MASTER

Order advancement and delivery scheduling in the retail supply chain

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Order advancement and delivery scheduling in the retail supply chain

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Abstract

This master thesis describes a research performed at Jan Linders Supermarkten B.V.. The master thesis is about order and delivery scheduling in a retail environment. The costs related to transportation and handling in the stores and the DC are taken into account and it is assumed that all products are available in the DC for order picking. In previous research about optimizing the order and delivery schedule, delivery patterns are assigned to stores and items, and thereby delivery moments are excluded for specific items to advance orders. This reduces the responsiveness on deviations in consumer demand. In this thesis an order and delivery scheduling process is presented. In this iterative process first an initial number of deliveries are determined and then it is tried to obtain a maximum smoothed workload against minimum costs by determining the reorder level increments per item. By adjusting the reorder levels it is not needed to exclude delivery moments for specific items to advance orders. The new order and delivery scheduling process is applied to three stores. This research has shown that a better coordination between instore requirements and processes and upstream logistics activities could have a considerable cost impact.
Management summary

This master thesis is conducted at Jan Linders Supermarkten B.V., a grocery retailer in the Netherlands. The company has a nationwide market share of 1%, but the stores are located in only the South-East region of the Netherlands. Since the start Jan Linders is family owned and there are no franchisers involved. In this thesis the supply chain from the distribution center (DC) to the stores will be reviewed and the direct-to-store deliveries are out of scope.

The inducement for starting this thesis is the complexity of the current order and delivery schedule. As a consequence of the relative small company size problems were solved by creating an exception in the existing processes for specific items, item sets or stores. Throughout the years the result of creating all these exceptions is that the underlying structures and decision rules are lost. The management of operations has become a complex task. In the current order and delivery schedule not all relevant subsystems are taken into account, which has led to local optimization in the supply chain. The goal of order and delivery scheduling is customer satisfaction, expressed by in-store availability and customer response, at minimum costs. In this thesis a cost-efficient order and delivery schedule was developed. The research question of this thesis is shown below.

What is a cost-efficient order and delivery schedule per store for Jan Linders Supermarkten B.V. by taking into account a reasonable in-store availability level and the most relevant costs for transportation, the stores and the DC?

From the literature review can be concluded that there is a lack of research about an integrative approach that minimizes transportation, handling and inventory costs in a retail supply chain by workload balancing. Kuhn and Sternbeck (2014) came closest to an integrative approach, but there are some limitations in their study. Their research does not take into account the effect of shelf capacities and it excludes delivery moments for specific items, which reduces the responsiveness on fluctuations in consumer demand. Because of the need for workload balancing in transportation, as well as the stores as the DC, a new replenishment policy based on order advancement theory is developed and applied in this thesis.

Order advancement is embedded in the new order and delivery scheduling process. This process starts with determining the initial number of deliveries. Then the target workload per period is defined and finally the order advancement algorithm is applied, which determines the order quantities per item. The item selection algorithm adjusts reorder levels per period to advance orders. The algorithm stops when the target volume is obtained or when there is no more smoothing volume available. In every iteration a new target workload will be defined and the iterating process stops if the costs per store are minimized and the constraints are met.

For determining the number of deliveries and the level of order advancement a cost function is used. This function includes cost components related to the workload difference, transportation, handling in the stores and the DC, and the inventory levels. The workload difference, handling costs and inventory costs are given per consumer unit and the transportation costs depend on the driving distance from the DC to the stores, the loading and unload time and the average driving speed.
Within the order and scheduling process bundling of store deliveries per route is not included and therefore the fixed delivery costs per store could be overestimated.

The order and delivery scheduling process is applied to three stores with a weekly demand level that is not larger than six truckloads. Stores with a weekly demand level larger than six truckloads will still receive 12 deliveries. After the application of the order and delivery scheduling process can be concluded that the workload cannot be smoothed completely for every store. Only for the stores with a low demand level the workload can be smoothed completely. For 35 stores, six deliveries should be scheduled and 12 stores an extra (7th) delivery must be scheduled.

The performance improvement differs per logistics subsystem and per store. For stores with a maximum demand level of six truckloads the cost savings in transportation are expected to be 12.2%. Due to the reduction in the number of stops by 34.0%, the transportation planning will become less complicated. If order advancement will be applied to all stores, the peak workload in the DC and transportation is expected to reduce from 1.70 towards 1.18 times the non-peak workload.

A sensitivity analysis is performed for the stacking efficiency and the shelf capacity. Store 1200 has one of the highest utilization degree per roll-container (RC). If the same stacking efficiency would be reached for all stores, the total delivery volume for all stores will reduce by 10.5%. The number of stores with a required delivery volume of six truckloads will reduce by one and the utilization degree for those stores will reduce by 8.5%. It is concluded that the stacking efficiency of RC’s should be stabilized to prevent unscheduled deliveries. From the sensitivity analysis of the shelf capacity can be concluded that the advancement potential is sensitive for deviations in the shelf capacities. The effect is larger for a reduction of the shelf capacity than for an increase of the shelf capacity.

The design as proposed during this research has some limitations. All of these limitations can be seen as options for future research and these are summarized hereafter.

- For items under promotions only the target workload pattern is determined in the order and delivery scheduling process per store. This means that for reaching the workload a more detailed replenishment policy must be defined.
- Inventory routing is not included in this research and therefore the approximation of the fixed delivery costs could be inaccurate and this could lead to a suboptimal delivery schedule per store. To reduce the supply chain costs the order and delivery scheduling process vehicle routing should be integrated. This will provide a more accurate approximation of the fixed delivery costs and could lead to a different target workload level per store.
- In the order advancement algorithm a minimum advancement quantity (MAQ) of 0.1 CU is used. The effect of different values for the MAQ on the real level of advancement could be analyzed and because it could affect the level of order advancement.
- For a more accurate approximation of the effect on order advancement in terms of costs, more cost drivers should be defined. (e.g. number of case packs and order lines).
- A reduction in the number of order lines will reduce the handling costs in both the stores and the DC. Therefore it is recommended extent the model so that it could reduce the number of order lines, by advancing orders from multiple peak days and smooth them together towards a non-peak day for example.
This thesis came up with several recommendations for Jan Linders Supermarkten B.V. and these are summarized hereafter.

- Bundle perishable and non-perishables per store delivery to obtain significant cost savings. Those are currently delivered separately and lead to a large number of stops.
- Implement the order advancing algorithm and replace the current order and delivery schedule to reduce the complexity of managing the supply chain.
- Improve the stacking efficiency of RC's to reduce the transportation costs significantly.
- Improve the accuracy of the shelf capacity data in the ASO-system to prevent an unexpected high level of backroom inventory.
- Improve the alignment between truck arrival times and shelf stacking times to prevent an unexpected low availability level or unnecessary inventories in the backroom.
- Investigate the possibilities for starting the discount period after a non-peak period to reduce the promotional delivery volume during the peak period.
- Reduce the inventory build-up at the start of the discount period, because the current inventory build-up of 96% is more than the required 40%.
- Investigate the store and the DC preferences to determine the exact loading and unloading time windows, because the available workforce and the wage levels could deviate during the day and during the week.
- Improve the definition of the utilization degree for trucks by including the total driving distance as parameter for a more representative performance indicator for transportation.
Preface

This master thesis presents the result of my graduation project performed at Jan Linders Supermarkten B.V. for the Master of Science in Operations Management and Logistics at the Eindhoven University of Technology. Within the multidisciplinary study I chose to focus on the operations planning and logistics and I got the opportunity to conduct this research under the control of the sub department Operations Planning And Control. My interests in the research field of retail operations came from my experiences from a part-time job at a retail supplier of fruit and vegetables, which have shown me the challenges and dynamics of different retailers as a response on the dynamics of consumer demand. Due to this challenging master thesis project I got the opportunity to build my knowledge of retail supply chain planning processes.

I have completed this master thesis due to the motivation and valuable support of many people. At first I want to thank Rob Broekmeulen for sharing his in-depth knowledge of retail supply chains and very valuable feedback during this challenging project. Moreover I want to thank him a lot for his solid support, the amount of time invested and motivational sessions. I also want to thank my second supervisor Luuk Veelenturf for his critical attitude and valuable questions.

Jan Linders was an inspiring surrounding to do my graduation project. I want to thank all of my colleagues for both their formal and informal support. Especially, I want to thank the management for giving me this opportunity, which was a valuable contribution to my personal development and hopefully also for the future of the company.

In this list of thankful words, I cannot forget my family for their unconditional support during my entire study to get the best out of myself. I want to thank them for giving me a solid base to build my future on!

Jeroen Kuijvenhoven

Eindhoven, February 2016
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<td>automatic store ordering system</td>
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<tr>
<td>CU</td>
<td>consumer unit</td>
</tr>
<tr>
<td>DC</td>
<td>distribution center</td>
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<td>MAQ</td>
<td>minimum advancement quantity</td>
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<td>RC</td>
<td>roll-container</td>
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1 Introduction

This chapter introduces the company involved by discussing the history, market position and the main company developments. Thereafter a short problem introduction is given and at last the report structure is presented.

1.1 Company description

1.1.1 History and Market position

Jan Linders Supermarkten B.V. is a regional Dutch retailer, which was founded in 1963 by Jan Linders. In that year Jan Linders opened his first supermarket in Gennep. Since the start Jan Linders is a family owned company and there are no franchisers involved. Jan Linders chose to deliver its stores from a single central distribution center (DC), which is still located in Nieuw Bergen. Also the head office is located in Nieuw Bergen. At this moment the company owns 57 stores in the South-East region of the Netherlands, but is expanding their region towards the North-East. The main developments during the last decade are discussed in paragraph 1.2.2.

