in de geanalyseerde periode. De werklast daarentegen fluctueert wel per dag en per docktijd, wat verklaard kan worden door de huidige niet-gebalanceerde indeling van het bestel- en afleveringschema. Een jaarlijks patroon in de vraag kan worden ontdekt voor elk DC. In de eerste drie maanden van het jaar is de vraag het laagst van het jaar. Hierna start een periode van hoge vraag door de feestdagen en de zomer. Na de zomer daalt de vraag weer. December kan worden gezien als de laatste periode in een jaar met hoge vraag door Sinterklaas en Kerstmis.

**Herontwerp**

Uit de onderzoeksvraag blijkt dat het bestel- en afleverschema en het batching algoritme suboptimaal zijn en moeten worden herontworpen. Door winkels te zoeken met een vergelijkbaar bestelpatroon en deze combineren in een docktijd verbeteren de prestaties van het batching algoritme en dus de productiviteit. Omdat een batch in het CDC bestaat uit maximaal twee orders kan de optimale oplossing gevonden worden in polynomiale tijd als *weighted matching* wordt gebruikt.

Vergelijkbare bestelpatronen tussen winkels kunnen worden gevonden door batches te maken van matchende orders van een hele week. Hierdoor worden verschillen in bestelmomenten omzeild. Docktijden worden gemaakt met een batching algoritme met een capaciteit van acht winkels. De grootste winkel wordt eerst geselecteerd en winkels met het meeste aantal matchende orders worden aan de docktijd toegevoegd. Een nieuwe docktijd wordt gemaakt als de docktijd vol is.
De nieuwe indeling van docktijden leidt tot een toename van 5.2% in batchpunten voor een controle periode als het huidige algoritme wordt gebruikt en een toename van 6.5% in batch punten als de *weighted matching* oplossing wordt gebruikt om het aantal punten te maximaliseren. De afstemming van product groepen is niet meegenomen in deze analyse omdat de order samenstelling hierdoor zou veranderen, wat zou betekenen dat het hele bestelsysteem gesimuleerd moet worden.

Als het batching algoritme wordt aangepast naar de *weighted matching* oplossing kan ook de doelfunctie worden aangepast. Een lineaire regressie in SPSS laat zien dat de picktijd voorspeld kan worden door het aantal producten in een batch terwijl de navigatietijd voorspeld kan worden door het aantal orderreels, het aantal batch punten en het aantal gang dat bezocht moet worden. Dit model is als volgt:

**Navigatietijd**

\[
N_{\text{avigatietijd}} = 4,428 + 0,270 \cdot Order\text{regels} - 0,064 \cdot Punten + 1,597 \cdot Gang6 + 3,339 \cdot Gang8 + 4,252 \cdot Gang10
\]

Het aanpassen van de doelfunctie naar deze navigatietijd leidt ertoe dat de tijd die nodig is om de batches te verzamelen direct geminimaliseerd wordt.

De analyse laat zien dat meer dan 200 uur navigatietijd kan worden bespaard in het WYG DC in een half jaar. Als dit over het hele CDC wordt geëxtrapolereerd zijn de verwachte jaarlijkse kostenbesparingen meer dan €180.000. Als alleen de docktijden worden aangepast zijn de verwachte kostenbesparingen per jaar meer dan €7.000. Als ook de bestelmomenten van productgroepen worden afgestemd per docktijd, kunnen de besparingen richting de besparing van het aangepast algoritme gaan, al is onbekend in welke mate.

**Implementatie**

Het aanpassen van de docktijden en de momenten waarop productgroepen besteld mogen worden bestaat alleen uit het aanpassen van parameters in het systeem. Het aanpassen van het batching algoritme naar de *weighted matching* oplossing vereist aanpassingen aan het order vrijgave systeem Compass. Omdat dit systeem op maat gemaakt wordt voor Sligro, is het doorvoeren van veranderingen hierin een realistische optie.

De mensen die verantwoordelijk zijn voor deze veranderingen binnen Sligro zullen moeten beoordelen of het de moeite waard is om het voorgestelde herontwerp te implementeren. Om de risico’s te beperken kan er ook voor gekozen worden om het herontwerp stap voor stap in te voeren, bijvoorbeeld door eerst de docktijden en bestelmomenten van productengroepen voor slechts een distributiecentrum aan te passen.