The market position of Jan Linders Supermarkten B.V. (hereafter Jan Linders) can be expressed in the performance development and the appreciation from a customers’ point of view. Foodmagazine (2014) states that Jan Linders is the most valued supermarket chain from a customer perspective in the Netherlands by their customers. Jan Linders ranks highest on quality of the assortment and the perceived service. Both the average development of turnover and the customer base makes that the company occupies the fourth position for the overall performance. During the last six years the company won the award as the best performer in the fresh segment in the Netherlands each year. This performance is seen as an important driver for its success to maintain their 1% market share and slowly increase their turnover according to the market growth in the Dutch retail sector (CBS, 2015).

The European retail sector is characterized by a high level of consolidation and an increasing pressure on profit margins (Hübner, Kuhn, & Sternbeck, 2013) (McCarthy-Byrne & Mentzer, 2011). To protect itself against these market trends and, more specific, to obtain price discounts and procurement power by their suppliers, Jan Linders is a member of the Dutch retail procurement cooperative Superunie. The members of Superunie together represent a 30% market share of the Dutch retail market.

1.1.2 Main company developments

During the last decade, there were several important company developments. This paragraph outlines the important developments related to order and delivery scheduling.

Distribution Center (DC): In 2007 Jan Linders opened a new DC in Nieuw Bergen. Shortly after opening the new DC, Jan Linders had large problems to structure and control their operations which resulted in low availability levels in the stores. To structure the logistical processes new ordering segments and delivery patterns, represented by different colors, were defined. The assignment of products to a certain delivery pattern was based on turnover as well as the physical aspects of the products such as the storage temperature and the shelf life. In 2011, the assignment of the dry grocery category was re-evaluated. During the period of structuring the operations at the DC, the
decision to deliver most of the fresh produce before store opening was made. This decision together with the definition of the ordering segments, are still the most important determinants for the current order and delivery schedule and replenishment policy.

**Information systems:** During 2011 Jan Linders introduced an automatic store ordering (ASO) system, called F&R. This system provides an order quantity advice based on a forecast, which is sent as a proposal to store managers. This order advice can be adjusted by them, before the proposed order becomes the final quantity. At this moment the ASO system is not used for some small perishable product categories. In the first half of 2016 the company will start with a new information system for the DC. This system will propose order quantities for planners and suppliers.

**Third party logistics service provider:** For several decades Jan Linders has been cooperating with a third party logistics service provider. Jan Linders is co-owner of 24 trucks, which makes it more profitable to maximize the utilization of these trucks. Those cofinanced trucks will be called dedicated trucks, and cannot be used by other parties. The actual transport planning is not outsourced to the logistics service provider and is done by Jan Linders’ transportation department.

**Customer pick-up:** At-home delivery and customer pick-up are main developments in retail to increase customer service. Customer pick-up means that the customer can order online at home and that he can pick-up his order at a pick-up point. Jan Linders is implementing customer pick-up in the stores at this moment. The orders will be collected in the store by store personnel and therefore the supply chain structure does not change due to this development. Note that the collection of customers’ orders could increase the store handling costs significantly.

### 1.2 Problem introduction

Jan Linders is looking for opportunities to optimize their supply chain from DC towards their end-consumer. The first step is to evaluate the current order and delivery schedule. In this thesis the current order and delivery schedule will be evaluated. The order and delivery schedule determines the length of the review periods and lead times. Given the length of the lead times the number of delivery moments per product per store and the delivery quantities can be determined.

Jan Linders owns one central DC that delivers all stores. In this report it will be assumed that all products are available for order picking in DC and the direct to store deliveries are excluded. The supply chain per store is shown in figure 1. Each rectangle indicates a process and each triangle represents a stocking point. The arrows show the product flows in the supply chain. The reversed logistics (e.g. empty crates and outdated products) are not visualized because this product flow is out of scope. The black rectangle indicates from where the supply chain is under research.

![Figure 1 – Supply chain of Jan Linders](image_url)
The company is able to use a homogeneous vehicle fleet for transportation and each truck can be divided into three different temperature zones. This makes it possible to load a truck with roll-containers (RC’s) that have to be stored at different temperatures. This creates large flexibility for scheduling their transport from the DC to the stores. A unique characteristic of the current delivery schedule is that a large part of the perishable goods is delivered in the morning before store opening. This could be the base for their positive distinguishable performance for the segments with perishable products.

During the last years their order and delivery schedule has been adapted many times and at this moment it is no longer clear how well their current replenishment system performs. Therefore an important aim of this master thesis is to define the base requirements for order and delivery scheduling. In this thesis a new replenishment policy should be developed by taking into account the most important cost drivers.

1.3 Report structure

The master thesis project is part of a business solving process and the process steps are defined by Van Strien (1997) and shown in figure 2. In chapter 2 the scope of this research is defined and it provides the problem definition obtained from the problem mess and problem analysis. Given this problem definition, research questions are defined and a summary and the solution concepts of the preliminary literature review are given. The design stage is divided in four steps, the conceptual design (chapter 3), detailed design (chapter 4), sensitivity analysis (chapter 5) and integration (chapter 6). The conceptual design introduces the idea for solving the business problem and defines the functional requirements. The detailed design comes up with a quantitative model according to the conceptual model. With this quantitative model the values of the design parameters can be determined. After the detailed design a sensitivity analysis is performed and the results will be used in the last part of the thesis, the integration. In this part the effect on operations will be discussed and recommendations for implementation will be provided. Implementation of the solution and the evaluation step is outside of the scope and will not be discussed in this report.

![Figure 2 – Business problem solving cycle](image-url)
2 Problem definition

This chapter introduces the problem and starts with defining the scope of this research project. Thereafter the problem is described and research questions are defined. Afterwards a literature review is provided and the available solution directions are discussed. Finally it will be discussed what this research could add to the existing literature about order and delivery scheduling in retail.

2.1 Scope

The guide of the scope definition will be the demand and supply chain operations planning framework from Hübner, Kuhn & Sternbeck (2013) as shown in figure 3. The black rectangles, rectangles with a ‘C’ and not marked rectangles, reflect ‘under research’, ‘constraints’ and ‘not in scope’ respectively and are discussed hereafter.

![Demand and supply chain operations planning framework](image)

Figure 3 – Demand and supply chain operations planning framework (Hübner et al., 2013)

Changes on the long term refer to the strategic level. These changes require large investments and will have a large impact on the entire supply chain. Except from the distribution planning all other strategic planning issues will be out of the scope for this research. Distribution planning contains the physical DC-to-store distribution structure and the strategic partnership with logistics service providers. The physical distribution structure will not be changed. The current contract with the third party logistics provider expires this year and therefore a recommendation must be provided about cooperation with a logistics provider in the future. On the tactical level ‘product segmentation and allocation’ and ‘distribution planning’ are under research and will be the core of the research project. On the tactical level the ‘inbound planning’ is out-of-scope, because it will be assumed that products are always available for order picking in the DC. The ‘instore planning’ and ‘production planning’ aspects will be seen as optimization constraints. On the operational or short-term level only the constraints from transport planning will be taken into account. This means that this thesis is performed on a tactical level. Transport planning is about determining operational order quantities.
with respect to the delivery frequency, distribution and storage capacity and the tactical replenishment procedure. The operational outbound route and transport scheduling and outbound ramp management is also out of scope and only the relevant related constraints will be taken into account.

The most important operational cost factors for the supply chain under research are related to inventory, handling in the DC and the store, and transportation. In figure 4 is shown what the relative cost sizes are based on the company data from year 2014. The company has indicated that the amount of outdating should not increase in the new design and therefore this is a hard design restriction. The cost for outdating are left out-of-scope and the hard design restriction will be translated in a minimum number of deliveries per week, which will be explained in chapter 3. From figure 4 can be concluded that we should be careful with focusing on inventory costs, because a small change in other costs factors will outweigh a change in inventory costs.

![Figure 4 – Distribution of operational supply chain costs at Jan Linders](image)

2.2 Problem description

Due to the relative small company size compared to other retailers, many problems can be solved by creating an exception in the existing processes for specific items, item sets or stores. Throughout the years the consequence of creating exceptions is that the underlying structures and decision rules are lost and management of operations has become a complex task. Related to the order and delivery schedule the examples below support the findings about creating exceptions:

- **Store manager (local decision maker) is responsible for ordering quantities and adjusts on average 14,1% of the orders proposed by the ASO-system (Appendix A).** Store managers cannot take into account the effect of his decision on other parts of the supply chain which could lead to sub-optimality.
- **Many different delivery patterns, many ordering segments.** In appendix B, a small part of the order and delivery schedule of one week and one store is shown. Each store has its own pattern and this increases the complexity upstream in the supply chain to come up with improvements.
- **No clear underlying decision rules about assigning products to a certain delivery pattern.** During several interviews it was revealed that the decision rules for assigning products are lost or not clearly specified.
• **Transportation and the DC costs are not taken into account in the current order and delivery schedule.** At this moment six times a week most of the perishables are delivered in a time window of 3 hours and all non-perishables in a different time-window of 5 hours in all stores. This has led to two workload peaks in the DC and reaching capacity limitations of the outbound zone. For transportation is has resulted in a large number of stops and a low utilization rate, because each store needs on average only 4.9 truckloads per week. To reduce overcapacity around 10% of the routes from the static transport schedule are adjusted, which is very time-consuming.

• **Truck arrival times and actual shelf stacking moments do not correspond with the times known by the ASO-system. Moreover, the actual truck arrival time is also not aligned with the actual shelf stacking moment.** Misalignment will lead to unnecessary long lead times or a bad product availability level.

It can be concluded from those findings that there is a lot of local optimization in particular parts of the supply chain, without taking into account the effect on other parts in the supply chain. This has led to the current detailed and complex order and delivery schedule. Together with the fixed delivery moments at the store the supply chain seems to be inflexible. The result is that supply chain management has become a complex task and process improvements are hard to realize. Due to local optimization and the complexity of the current order and delivery schedule it has become questionable how well the system performs compared to an optimal situation. An optimal situation can be defined as; ‘A situation in which a minimum of resources and raw materials is used to create maximum value for all stakeholders’. From the argumentation above the following problem statement is defined;

> The current complex order and delivery schedule, as a result of local optimization, makes it hard to reduce related costs of resources at Jan Linders Supermarkten B.V..

### 2.3 Research Questions

The goal of order and delivery scheduling is customer satisfaction, expressed by in-store availability and customer response, at minimum costs. Based on the goal and problem definition the following research question is defined;

> What is a cost-efficient order and delivery schedule per store for Jan Linders Supermarkten B.V. by taking into account a reasonable in-store availability level and the most relevant costs for transportation, the stores and the DC?

To answer the research question two sub-questions must be answered. First the ordering policy will be determined that will be used to provide the ordering quantities per Stock Keeping Unit (SKU) per store. A SKU can be defined as a unique warehousing item because of its characteristics (brand, price, size, etc.). From now on the term item will be used when we refer to a SKU. By determining the order quantities it must be taken into account that the policy contributes to solving the capacity problems of the DC at the end of the week.
The second question is about the stacking efficiency of roll-containers (RC's). At this moment there is a large variability in the stacking efficiency between days and stores. This could have a large influence on the feasibility and performance of the final solution due to the capacity restrictions of trucks. To investigate this effect, a sensitivity analysis will be performed. The related sub-questions are shown below.

1. How to determine the order quantities per item?
2. What is the effect of fluctuations in the utilization degree per RC due to stacking deficiencies in the DC?

2.4 Literature review

Together with solving the business problem, the aim of this thesis is to make a contribution to the academic literature available on this topic. This literature review is a summary of the literature review which is made by the author preliminary to this thesis (Kuijvenhoven, 2015) and consists out of two parts. At first the problem characteristics are defined. Kuhn & Sternbeck (2013) state that processes in DC and stores are heavily influenced by the order and delivery schedule and indicates the need for an integrative approach. In the second part it is discussed to what extent an integrative approach is available in literature.

2.4.1 Problem characteristics

Non-stationary demand; Demand in retail follows a week pattern and this is a generally known characteristic in a retail environment (East, Lomax, Willson, & Harris, 1994) (Ehrenthal, Honhon, & Van Woensel, 2014). The demand with seasonal variation is generally known as non-stationary demand (Mattsson, 2010). If the demand pattern repeats every cycle of a fixed length it is called demand seasonality (Zipkin, 1989).

Divergent two-echelon inventory system; A supply chain with one DC from which all stores are deliver is known as a two-echelon divergent inventory system and more specific the 'one warehouse and N retailers’ inventory system (Axsäter, 1990).

Inventory routing problem (IRP); The problem involved is a periodic Inventory Routing Problem (IRP) and integrates inventory management, vehicle routing and delivery scheduling decisions. IRP’s are typically hard to solve and most algorithms are heuristics. (Coelho, Cordeau, & Laporte, 2014)

Dynamic lot sizing problem; To reduce the relevant supply chain costs a trade-off must be made between setup costs (handling) and inventory costs. In literature this trade-off was first established by Harris (1913) and called the Economic Order Quantity (EOQ). Wagner and Whitin (1958) were the first authors who extended the EOQ-model to make it deal with dynamic, but still deterministic and non-seasonal, demand and a finite time horizon and is called a dynamic lot sizing problem.

2.4.2 Integrative approach

For answering the research question an integrative approach must be found. This paragraph discusses the availability of integrated approaches for solving the business problem.

Order advancement
Accounting for demand seasonality in inventory management in a retail environment can lead to substantial cost savings for inventory holding, handling and stock-outs (Ehrenthal, Honhon, & Van Woensel, 2014). Demand seasonality can be dealt with by advancement of orders from peak to non-peak days. In retail order advancement is applied by store managers to improve generated ordering quantities from automated inventory replenishment systems (van Donselaar, Gaur, van Woensel, Broekmeulen, & Fransoo, 2010). They found that order advancement by store managers is profitable. Donselaar et al. (2010) compares this problem to a capacitated lot sizing problem, because shelf capacity restrictions have to be taken into account. Order advancement will increase the inventory on hand in the store and when it exceeds the shelf capacity the left overs have to be stored in the backroom. This phenomenon is also known as the backroom effect and a consequence of a misalignment between case pack size, shelf capacity and reorder point (Eroglu, Williams, & Waller, 2013). The restocking activity is a non-value-adding process and the source of many problems (Sternbeck, 2013). To balance the workload for items with seasonal demand and obtain substantial cost savings, orders have to be advanced from peak to non-peak days, but the case pack size, reorder point and available shelf capacity must be aligned to prevent a handling cost increase due to restocking. Order advancing will also change the workload per period for transportation and the DC and order advancement can be used to reduce workload differences in the supply chain and thereby it could reduce the extra costs related to workload peaks.

**Inventory routing**

Bertazzi, Bosco, Guerriero, & Lagana (2013) and Coelho et al. (2012) have introduced solution methodologies for dynamic and stochastic inventory routing problems that minimizes total inventory, distribution and shortage costs. But what lacks in the dynamic and seasonal inventory routing solution from Coelho et al. (2012) are case pack sizes, the outbound capacity restrictions from the DC and a direct link with the handling efficiency in the store and the DC by advancing orders. Gaur and Fisher (2004) were the first authors that have considered a periodic IRP in a retail environment instead of supply chains with vendor-managed inventory by taking into account time-varying demand, but they did not take into account the handling costs in the DC and the stores or the benefits of order advancement. Inventory routing is restricted by the available workforce for order picking and shelf stacking and the potential level of order advancement.

**Joint replenishment policy**

An important driver for order and delivery scheduling is to benefit from setup costs (e.g. transportation costs per delivery). To benefit from setup costs the replenishment moment and quantity per item must be adjusted. This type of problems is better known as a Joint Replenishment Problem (JRP). Sternbeck & Kuhn (2014) were the first authors that come close to an integrative JRP approach for order and delivery scheduling. They assigned delivery patterns to stores by taking into account transportation, handling and inventory costs. However, their research lacks stochastic effects and specific research about the impact of delivery frequencies on store processes that are limited by shelf capacity and case pack sizes. They also used a set of predefined delivery patterns, which restricts the amount of optional delivery moments in time and could result in an optimality gap. Ehrental et al. (2014) suggest that future research should investigate workload scheduling and balancing in the retail supply chain (such as seasonal capacity constraints and cost). Workload balancing can be obtained by order advancement and therefore a joint replenishment policy based on order advancement is preferred. From this can be concluded that research lacks an integrative
approach that balances the workload in the supply chain, by taking into account the relevant costs factors, and shelf capacity limitations.

2.4.3 Conclusion

From the literature review can be concluded that there is a lack of research about an integrative approach that reduces transportation, handling and inventory costs in a retail supply chain by workload balancing. Kuhn and Sternbeck (2014) came closest to an approach but there study does not take into account the effect of shelf capacities and their study excludes delivery moments for certain items, which reduces the responsiveness on consumer demand. It can be concluded that no direct solution for our problem instance is available. Because of the need for workload balancing in transportation, as well as the stores as the DC, a new joint replenishment policy based on order advancement theory should be developed in this thesis. The need for workload balancing will be explained further in chapter 3. This thesis will focus on developing periodic lot sizing or replenishment policy based on order advancement theory to determine the delivery quantities per item and per store. Including vehicle routing will create dependencies between order and delivery schedules of different stores and will add a lot of complexity. Therefore it will be for future research to extent the developed order advancement model by including vehicle routing.
3 Conceptual design for workload balancing

The goal of order and delivery scheduling is to create maximum value by ensuring product availability, taking into account the relevant supply chain costs and its capacity restrictions. Workload balancing can be achieved by advancement of orders from peak days towards non-peak days. From a supply chain perspective it is expected that costs can be reduced to a large extent if the workload in each part of the chain is smoothed. This chapter first discusses the need for workload balancing, also called workload smoothing, in each part of the supply chain that is under research. Thereafter the conceptual design requirements are provided and finally the conceptual design is presented.

3.1 The need for workload balancing

In this paragraph the need for workload balancing is discussed. At first the demand pattern during the week is discussed. Consequently it is discussed why the workload between days must be balanced for as will transportation, the stores and the DC. Finally it will be discussed why there is also a need to balance the workload during the day.

3.1.1 Demand pattern

In figure 5, the demand pattern of one week is shown in number of consumer units (CU). At this moment there are no deliveries on Sunday and therefore we have to accumulate the demand of Saturday and Sunday to approximate the delivery quantity just before Saturday in case of a Just-in-Time (JIT) replenishment policy. The result is that the delivery peak in the supply chain is actually for covering the demand for Saturday and Sunday. The demand on Saturday and Sunday is on average 2.08 times the demand on Monday. This means that if the delivery volume is not smoothed, the shelf stacking, transportation and picking capacity just before the weekend has to be larger than the twice capacity for the delivery on Monday. Because of the capacity boundaries in the supply chain the delivery volume must be smoothed and orders have to be advanced. The need for workload smoothing will be discussed in a more extensive way in the next paragraphs for transportation, as well as the stores and the DC.

![Figure 5 - Demand and delivery pattern in #CU](image)

In figure 5 can be seen that the delivery pattern deviates from the demand pattern and one could conclude that there is already some workload smoothing. This is realized by not allowing 40% of the stores to order dry groceries for delivering on Saturday by delivering non-perishables promotional items for the upcoming discount week on Wednesdays and Thursdays already and by excluding...
delivery moments for certain items. All of those choices to smooth the workload have not led to a reduction in the responsiveness on consumer demand and a significant level of workload smoothing.