**Conclusies en aanbevelingen**

De analyse van de huidige situatie heeft laten zien dat de werklast verdeling in het distributiecentrum niet gelijk verdeeld is over de docktijden omdat het aantal winkels per docktijd niet gelijk is. Ook is duidelijk geworden dat verschillende periodes van vraag bestaan in een jaar en dat deze per distributiecentrum iets verschillen. Daarnaast valt op dat de productiviteit per verzamelaar veel verschilt. De prestaties van het batching algoritme zijn suboptimaal en het is duidelijk dat een groot deel van de batches bestaat uit orders van winkels uit verschillende docktijden.
Het aanpassen van het batching algoritme leidt tot een toename van 6.5% van het gemiddelde aantal batch punten in de geanalyseerde periode. Aanpassing van de docktijden leidt tot een evenwichtigere verdeling van het aantal orders per docktijd, wat verklaard kan worden door een betere verdeling van winkels in de docktijden.

Afstemmen van productgroepen binnen een docktijd helpt om het gemiddeld aantal batch punten verder te verhogen. Als product groepen door meerdere winkels in een docktijd besteld mag worden, kan worden voorkomen dat overeenkomsten tussen winkels niet worden benut. De verwachte kostenbesparing per jaar valt tussen €7.000 als de docktijden worden aangepast en €180.000 als het optimale batching algoritme wordt gebruikt om de navigatietijd te minimaliseren.

Het wordt aanbevolen om verder te onderzoeken:
- Tot op welke hoogte het mogelijk is product groepen en docktijden af te stemmen zonder dat winkels hier last van hebben.
- Of het de moeite waard is om het optimale batch algoritme in te voeren.
- In welke volgorde/fases het herontwerp moet worden ingevoerd.

Academisch gezien draagt dit project bij aan de literatuur door de verbeteringen die kunnen worden behaald door de optimale batch methode te gebruiken in plaats van een suboptimaal algoritme te kwantificeren. Het verschil tussen het huidige batching algoritme dat bij Sligro in gebruik is wordt vergeleken met de weighted matching oplossing in dit project.

Beperkingen van dit onderzoek zijn dat de optimale oplossing van het batching algoritme alleen rekening heeft gehouden met de navigatietijd en het aantal batchpunten. Andere doelfuncties zijn niet beschouwd. Ook is de optimale oplossing met slechts een andere algoritme vergeleken. Door de optimale oplossing met meerdere heuristieken en distributiecentrum karakteristieken te vergelijken worden de prestaties van die heuristieken duidelijker.
Appendix B: Multiple regression model pick time

In this appendix the linear regression can be found that is used to determine the relation between the picking time and the number of products in a batch.

Data from weeks 2-13 from the WYG DC is used. Picking time for each batch is used as the dependent variable while the number of products in a batch is used as the independent variable.

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>N</td>
</tr>
<tr>
<td>Picktime</td>
<td>27.0846</td>
<td>11.62380</td>
<td>1552</td>
</tr>
<tr>
<td>Products</td>
<td>897.84</td>
<td>304.245</td>
<td>1552</td>
</tr>
</tbody>
</table>

Table 17 - Descriptive statistics multiple regression

As can be seen from Table 17 above, 1552 cases are used in the analysis. The average number of products is almost 898 while the average pick time a batch is a little over 27 minutes.

<table>
<thead>
<tr>
<th>Correlations</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Picktime</td>
<td>Products</td>
<td></td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.000</td>
<td>.754</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.754</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Sig. (1-tailed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.000</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1552</td>
<td>1552</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1552</td>
<td>1552</td>
<td></td>
</tr>
</tbody>
</table>

Table 18 - Correlations multiple regression.

From Table 18 above it can be seen that the correlation between Picktime and Products is quite high, which was expected. This correlation was also found in the data inspection that can be found in Table 6 of this report. The enter method is used to insert the Products variable into the model in Table 19 below.

<table>
<thead>
<tr>
<th>Variables Entered/Removeda</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Variables Entered</td>
<td>Variables Removed</td>
<td>Method</td>
</tr>
<tr>
<td>1</td>
<td>Productsb</td>
<td>.</td>
<td>Enter</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Picktime
b. All requested variables entered.

Table 19 - Variables entered multiple regression
Table 20 - Model summary multiple regression.