3.1.2 The need from a transportation perspective

The reason to start discussing the need of workload smoothing from the transportation perspective is because of the size of the potential cost savings. To deliver sufficient volume to cover the expected weekly demand, each store must receive a minimum number of truckloads. The costs for the minimum number of deliveries could be seen as sunk costs and therefore this minimum number of truck deliveries will be the starting point of the design. If more trucks are needed than the number of available dedicated trucks, extra non-dedicated trucks must be hired. The costs for hiring non-dedicated trucks are approximately 10% higher than the non-dedicated trucks. At this moment the company on average hires ten dedicated trucks on peak days and zero on non-peak days. At this moment most of perishable products are delivered before store opening in a time window of three hours and most the non-perishables are delivered afterwards in a time window of five hours. This means that each store on average has two deliveries per day and all stores have to be delivered twice in two small time windows. The utilization degree in 2014 on average was 78.8% and is measured by the number of loaded RC’s as a fraction of the truck capacity in RC’s. This means that if the delivery volume of multiple stores is bundled the utilization degree could be as high as if there is only one single delivery, even when the total driving distance of the bundled truckload is larger. Thus an increase in the total driving distance does not affect the value of this performance measure. On average there are 1.73 stores per route and therefore the efficiency can be increased by reducing the number of stops and thereby also the total driving distance.

To analyze the potential effect of workload smoothing, the delivery quantities in roll-containers (RC’s) were collected manually for week 3, 4 and 11 in year 2015. In the current situation there is a stacking efficiency improvement of 9.9% and 15.1% RC for respectively Friday and Saturday. This percentage is obtained by physically counting the number of empty RC’s on Friday and Saturday that resulted from restacking RC’s just before loading a truck, and from counting the number of almost empty RC’s for the truck loads with sufficient spare capacity. To check the accuracy, the physically counted number of RC’s is compared with the manually registered number of savings by restackers. The order pickers confirmed the finding that from Monday until Thursday hardly any restacking of RC’s is done before loading the trucks due to sufficient planned transportation capacity. Restacking can be applied every day of the week and could lead to lower transportation costs. However, it is only beneficial when the reduction in transportation costs will outweigh the restacking costs.

Based on the historical number of RC’s transported to the stores the required number of deliveries are determined and shown in figure 6 on the next page. The number of deliveries is determined by dividing the total number of RC’s per store per week by the loading capacity per truck. If the delivery quantity is smoothed and the stacking efficiency of RC’s remains the same, 47 stores can be delivered with only six trucks per week and only ten stores require more deliveries. Note that by restacking every of the week, the required number of trucks will be lower. For now it will be assumed that this is excess capacity. The costs for the minimum number of deliveries can be seen as sunk costs.
Nowadays, there are around 368 routes per week with on average 1.73 stops per route, which means that there are on average 636 stops per week. The large number of stops is caused by the decision to deliver the perishables and non-perishables in a different time window. The reason for the current distinction is that all stores must receive the perishables before store opening in a small time window. This distinction has led to huge inefficiencies for transportation, the DC and the stores.

From interviews reveal that disjunctive deliveries for perishables and non-perishables is not required. Delivering both categories together is most beneficial if the number of stops can be reduced. To prevent that the delivery volume at the end of the week exceeds one truckload for most of the stores, and to prevent that two stops are required at the end of the week, the delivery volume must be smoothed. If we assume that in the new design each store will still receive a delivery with perishables from Monday until Saturday and the perishables and non-perishables are bundled, at least 365 stops are required. Note that this means that we are able to smooth sufficient volume to prevent that the delivery volume at the end of the week exceeds truck capacity. In addition, if each truck will get only one stop per route, 365 routes are needed per week and the utilization degree measured in loaded RC’s will become 77.4% compared with 78.8% now.

Due to the decrease in the number of stops the traveling distance will reduce to a large extent and the utilization degree actually becomes significantly higher. Further efficiency improvements can be made by bundling truckloads, although vehicle routing is outside the scope of this thesis. The reduction in number of stops shows the urgency for workload balancing to obtain a cost reduction for transporting the goods from the DC towards the stores.

![Figure 6 – Required number of deliveries per store per week based on three weeks data.](image)

### 3.1.3 The need from a store perspective

As shown in figure 4, the handling costs in the store are one of the main cost factors. Workload balancing can only be beneficial if the store handling costs do not increase to a large extent. Van Zelst, Van Donselaar, Van Woensel, Broekmeulen, & Fransoo (2006) have investigated the most important drivers for shelf stacking. The fraction of time that a shelf stacker spends per activity is shown in figure 7. Searching, preparing the shelf and traveling account for 21% of the stacking time. Those activities are related to the number of order lines. The number of order lines represents the expected number of times that a certain item will be ordered. If there is no capacity restriction it is most beneficial from a store perspective to have a minimum number of order lines. In the store, three different replenishment processes are executed: regular, idle and concurrent replenishment.
from which the last two concern the replenishment of leftovers from the backroom planned and unscheduled (due to out-of-stocks) respectively.

A reduction in the number of order lines increases the delivery quantity per item. If the delivery size of an item does not fit in the shelf, the “overflow inventory” has to be transported to the backroom, which is an uncontrolled stocking point. The overflow inventory has to be restacked by idle or concurrent replenishment. The workload that arises by stacking the shelves, accounts for the largest share of the operational costs and restacking will negatively affect the workload and related costs even more (Van Zelst et al. 2006). For products with a relative large demand compared to their shelf capacity it is most efficient to have a Just-In-Time (JIT) replenishment policy, because this policy will result in a lower inventory level, which lowers costs for restacking.

The amount of advancement will be expressed by the maximum amount of inventory build-up per day. This volume must be stored in the shelves beyond the inventory that is required to continue operations. Let $p_{it}^{\text{JIT}}$ be the fraction of the weekly demand delivered for item $i$ on day $t$ with a JIT-policy and actually denote the seasonality pattern. Let $I$ and $T$ be the set of all items and days;

$$p_{it}^{\text{JIT}} = \frac{\mu_{it}}{\sum_{\tau \in T} \mu_{i\tau}}$$  \hspace{1cm} (1)

Let $p_{it}^{\text{Target}}$ be the fraction that is ordered for review period $t$. Let $I_t$ denote the cumulative difference between the delivery volume given a JIT approach and the target delivery volume per period.

$$I_t = \sum_{\tau=1}^{t} [p_{\tau}^{\text{Target}} - p_{\tau}^{\text{JIT}}]$$  \hspace{1cm} (2)

It is now possible to define the amount of inventory build-up per item ($Y_{it}$). The amount of inventory build-up is defined by two terms. The first term represents the cumulative difference between the JIT delivery pattern and the target delivery pattern (2). The second term is an adjustment for the possibility that orders are advanced to the end of the preceding week;

$$Y_{i}(t) = \sum_{\tau=1}^{t} [I_{\tau} - \min[I_{1}, \ldots, I_{t-1}]]$$  \hspace{1cm} (3)

Given the average demand pattern over all stores, as shown in figure 5 it is now possible to define the expected average required inventory build-up per period. To realize a fully smoothed workload from Monday till Saturday the largest amount of inventory build-up during the week should be equal

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image.png}
\caption{Processing times of a shelf stacker (Van Zelst et al., 2006)}
\end{figure}
to 15.7% when the delivery volume is fully smoothed from Monday until Saturday and 14.1% if the delivery volume is smoothed from Monday until Sunday. This means that for a smoothed workload from Monday until Saturday 15.7% of the weekly demand must be stored in the shelves beyond the required inventory to continue operations. The larger amount of inventory build-up for smoothing from Monday until Saturday is caused by the expected demand on Sunday that must be delivered earlier. This volume cannot be delivered on the peak days just before Sunday and therefore this volume also has to be smoothed to the start of the week, which increases the total amount of inventory build-up.

3.1.4 The need from a DC perspective

The capacity of the DC is determined by, for example, the storage capacity, number of docks, available workforce, etc. All of these resources have related costs. The more the workload is smoothed, the larger the throughput can be before the available capacity will be reached and additional costs are needed to enlarge the capacity. In general, the main design criterion of a DC is the maximum throughput to be reached at minimum investment and operational costs (Rouwenhorst, Reuter, Stockrahm, van Houtem, Mantel, & Zijm, 2000). Van Dun (2012) concluded that there is a lack of research for workload smoothing in the DC and the influence of congestion on the total efficiency and cost for handling operations.

At this moment almost all stores receive the perishable items in the early morning before store opening and thereafter they receive the non-perishables in a second delivery in a time window of five hours. The consequence is that this results in two large peaks in the DC in two different outbound zones. Due to the demand peak at the end of the week, the DC runs up to its capacity boundaries in both the outbound zones and in the picking process. Because of the company growth, the problems related to capacity restrictions in the DC must be tackled on the short term. The capacity problems can be solved by order advancement or by an investment for the expansion of the available resources in DC at the end of the week. Order advancement from peaks to non-peaks will lead to a reduction in the required resources at the end of the week and a higher utilization of the available resources at the start of the week. This means that order advancement could save investment costs and it could increase the efficiency of the available capacity. In addition, workload peaks are also not desirable for labor planning and the performance of employees.

To realize costs saving in both DC and transport, the perishable and non-perishables should no longer be delivered separately, which creates larger flexibility to smooth the workload. Changing the delivery times in the stores and adjustment of the transportation planning, can also create more deviation in the loading times of trucks. This could result in a more smoothed workload for order picking. During several interviews the company has already indicated that delivering perishables a couple of hours after store opening will hardly harm their fresh-image. Moreover, it is likely that it will not affect the shelf life if other processes as suppliers’ deliveries, order picking and shelf stacking will be aligned.

3.1.5 The need for intraday workload balancing

Advancing orders will not automatically prevent workload peaks in the DC and transport. When a lot of trucks must be loaded at the same moment and a lot of stores must be delivered at the same moment intraday workload peaks will be created. This paragraph discusses the effect of the delivery
times on operations, costs and customer experience. In this report the delivery times in the store are equal to the moment that the delivered items are available at the shelves. To determine the delivery times in the store there are both quantitative and qualitative aspects that must be taken into account and those are presented in this paragraph. Determining the actual arrival times is a short-time operational planning question and therefore not in the scope of this research.

The first qualitative aspect is related to the consumer’s shopping experience. From a customer’s perspective it is not desirable to have a lot of shelf stackers in the stores during peak hours. This means that during peak hours it could be argued that there should be as few as possible shelf stacking activities to improve the shopping experience of the consumer. Another important issue is related to the freshness of the perishables. When perishables are delivered in the evening before, the shelf life will reduce with almost half a day, because it is very unlikely that it will be sold that evening. The quantitative aspects are related to the handling and transportation costs. During the day the costs of the shelf stackers will vary, because the availability of employees with low wages could be vary during the day due to for example the availability of students. For the DC and transportation an additional fee is required for working in the evening or at night. From a transportation perspective, it must be taken into account to minimize the use of non-dedicated trucks. The utilization of the dedicated truck must be optimized to reduce the costs for hiring non-dedicated trucks and this can be realized by smoothing the delivery moments during the day so that the dedicated trucks can be used for a long period per day. It must also be noticed that due to rules of the local government some stores cannot be delivered during opening hours. Both the quantitative and qualitative aspects make it a complex task to determine the optimal arrival times at the stores, but it is recommended to take into account the preferences for transportation, as well as the DC and the stores.

3.2 Design requirements

In this paragraph the design requirements are presented and those requirements must be included in the new design for order advancement.

3.2.1 Planning horizon

Advancement between planning weeks increases the planning complexity and it can only be applied to items with sufficient shelf capacity. Order advancement from one week to another is only beneficial for items if more than the weekly demand volume can be stored within shelf capacity. In this way the expected number of order lines can be reduced, which increases the handling efficiency. It is expected that order advancement beyond weeks can only be applied to a small number of items and because of the potential increase in complexity the planning horizon will be equal to one week. The planning horizon will start on a delivery day with the largest negative difference between this day and the preliminary delivery day so that the largest amount can be advanced within a week.

3.2.2 Replenishment policy

At this moment the order quantity is determined with an \((R,s,nQ)\)-order policy. This means that the inventory position is reviewed, or checked, every period of length \(R\) and if the inventory on hand minus the outstanding orders at that moment is strictly below \(s\) the system orders \(n\) case packs of size \(Q\). There is no reason to introduce a new replenishment policy. The literature review
(Kuijvenhoven, 2015) has indicated that a can-order policy can also be applied to smooth the workload. Implementing a can-order level can be seen as an extension of the $(R,s,nQ)$-policy (Cerda & Espinosa de los Monteros, 1997).

3.2.3 Items useful for advancement

In paragraph 3.1.3 is shown that the number of stops can be reduced to a large extent if only the minimum number of deliveries is scheduled. To be able to reach the target workload equal to the minimum number of deliveries order advancement must be applied. Order advancement will be realized per item, but it does not mean that the workload for individual items must be smoothed. To compensate for items for which advancement cannot be applied, orders for other items must be advanced to a larger extent and a workload peak will be created at the start of the week. Due to perishability and overflow inventory not all items in the assortment can be used for workload smoothing and this is explained in the next section.

Perishability

Order advancement will lead to an increase in inventory and therefore could lead to an increase in outdating. In addition, due to order advancement the expected number of order lines could reduce. This means that the shelf is replenished less frequently with fresh products and therefore the average age of the in-store inventory will increase and the amount of outdating will increase. Due to the vision of Jan Linders, the awards for their fresh-product segments and the risk for outdating, non-promotional perishable items must be delivered just in time, at least daily from Monday till Saturday. This delivery frequency is the same in the current situation. Perishable items are items with a shelf life shorter than 25 days. Promotional perishables can be advanced, because due to the high demand rate the effect of order advancement on the probability of outdating is expected to be small.

Overflow inventory for non-promotional items

If the inventory on hand right after delivery exceeds the available shelf capacity, restacking is required. The inventory that does not fit in the shelf must be stored in the backroom and, as already stated, this is an uncontrolled stocking point which leads to a large decrease in handling efficiency. From a supply chain’s perspective can be concluded that having extra overflow inventory is only beneficial when savings in transportation and DC outweigh the cost increase.

When the probability of overflow inventory per item is small, it is likely that order advancement can be applied without an increase in handling costs. If the expected weekly demand can be delivered at once without an increase in backroom inventory, there is a lot of flexibility to determine the moment in time that the volume will be delivered. This flexibility can be used to deliver more on non-peak days to reduce the delivery volume at peak days.

Overflow inventory for promotional items

It has already been argued that it is likely that non-promotional items with a high probability of overflow inventory will be excluded from order advancement. Despite the extra costs related to handling, backroom inventory is required for some promotional items.
The company has one discount period length for promotions and this period starts on Monday and ends on Sunday. There are three different arguments for advancing promotional orders. Relative to non-promotional items, promotional items require more:

- presentation stock due to commercial considerations.
- safety stock due to larger deviations in demand.
- safety stock due to forecasting errors in the expected demand.

Due to the requirement of advancing promotional orders there must be enough capacity available in the supply chain to deliver sufficient goods just before the discount period starts. Winter (2015) suggests an initial delivery size of 40% of the forecasted weekly demand volume. This means that regardless of the high probability of overflow, order advancement will be applied to promotional items. Because of the large volume involved, the decrease in handling efficiency due to holding backroom inventory is not comparable with the decrease in handling efficiency for non-promotional items in the backroom. It is not said that it is beneficial to put promotional items in the backroom, because it will always increase the store handling costs. It is only mentioned that promotional items in the backroom are needed for having sufficient inventory at the start of a discount period and it is cheaper than holding items with a low demand volume in the backroom.

3.2.4 Planning the promotional items

Promotions are characterized by their large deviations in demand compared to regular items. To get information about the deviations between the demand levels among weeks for both promotional and regular demand, the demand volume of ten weeks and three stores are compared by using ANOVA (Field, 2009). The results are shown in Appendix C. For both the total demand and non-promotional demand can be concluded that the variances and total demand per week are not significantly different, because the significance values of the Levene’s Tests and T-Tests are larger than 0.05. From the Levene’s tests can be concluded that the variances of the promotional demand per week are significantly different and therefore the Robust Tests of Equality of Means must be used. Also for this test the significance value is smaller than 0.05 and this means that the total weekly promotional demand volume per week is significantly different.

From the analysis can be concluded that for weeks with significantly more or less promotional demand the regular demand will not increase or decrease significantly. It can be stated that the amount of promotional demand will have no influence on the non-promotional demand or planning the delivery volume for the non-promotional demand. Because of the significant deviations in promotional demand and also in the set of items under promotion, the delivery volume for promotional items per period will be determined only on an aggregate level. This means that determining the delivery quantity per promotional item per delivery moment is outside the scope of this thesis and only a total target delivery volume per period will be defined for this set of items. The total demand volume per week is not significantly different and therefore a tactical order and delivery schedule can be used.

3.2.5 Number of delivery moments per store

To realize cost savings, the delivery volume per day must be smoothed for transportation, as well as the stores and the DC. Part of the problem definition is that the current clustering of items into
ordering segments is not done in a structural way and not based on clear decision rules. This has led to the current complex order and delivery schedule and therefore it is not desirable to use the current clustering of ordering segments in the new design.

Most recent work about order and delivery scheduling is about assigning delivery patterns to stores (Gaur & Fisher, 2004) (Ronen & Goodhart, 2008) and assigning delivery days to items (Van Dun, 2013) (Sternbeck & Kuhn, 2014) (Cardos & Garcia-Sabater, 2005). Excluding delivery moments on peak days can be used to smooth the workload and it reduces the amount of deliveries. However, excluding delivery days decreases the response time and thereby the flexibility of the supply chain to react on demand deviations. To prevent a decrease in the freshness of the perishable products and to support the performance of Jan Linders for their segments with perishables each store will have at least one delivery per day from Monday until Saturday. This means that the amount of deliveries cannot be reduced to a large extent, because each store has a minimum of six deliveries or more per week. Scheduling more deliveries than the required number of deliveries will affect the inventory levels handling costs or transportation costs. Due to capacity restrictions of the backroom and the available workforce in the store, the maximum delivery volume per day is equal to two truckloads. To determine the final number of delivery moments per day per store a cost comparison will be made in the detailed design.

3.2.6 Number of delivery moments per item

Given the number of deliveries per store a decision must be made on how many times an item should be ordered within a week. Van Buel (2009) applied a fast, medium, slow mover clustering policy and assigned base order and delivery schedules to each of these categories for each store to smooth the delivery volumes throughout the week. In the assigned delivery schedules the slow movers have fewer ordering moments compared to the fast movers. This means that delivery moments are excluded for slow moving items and this reduces the response time. He concluded that clustering could lead to new workload peaks and the clustering step must be improved in a way that each item is assigned to a cluster based on the specific demand rate per store and not based on the average demand rate over all stores. Because of those limitations a model that uses item segmentation is not preferred for order advancement.