From Table 20 above it can be seen that the R squared of the model is moderate, 0.569. This means that almost 57% of the variance is explained by the model. The Durbin-Watson test is close to 2 so there are no points of concern on this point. From Table 21 below it can be seen that the model is highly significant.

Table 21 - ANOVA table multiple regression

In Table 22 above the coefficients of the model are depicted. Both the constant and the number of products in a batch are highly significant. VIF statistics are equal to one because only one variable is used. It can be seen that each product takes about 0.029 minute of picking time, almost equal to the value in Table 6.

In Table 23 below it can be seen that 27 cases have a standardized residual larger than 3. This is less than 2% of the total cases so there is no reason for concern on this point.
### Casewise Diagnostics

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Std. Residual</th>
<th>Picktime</th>
<th>Predicted Value</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>134</td>
<td>3.531</td>
<td>50.01</td>
<td>23.0542</td>
<td>26.95581</td>
</tr>
<tr>
<td>265</td>
<td>3.128</td>
<td>57.85</td>
<td>33.9773</td>
<td>23.87273</td>
</tr>
<tr>
<td>349</td>
<td>-4.351</td>
<td>27.48</td>
<td>60.6942</td>
<td>-33.21415</td>
</tr>
<tr>
<td>362</td>
<td>3.828</td>
<td>65.36</td>
<td>36.1388</td>
<td>29.22117</td>
</tr>
<tr>
<td>516</td>
<td>3.201</td>
<td>47.60</td>
<td>23.1695</td>
<td>24.43053</td>
</tr>
<tr>
<td>538</td>
<td>3.296</td>
<td>46.28</td>
<td>21.1232</td>
<td>25.15681</td>
</tr>
<tr>
<td>602</td>
<td>3.438</td>
<td>58.23</td>
<td>31.9886</td>
<td>26.24136</td>
</tr>
<tr>
<td>711</td>
<td>3.209</td>
<td>46.97</td>
<td>22.4778</td>
<td>24.49223</td>
</tr>
<tr>
<td>759</td>
<td>3.640</td>
<td>65.31</td>
<td>37.5222</td>
<td>27.78777</td>
</tr>
<tr>
<td>777</td>
<td>3.153</td>
<td>52.94</td>
<td>28.8760</td>
<td>24.06401</td>
</tr>
<tr>
<td>829</td>
<td>3.446</td>
<td>62.27</td>
<td>35.9659</td>
<td>26.30409</td>
</tr>
<tr>
<td>846</td>
<td>3.025</td>
<td>47.07</td>
<td>23.9765</td>
<td>23.09355</td>
</tr>
<tr>
<td>897</td>
<td>3.375</td>
<td>57.58</td>
<td>31.8157</td>
<td>25.76429</td>
</tr>
<tr>
<td>912</td>
<td>3.468</td>
<td>62.38</td>
<td>35.9083</td>
<td>26.47174</td>
</tr>
<tr>
<td>920</td>
<td>3.827</td>
<td>65.12</td>
<td>35.9083</td>
<td>29.21174</td>
</tr>
<tr>
<td>924</td>
<td>3.291</td>
<td>56.68</td>
<td>31.5563</td>
<td>25.12368</td>
</tr>
<tr>
<td>1010</td>
<td>3.400</td>
<td>63.13</td>
<td>37.1764</td>
<td>25.95362</td>
</tr>
<tr>
<td>1050</td>
<td>3.018</td>
<td>58.48</td>
<td>35.4471</td>
<td>23.03287</td>
</tr>
<tr>
<td>1066</td>
<td>3.646</td>
<td>52.96</td>
<td>25.1293</td>
<td>27.83072</td>
</tr>
<tr>
<td>1103</td>
<td>3.205</td>
<td>53.74</td>
<td>29.2795</td>
<td>24.46052</td>
</tr>
<tr>
<td>1133</td>
<td>3.544</td>
<td>60.11</td>
<td>33.0550</td>
<td>27.05499</td>
</tr>
<tr>
<td>1138</td>
<td>3.046</td>
<td>55.01</td>
<td>31.7581</td>
<td>23.25193</td>
</tr>
<tr>
<td>1231</td>
<td>-3.904</td>
<td>14.81</td>
<td>44.6121</td>
<td>-29.80215</td>
</tr>
<tr>
<td>1321</td>
<td>3.147</td>
<td>57.25</td>
<td>33.2279</td>
<td>24.02207</td>
</tr>
<tr>
<td>1355</td>
<td>3.403</td>
<td>59.98</td>
<td>34.0061</td>
<td>25.97391</td>
</tr>
<tr>
<td>1364</td>
<td>3.180</td>
<td>58.51</td>
<td>34.2367</td>
<td>24.27334</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Picktime

Table 23 - Casewise diagnostics multiple regression.
Charts

Figure 15 - Standardized residual histogram multiple regression.