In the DC and the stores family grouping is used and the advantage of using family grouping is that it saves shelf stacking time in the store. Using family grouping in DC also means that the picking locations of non-perishables in the distribution center are not allocated according to the current clustering of items in the delivery schedule or the turnover per item. In other words, items with the same (number of) delivery moments are not put together to improve the picking efficiency and therefore moving away from clustering products will not result in a reduction of the picking efficiency in the DC.

The maximum number of order lines or the number of delivery moments per item will be restricted to one per day even if there are two deliveries per day. The reason is that splitting the ordering quantity over two moments per day will lead to an increase in both the handling in the DC and in the stores for visiting the picking location or shelf twice per day. To create minimum response time given the number of deliveries, no delivery moments will be excluded for certain items. Order
advancement without excluding delivery moments can be realized by adjusting the reorder levels throughout the week, which changes the probability of ordering per day.

### 3.2.7 Lead time and review period length

The lead time ($L$) is defined as the time that passes from the moment that the final order quantity per item $i$ ($τ_i$) is determined and approved, until this ordered quantity is available at the shelf for sale. From interviews is revealed that a lead time of one day is realistic, but due to the difference with the current lead times many processes, and the timing of those processes, have to be adapted. A lead time of one day and a delivery Monday in the early morning requires order picking on Sunday and this could lead to higher order picking costs. Due to the 100% larger wage costs on Sunday for order pickers, it could be decided to set the lead time equal to two days if orders cannot be picked on the Monday morning so that they can be picked on Saturday (figure 8, timeline B). By implementation, it must be chosen which stores will have a lead time of one day for the delivery on Monday and which stores will have a lead time of two days, by taking into account the workload for order picking in the DC on the Monday morning.

The minimum number of deliveries per day is equal to at least one, from Monday until Saturday. Therefore, the length of the review period ($R$) will be set to one day for ordering on Saturday until Thursday (figure 8, timeline A and B) and two days for the stores that order on Friday with no deliveries on Sunday (figure 8, timeline C).

![Figure 8 – Schematic representation of lead times and review periods, with $τ_i$ randomly chosen.](image)

### 3.2.8 Summary

In chronological order, the following design decisions are made and will become requirements for the conceptual and detailed design;
- Direct-to-store deliveries are excluded.
- Planning horizon of 1 week.
- The $(R,s,nQ)$-policy will be maintained.
- Non-promotional items with a shelf life shorter than 25 days will be excluded for order advancement to prevent a cost increase for outdated.
Promotional items will be used for order advancement and only on an aggregate level the delivery quantity will be determined.

At least six order and delivery moments per week per store.

No more than two deliveries per day per store.

No delivery days will be excluded for specific items.

Lead time is equal to one day. Exception; Items delivered on Monday in the early morning could have a lead time of two days.

Review period is equal to one day. Exception; Items ordered on Friday have a review period length of two days if there are no deliveries on Sunday.

### 3.3 Conceptual design

The design requirements can be translated into a conceptual design for workload smoothing. First the truckload and target workload are defined. Then the part of the shelf capacity available for advancing orders, also called the excess shelf capacity, is defined. How order advancement can be realized by changing reorder levels and how the amount of backroom inventory can change is discussed next. In the fourth and fifth paragraph the order and delivery scheduling process is described and the algorithm for selecting orders from items for advancement is discussed. Finally the feasibility of the conceptual design and the effect in terms of costs will be discussed.

#### 3.3.1 Excess shelf space

The excess shelf capacity is the difference between the shelf space and the maximum inventory on-hand required for carrying out the current operations with respect to customer service and costs (Broekmeulen, van Donselaar, Fransoo, & van Woensel, 2004). The maximum inventory is equal to the minimum reorder level required to continue operations during the lead time and review period plus the case pack size minus 1. Note that the maximum inventory on-hand will be reached if the demand during the lead time is equal to zero and the inventory on-hand at the moment of review is 1 unit lower than the reorder level required for operations.

It will be assumed that the amount of presentation stock for all items that can be used for order advancement is equal to zero. Order advancement will lead to more inventory build-up in the store in non-peak periods and therefore by assuming zero presentation stock it is not likely that it will lead to a large reduction of the average inventory levels. Another argument of assuming zero presentation stock is that presentation stock reduces the excess shelf space that can be used for order advancement and therefore presentation stock could lead to extra backroom inventory when there is not sufficient excess shelf space to smooth the workload completely. It is recommended to redefine the amount of presentation stock per item after implementation of the design for workload smoothing.

#### 3.3.2 Changing reorder levels

Realization of order advancement for non-promotional items will be performed by changing reorder levels per individual item. Note that determining the reorder levels of individual promotional items is outside the scope of this research. A reorder level without advanced orders consists of safety stock and the expected demand during lead time and review period. The amount of safety stock will be constant during the week, because Mattson (2010) has shown that the existence of moderate seasonal variations does not make it worthwhile to make seasonal adjustments to calculate safety
stocks. Moderate seasonal variation is defined as a change ratio in demand from one period to another that is not larger than 0.7 and the peak demand is not larger than 3 times the non-peak demand. For Jan Linders the demand during the peak day is 1.90 times higher than the non-peak demand and therefore a constant safety stock will be determined.

To obtain an equal service level there must be more safety stock to serve unexpected high consumer demand on peak periods, because when the demand increases it is more likely that the demand will be larger than expected. To guarantee that the target fill rate is met, the amount of safety stock will be based on the demand variation during the peak. From this can be concluded that a constant safety stock already contributes to workload smoothing, because the required safety stock at non-peak days is likely to be lower for covering unexpected demand according to the service level.

When orders are advanced, the delivery quantity will exceed the expected demand for the upcoming period and thereby the inventory level will increase. This will lead to extra inventory, besides the inventory required to continue operations and is called inventory build-up. For the amount of inventory build-up a new parameter will be introduced to determine the adjusted reorder levels and is called the reorder level increment. During the week at least a constant level of availability must be obtained and no reorder levels will be set lower than the level required to continue operations with respect to customer service and costs. Due to order advancement within a week, the reorder level increment for the reorder level that covers the review period with peak demand will be equal to zero. For the other periods the reorder level increment per review period is at most equal to the expected demand from the next review period until the end of the planning week.

In figure 9 an example is shown for one item, based on the fractional demand per review period for a store with six deliveries. In the example we assume that the planning week starts in period one and ends directly after period six and this means that the reorder levels from period six until period four can be adjusted to advance orders within the week. The maximum reorder level increment is in period six and equal to 0.89 and indicates the maximum amount of advancement. The delivery volume per period is equal to the difference between the reorder level increments of previous and the current period plus the expected demand during the review period.

![Figure 9 - Adjusted reorder levels per review period if all orders are advanced and delivered in period 1.](image-url)
3.3.3 Expected amount of backroom inventory

In the current replenishment policy for determining the order quantities, shelf capacity restrictions are not taken into account. To minimize backroom inventory it is most efficient to apply order advancement to items where it does not lead to an increase in overflow inventory. If the probability of backroom inventory is zero, the maximum reorder level can be equal to at least the shelf capacity minus the case pack size plus 1. To determine this level two assumptions are made. First it is assumed that there will be zero demand during the lead time. Second it is assumed that the inventory position is multiple case packs plus one consumer unit below the reorder level when an order is placed. However, both assumptions are a worst case scenario and therefore it is likely that the maximum reorder level can be higher without increasing the amount of backroom inventory. It is important to note that due the lead times and the review period lengths there are no outstanding orders at the moment that the inventory position is reviewed and therefore the inventory on-hand is equal to the inventory position at the moment of ordering. It also means that at any moment in time there is at most one outstanding order for any item and therefore the inventory on-hand in the store is largest directly after a delivery moment.

The positive difference between the reorder level and the inventory on hand will be defined as the Undershoot. In fact it is likely that there is at least some demand during lead time or that the undershoot is larger than one unit. Therefore it is possible that the inventory position at the moment of ordering can be higher than the shelf capacity minus case pack size plus 1, without increasing the amount of backroom inventory significantly. Both the lead time demand and the undershoot are stochastic factors and must be taken into account to calculate the expected amount of backroom inventory and the probability of overflow inventory.

3.3.4 Order and delivery scheduling process per store

At first it has to be determined how to express the delivery volume or target volume. Due to variation in the stacking efficiencies of RC’s it is not possible to calculate the exact number of RC’s that is required for transporting the delivery volume in consumer units (CU) or case-packs. Therefore it is only possible to estimate the delivery volume for a given amount of orders. The demand pattern expressed by the physical volume or turnover deviates at most respectively 0.30% and 0.63% of the pattern in CU’s that is shown in figure 5. From this can be concluded that it does not make a large difference which criteria is used to determine the transportation volume per review period. However, this does not mean that both the number of CU’s sold and demand value can be used to forecast the expected delivery quantity. For reasons of simplicity and the small difference in demand pattern in physical volume or turnover, the delivery pattern will be quantified by the number of consumer units.

The order and delivery scheduling process will consist of three steps. Per store there is already determined that each store will have a minimum number of deliveries. This required number of deliveries is either based on the minimum number of trucks needed for transporting the entire weekly delivery volume or needed to have sufficient and frequent replenishment moments for the perishable items. The first step of the order and delivery scheduling process is determining the minimum number of deliveries per store which could result in a cost-efficient order and delivery schedule per store.
In the second step those required deliveries will be assigned to specific days and the target load per truck delivery will be determined, given the related costs. In paragraph 3.2.5 is already discussed that the number of deliveries per day could affect the level of workload smoothing. However, this does not mean that the delivery volume is always smoothed if the number of deliveries per day is equal, because this also requires an equal truckload. Bundling truckloads could reduce the total driving distance for delivering all stores. For implementation of this improvement vehicle routing must be included, which is outside the scope of this research.

In the third step the target workload of step 2 must be obtained by advancing orders. If there are not sufficient orders or if there is not sufficient excess shelf capacity it could be possible that the target workload of step 2 cannot be obtained. Given the difference between obtained and target workload the required number of deliveries will be updated or not and this iteration will be executed until the costs are minimized. In figure 10 the order and delivery scheduling process is shown and in the next paragraph the item selection algorithm will be presented. In the order and delivery process five constraints must be taken into account;

1. The total expected demand volume must be delivered every week.
2. The number of deliveries per day must be smaller than or equal to two (N_t<=2), because of instore handling capacity.
3. The probability of overflow for non-promotional items that will be used for advancement must be restricted to prevent unmanageable backroom inventory due to many items or too much volume in the backroom.
4. A target level of availability of 99% must be reached for the non-perishables.
5. The inventory build-up for promotional items in the upcoming discount period must be at least 40% of the expected weekly demand and order advancement towards the start of the discount period is only allowed from Thursday until Sunday towards the end of the previous discount period if one truck stop can be saved.

![Figure 10 – Order and delivery scheduling process](image)

### 3.3.5 Item selection

In paragraph 3.1.2, it was shown that in case of no deliveries on Sunday at most an inventory build-up of 15.7% of the weekly volume must be realized to obtain a fully smoothed workload. It is already argued that non-promotional perishable items will not be used for order advancement. The non-perishable and promotional items can be used for order advancement but not every item is required to smooth the workload, because those items represent 66.0% of the weekly delivery volume. To
minimize the negative effects on operations and costs the most suitable items must be selected and therefore a further classification is required. This classification is based on the expected demand volume and the probability of backroom inventory per item.

For the selection of items a Greedy algorithm will be used. This algorithm is a heuristic that makes choices locally and the choices will be about selecting specific items for order advancement to obtain a predefined target workload. For the selection of items, orders will be advanced from the largest peak towards the period with the largest gap and this means that it does not make a difference whether orders are pushed or pulled towards a gap. The peak and gap will be defined as respectively the largest positive and negative difference between the workload based on the level of advancement and the target delivery volume. Due pushing items from the largest peak towards the largest gap, the difference between the peak and non-peak workload is reduced to the largest extent if the algorithm stops when there is no more advancement volume available. In figure 11 a simplified example is shown for 5 steps of the item selection algorithm for obtaining a target workload per period equal to \(1/6\)th of the expected weekly demand volume.

![Figure 11 – Simplified representation of the item selection algorithm with a target workload equal to 1/6](image)

The first set of items consists of non-perishable, non-promotional items that will not lead to an increase in backroom inventory. To reduce the number of items for which order advancement will be applied, items with a large demand volume must be selected first. It is possible to include the effect of the case pack size compared to the expected demand per item. By selection of the items with a large case pack size over expected demand ratio, the difference in reorder levels will be relatively small. The consequence of small difference between reorder levels is that when there is at least some demand it could trigger an order with almost the same probability per period. This means that small differences between reorder levels per period could lead to an irregular order pattern and it will become questionable whether orders will be advanced. This is a reason to select items with a small case pack over expected demand ratio first, because it will reduce the risk of irregular ordering. Note that excluding deliveries, which is not the case in our design, is also a way to avoid the risks of irregular ordering. On the other hand, selecting items with a large ratio first can be preferred, because for these items it is most likely that the workload can be advanced completely with a low probability of overflow and can have a larger marginal gain in handling efficiency, as confirmed by Van Donselaar et al. (2010). Because of the uncertainty of the effect, the case pack size will not be taken into account for item selection.
In the next step of item selection some extra inventory in the backroom will be allowed. Note that the number of items in the backroom must be restricted, which reduces the complexity of inventory control in the backroom. This will be realized by setting a constraint on the probability of overflow. The item selection algorithm must stop if there is no more smoothing volume available given the constraints, or if the minimum advancement quantity is reached.

3.3.6 Feasibility of the conceptual design

The feasibility of the conceptual design is determined by the available resources for transportation, as well as the stores and the DC. The design starts by taking into account the truck capacity and it is already stated that there are an unlimited number of trucks available, but using more trucks than the number of dedicated trucks available requires an additional fee. Due to the unlimited number of trucks that can be hired the solution will be feasible from a transportation perspective.

From a DC perspective it is argued that workload smoothing reduces the required capacity on peak-periods and thereby order advancement will lead to a feasible design if not all orders must be picked and loaded in a small time window.

From a store perspective, the capacity of the shelves, and thereby the capacity of the backroom, are taken into account in the item selection algorithm. The shelf capacity is not seen as a hard restriction and it is possible that items are allowed to make use of the backroom if needed. The backroom capacity in the store is undefinable, because it is also related to the planning of reverse logistics (e.g. empty crates and outdated products). Moreover, it is hard to compare the expected amount of backroom inventory in our design with the current amount of backroom inventory, because it depends on the frequency of idle and concurrent replenishments at this moment, and the current complex order and delivery schedule. Promotional orders that are delivered before the discount period will be advanced with fewer days which will create more space in the backroom compared to the current situation. In addition, due to the reduction in the number of stops per route it will be easier to take back the returned goods to the DC immediately without impeding loading and unloading at the next store. Due to the possibility to send back the returnables immediately, the available backroom capacity will increase. By taking into account these improvements, it is reasonable to assume that there is sufficient capacity in the backroom to handle an entire truckload. The available workforce is not taken into account in the design, because it will be assumed that this can be changed over time.

3.3.7 Cost Improvement

This paragraph discusses the effect on operational costs. From the current order and delivery schedule was concluded that most costs factors are not controlled or taken into account and one of the improvements of the new schedule is that they will be taken into account.

Sternbeck (2013) concluded that it is difficult to determine size dependent process times and costs in different logistics subsystems of a retail supply chain. He therefore states that more specific research is needed into the impact of delivery frequencies on store processes. The finding about specifying accurate size dependent process times and costs is confirmed in this thesis, and therefore we have to make some assumptions about the costs.
From transportation perspective can be stated that workload smoothing could result in lower costs due to hiring less extra trucks beyond the dedicated fleet, if the time windows of delivering the stores will not be made unnecessarily small. The transport costs will be expressed per delivery and only related to the number of stops and the driving distance from DC to store. The costs related to the total driving distance after bundling store deliveries per truckload require exact transportation planning and is not included in the scope. Due to excluding the benefits of a reduction in the total driving distance by bundling truckloads dependencies between planning deliveries’ per store are prevented and therefore the delivery scheduling process per store can be treated independent from other stores. On Sunday the wage costs in the entire supply chain will be assumed to be 100% higher than on other days of the week.

From a store perspective the workload during the period with peak demand will decrease and this will result in more inventory build-up during the week. This could increase the inventory costs, and the handling costs related to overflow inventory. It will be assumed that the handling and inventory costs are linear increasing with the number of consumer units. Therefore the costs of overflow inventory are related to the volume in the backroom. It will also be assumed that the wage costs per unit from Monday until Saturday are constant. In the store there are also subjective improvements due to order advancement. Due to the inventory increase the availability level will increase, which could increase customer satisfaction and it could also increase the total demand. Order advancement could also improve customers’ shopping experience, because less volume has to be stacked in the shelves during periods with peak demand. Both the availability benefits and the potential improvement of the shopping experience will be taken into account by using a cost factor related to the workload difference per period.

From the DC perspective it is also argued that the throughput can increase due to order advancement and therefore the cost reduction will appear on the long term when the total demand increases. The real cost savings related to a smoothed workload in the DC are hard to determine and this will also be included in the cost factor related to the workload difference per period.
4 Detailed design for workload balancing per store

In this chapter the conceptual design for advancing orders will be translated into a concrete model and the mathematical representation is given. Also a cost function that includes the relevant supply chain costs in the DC, transportation and the stores is defined and this cost function is used in the order and delivery scheduling process. After presenting the model, it will be applied for three stores to determine the new expected delivery quantity per item and the new workload pattern per item.

4.1 Order advancement model

The order advancement model is presented by different subsections. At first the notation is presented that will be used. Consequently a mathematical representation of the adjusted reorder levels and delivery volume, standard deviation, overflow inventory, and item selection algorithm is given. Finally the cost function and the corresponding constraints are presented.