From Figure 15 above and Figure 16 below it can be seen that there is no reason to assume that the data is not normally distributed. The standardized residuals differs slightly from the diagonal line but this is no real reason for concern.

Figure 16 - Normal probability plot multiple regression.
Appendix C: Multiple regression model navigation time

In this appendix the linear regression can be found that is used to determine the relation between the navigation time and the number of order lines of a batch, the number of batching points of a batch and the number of aisles to be visited.

Data from weeks 2-13 from the WYG DC is used. Navigation time for each batch is used as the dependent variable while the number of order lines in a batch, the number of batching points and the number of aisles to be visited are used as the independent variables.

The number of aisles that has to be visited for a batch is a categorical variable. So this variable is recoded into dummy variables first. Analysis shows that there is no significant difference between two and four aisles. That is why only the variables Aisles6, Aisles8 and Aisles10 are entered in this linear regression model.

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navtime</td>
<td>18,6102</td>
<td>9,57175</td>
<td>1558</td>
</tr>
<tr>
<td>BatchOL</td>
<td>50,60</td>
<td>31,348</td>
<td>1558</td>
</tr>
<tr>
<td>Points</td>
<td>20,87</td>
<td>20,362</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles6</td>
<td>.2510</td>
<td>.43371</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles8</td>
<td>.2561</td>
<td>.43662</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles10</td>
<td>.1399</td>
<td>.34702</td>
<td>1558</td>
</tr>
</tbody>
</table>

Table 24 - Descriptive statistics multiple regression

As can be seen from Table 24 above, 1558 cases are used in the analysis. The average navigation time is almost 19 minutes, the average number of order lines in a batch is a little over 50, the average number of batching points is almost 21, about 25% of the batches contains products spread over 6 aisles, almost 26% have products spread over 8 aisles and 14% have products spread over 10 aisles.
From Table 25 above it can be seen that the correlation between Navigation time and BatchOL and Points is quite high, which was expected. The enter method is used to insert the variables into the model in Table 26 below.

**Table 25 - Correlations multiple regression.**

<table>
<thead>
<tr>
<th>Pearson Correlation</th>
<th>Navtime</th>
<th>BatchOL</th>
<th>Points</th>
<th>Aisles6</th>
<th>Aisles8</th>
<th>Aisles10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navtime</td>
<td>1.000</td>
<td>.819</td>
<td>.570</td>
<td>.134</td>
<td>.176</td>
<td>.197</td>
</tr>
<tr>
<td>BatchOL</td>
<td>.819</td>
<td>1.000</td>
<td>.800</td>
<td>.201</td>
<td>.086</td>
<td>.101</td>
</tr>
<tr>
<td>Points</td>
<td>.570</td>
<td>.800</td>
<td>1.000</td>
<td>.206</td>
<td>-.066</td>
<td>-.045</td>
</tr>
<tr>
<td>Aisles6</td>
<td>.134</td>
<td>.201</td>
<td>.206</td>
<td>1.000</td>
<td>-.340</td>
<td>-.233</td>
</tr>
<tr>
<td>Aisles8</td>
<td>.176</td>
<td>.086</td>
<td>-.066</td>
<td>-.340</td>
<td>1.000</td>
<td>-.237</td>
</tr>
<tr>
<td>Aisles10</td>
<td>.197</td>
<td>.101</td>
<td>-.045</td>
<td>-.233</td>
<td>-.237</td>
<td>1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sig. (1-tailed)</th>
<th>Navtime</th>
<th>BatchOL</th>
<th>Points</th>
<th>Aisles6</th>
<th>Aisles8</th>
<th>Aisles10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navtime</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>BatchOL</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.004</td>
<td>.037</td>
</tr>
<tr>
<td>Points</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles6</td>
<td>.000</td>
<td>.000</td>
<td>.004</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles8</td>
<td>.000</td>
<td>.000</td>
<td>.037</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Aisles10</td>
<td>.000</td>
<td>.000</td>
<td>.037</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N</th>
<th>Navtime</th>
<th>BatchOL</th>
<th>Points</th>
<th>Aisles6</th>
<th>Aisles8</th>
<th>Aisles10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navtime</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
<tr>
<td>BatchOL</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
<tr>
<td>Points</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles6</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles8</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
<tr>
<td>Aisles10</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
<td>1558</td>
</tr>
</tbody>
</table>

**Table 26 - Variables entered multiple regression**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aisles10, Points, Aisles6, BatchOL</td>
<td></td>
<td>Enter</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Navtime
b. All requested variables entered.
From Table 27 above it can be seen that the R squared of the model is quite high, 0.714. This means that over 71% of the variance is explained by the model. The Durbin-Watson test is close to 2 so there are no points of concern on this point. From Table 28 below it can be seen that the model is highly significant.

In Table 29 above the coefficients of the model are depicted. All variables as well as the constant are highly significant. VIF statistics are higher than one but they don’t exceed 10 so there is no reason for concern. It can be seen that all variables have a positive influence on the navigation time, except for the number of points in a batch.
From Tables 30 and 31 above it can be seen that the Points and Batch order lines variables are correlated to some extent which is a confirmation of what was already seen before. In Table 32 below it can be seen that 19 cases have a standardized residual larger than 3. This is less than 2% of the total cases so there is no reason for concern on this point.
### Table 32 - Casewise diagnostics multiple regression.

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Std. Residual</th>
<th>Navtime</th>
<th>Predicted Value</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td>3.580</td>
<td>34.12</td>
<td>15,7550</td>
<td>18,36499</td>
</tr>
<tr>
<td>366</td>
<td>3.471</td>
<td>35.40</td>
<td>17,5943</td>
<td>17,80573</td>
</tr>
<tr>
<td>436</td>
<td>3.308</td>
<td>41.80</td>
<td>24,8294</td>
<td>16,97062</td>
</tr>
<tr>
<td>442</td>
<td>3.206</td>
<td>24.79</td>
<td>8,3416</td>
<td>16,44839</td>
</tr>
<tr>
<td>530</td>
<td>3.736</td>
<td>33.36</td>
<td>14,1942</td>
<td>19,16579</td>
</tr>
<tr>
<td>636</td>
<td>3.585</td>
<td>46.60</td>
<td>28,2103</td>
<td>18,38968</td>
</tr>
<tr>
<td>655</td>
<td>3.744</td>
<td>43.09</td>
<td>23,8854</td>
<td>19,20457</td>
</tr>
<tr>
<td>730</td>
<td>3.133</td>
<td>21.72</td>
<td>5,6501</td>
<td>16,06992</td>
</tr>
<tr>
<td>845</td>
<td>3.999</td>
<td>37.80</td>
<td>17,2854</td>
<td>20,51462</td>
</tr>
<tr>
<td>850</td>
<td>3.172</td>
<td>34.15</td>
<td>17,8758</td>
<td>16,27418</td>
</tr>
<tr>
<td>853</td>
<td>3.599</td>
<td>48.85</td>
<td>30,3853</td>
<td>18,46467</td>
</tr>
<tr>
<td>859</td>
<td>3.320</td>
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a. Dependent Variable: Navtime

From Figure 17 above and Figure 18 below it can be seen that there is no reason to assume that the data is not normally distributed. The standardized residuals differs slightly from the diagonal line but this is no real reason for concern.

Figure 17 - Standardized residual histogram multiple regression.

XIV
The scatterplots below show that the residuals are nicely distributed, so there is no reason to assume heteroscedasticity.
### Appendix D: Simulation results WYG DC

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Table 33 - Results batching simulation.
Appendix E: Store in dock time distribution

In the Table below the current dock times are displayed for the WYG, FD3 and KND DC’s.

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<tr>
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</tr>
<tr>
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</tr>
<tr>
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**Gemarkeerde tijden zijn vestigingen die meerdere keren per dag bestellen uit verschillende DC’s.**

Order pas doorstarten als de orders van de eerste plantijd reeds gebatcht of verzameld zijn.

Vervolgens tijd aanpassen.

Table 34 - Dock times WYG, FD3 and KND.
Appendix F: Simulation results dock times changes

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Table 35 - Old dock times versus new dock times.