4.1.1 Notation

In table 1 an overview is given for the indices, parameters and variables.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indices</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>item</td>
</tr>
<tr>
<td>t</td>
<td>moment in time, t∈{1,...,7}, with 1 start of the planning horizon</td>
</tr>
<tr>
<td>p</td>
<td>promotional item (1) or not (0)</td>
</tr>
<tr>
<td>Parameters</td>
<td></td>
</tr>
<tr>
<td>A_{it}</td>
<td>maximum reorder level increment for item i in period t</td>
</tr>
<tr>
<td>D_{it}(t)</td>
<td>stochastic demand for item i in period t</td>
</tr>
<tr>
<td>DD</td>
<td>total driving distance from the DC towards the store and back</td>
</tr>
<tr>
<td>L_{t}</td>
<td>lead time length for ordering just before period t</td>
</tr>
<tr>
<td>n</td>
<td>required number of deliveries</td>
</tr>
<tr>
<td>N_{t}</td>
<td>total number of deliveries in period t</td>
</tr>
<tr>
<td>P_{it}</td>
<td>Probability of overflow for item i in period t</td>
</tr>
<tr>
<td>R_{it}</td>
<td>Review period length for ordering just before period t</td>
</tr>
<tr>
<td>s_{si}</td>
<td>safety stock per item i</td>
</tr>
<tr>
<td>T_{E}, T_{W}</td>
<td>transport costs per delivery per store for equipment (E) and wages (W)</td>
</tr>
<tr>
<td>V_{i}</td>
<td>shelf capacity for item i</td>
</tr>
<tr>
<td>μ_{it}</td>
<td>mean demand per day for item i in period t</td>
</tr>
<tr>
<td>σ_{it}</td>
<td>standard deviation of the demand for item i in period t</td>
</tr>
<tr>
<td>Variables</td>
<td></td>
</tr>
<tr>
<td>AP_{i}</td>
<td>advancement potential for item i</td>
</tr>
<tr>
<td>d_{itp}</td>
<td>(promotional) delivery volume for item i in period t</td>
</tr>
<tr>
<td>(E)B_{itp}</td>
<td>(Extra)Backroom inventory (for promotions) for item i in period t</td>
</tr>
<tr>
<td>O_{i}</td>
<td>uniform distributed overshoot with O_{i} ∈ {0,...,Q_{i}}</td>
</tr>
<tr>
<td>S_{it}</td>
<td>reorder level for item i in period t</td>
</tr>
<tr>
<td>Δ_{t}</td>
<td>workload difference in period t</td>
</tr>
<tr>
<td>W_{t}</td>
<td>target workload in period t</td>
</tr>
<tr>
<td>w^{*+}_{t}</td>
<td>workload shortage(-) or surplus (+)</td>
</tr>
<tr>
<td>α_{it}</td>
<td>reorder level increment per period in item i</td>
</tr>
</tbody>
</table>
4.1.2 Adjusted reorder level per item and delivery volume

Order advancement will be realized by changing the reorder levels. Adjustment of the reorder levels leads to inventory build-up per review period as shown in paragraph 3.3.2, figure 9. Given the reorder level increments, it is possible to define the adjusted reorder levels per period and item.

\[ \forall i, t: s_{it} = ss_{it} + \sum_{r=t-L+1}^{t} \mu_{ir} + a_{it} \] (4)

The safety stock must be in such a way that the fill rate is at least above the target fill rate ($\beta_{Target}$).

\[ \forall i, t: \beta (ss_{it}, a_{it}) \geq \beta_{Target} \] (6)

The delivery volume per period $d_{it}$ is equal to the expected demand in the review period for which the delivery was made, corrected for the order advancement. The level of order advancement is the difference between the reorder level increments at the order moment ($t-L=t-1$) and the preceding order moment ($t-L-R=t-2$). From the example in figure 9 can be seen that the delivery volume in period 1 will be equal to 0.11+0.89-0=1, which means that the total expected weekly demand is advanced to period 1.

\[ \forall i, t: d_{it} = \mu_{i,t} + a_{i,t-1} - a_{i,t-2} \] (7)

4.1.3 Standard deviation per item

An accurate approximation of the standard deviation ($\sigma$) is a complex task in case of non-stationary demand (Mattsson, 2010). Determining the standard deviation based on the actual variation of historical data requires a long period of data to get an accurate approximation. Using too old data is risky because this data is likely to no longer be representative for the current level of demand. To determine the standard deviation in case of seasonal demand patterns and limited history, the relationship between mean ($\mu$) and $\sigma$ presented by Silver et al. (1998, p. 126) will be used; $\sigma = c_1 \mu^c_2$, with $c_1$ and $c_2$ as constant values. The constant values can be estimated via linear regression, with:

\[ \ln(\sigma) = \ln(c_1) + c_2 \ln(\mu) . \]

Appendix E shows the results for linear regression, based on the data of 10 selected weeks. The promotional demand is excluded, because the standard deviation for promotional sales is not needed for calculation. The linear models are significant and have an average adjusted R-squared of 0.88. For example the constant factors for demand on Friday are $\ln(c_1)$=1.104 and $c_2$=0.545. Due to the small difference between the constant factors on different days, $c_1$=1.12 and $c_2$=0.55 will be used for all days.

4.1.4 Expected backroom inventory and probability of overflow

For advancement of the non-promotional items the shelf-capacity must be known to determine the potential increase in backroom inventory and this is an important driver for the handling costs in the store. The item selection algorithm starts with setting a limit on the probability of overflow inventory per item. Just after a delivery moment the inventory level is equal to the inventory position at the moment of review minus the demand during lead time $D_i(L_t)$. The reorder levels are time-dependent and therefore the probability of overflow is also time dependent;
\[ \forall i, t: P_{it} = P[s_{it} - 1 + O_i - D_i(L_t) > V_i] \] (8)

with \( O_i \) defined as the difference between the inventory position just after ordering minus \( s_n \) and uniform distributed between zero and the case pack size. Due to the restriction on the probability of overflow can be replaces by a constraint for the maximum reorder level increment per item \( i \) in period \( t \) \((A_{it})\)

\[ \forall i, t: a_{it} \leq A_{it} \] (9)

The maximum probability of overflow will be limited to 3%. This means that an item can be found in the backroom at most once per month. This constraint prevents that many different items will be stored in the backroom, which increases the complexity of backroom operations and the related handling costs. The overflow inventory will be expressed by the expected number of consumer units in the backroom per period;

\[ \forall i, t: BI_{ito} = E[(s_{it} - 1 + O_i - D_i(L_t) - V_i)^+] \] (10)

To approximate the probability of overflow and the expected amount of backroom inventory in case of non-stationary demand version 4.5 of the DoBr-tool will be used (Broekmeulen & van Donselaar, 2015).

4.1.5 Item selection algorithm for non-promotional items

The item selection algorithm for non-promotional items is described in paragraph 3.3.5 and the mathematical representation is given in this paragraph. For each period, we want to be as close as possible to the target workload \((W_t)\), which is defined as the difference between the workload in case of Just-in-Time delivery and the target workload that should be obtained. The algorithm starts with pushing items from the period with the largest workload surplus \((w_t^+)(\text{largest peak})\) towards the period with the largest workload shortages \((w_t^-)(\text{largest gap})\). The algorithm selects items with the largest available advancement volume and for each selected item the value(s) of the reorder level increment(s) will be determined.

(Step 1) Let \( H \) be the set that contains the workload surpluses \((w_t^+)\) and \( L \) be the set that contains the workload shortages \((w_t^-)\) and calculate the reorder levels for all periods with all reorder level increments \( a_{it} \) equal to zero. Calculate the maximum reorder level increment \( A_{it} \) for all periods and all items, given the target probability of overflow.

(Step 2) Now select the period with the largest workload surplus in \( H \) and let \( h \) be equal to this period. Let \( l \) be equal to the period from \( L \) with the largest workload shortage. Calculate the advancement potential for every item, which is equal to minimum value of the expected demand in period \( h \) and all maximum available reorder level increments \( A_{it} \).

(Step 3) Select the item \( i \) with the largest advancement potential \((AP)\). If the advancement potential is smaller than the minimum advancement quantity \((MAQ)\), period \( h \) will be excluded from the set \( H \), because it is not likely that smaller advancement volume will contribute to obtain the target workload pattern. Now update the workload shortage and surplus in the set \( L \) and \( H \) for
period \( l \) and \( h \) and adjust the reorder level increments and all maximum reorder level increments from \( t=l-1 \) to \( h-2 \).

(Step 4) If the workload shortage and surplus that is reached is smaller than \( \epsilon \), or the set \( H \) is empty, then stop the item selection algorithm. If the condition is not met, go to step 2. The value of \( \epsilon \) indicates that a smaller workload difference will not make a significant difference from a practical point of view and more advancement is therefore no longer valuable. The value of \( \epsilon \) will be set equal to 10 consumer units, which is approximately equal to the average case pack size (9.25 CU. Step 2, 3 and 4 can be defined as a while loop and the mathematical representation is presented hereafter.

Step 1 \( \forall i, t: a_{it} = 0 \)
\( \forall i, t: \) calculate \( s_{it} \)
\( \forall i, t: \) calculate \( A_s \) given \( P_s \leq \) “Target”
\( H := \) set of all workload surpluses \( (w_i^+) \)
\( L := \) set of all workload shortages \( (w_i^-) \)

Do

\( h := \text{Min}(H) \)
\( l := \text{Max}(L) \)

The potential advancement volume is determined by \( A_s \) for \( t=l-1 \) to \( t=h-2 \) and not larger than \( \mu_{ih} \). Thus the advancement potential is defined as; \( AP_i = \min[A_{i,l−1}, ..., A_{i,h−2}, \mu_{ih}] \).
Select item \( i \) with the largest potential advancement volume \( AP_i \).

If \( AP_i < \text{MAQ} \) then

\( H \setminus \{w_i^+\} \)

Else \( w_i^+ = w_i^+ + AP_i \)
\( w_h^- = w_h^- - AP_i \)
For \( t=l-1 \) to \( t=h-2 \)
\( a_{it} = a_{it} + AP_i \)
\( A_{it} = A_{it} - AP_i \)

Next
End if

While \( (w_i^+ < \epsilon \text{ or } w_i^- > \epsilon \text{ or } |H| > 0) \)

4.1.6 Cost factors

For quantifying the change in terms of costs for handling in the DC and the store, and transportation costs factors are defined. All costs factors are shown in table 2 on the next page and are relative to the costs related to a regular replenishment in the store.

The handling costs are assumed to be equal per consumer unit and the wage costs are constant during the day. The extra costs for handling backroom inventory for non-promotional items depends on the number of days that it will be found in the backroom, because each day a shelf stacker will check at least once whether it can be put on the shelves or not. For promotional items the amount of backroom inventory is hard to calculate, because the shelf-capacity for most of the items is unknown due to a different presentation area. It is likely that most of those items will always have some backroom inventory which is required for operations. Due to the large volume involved the
backroom costs for promotional items are lower than for the non-promotional items and the backroom inventory will only be calculated over the inventory that is delivered more than one day in advance before the discount period will start. The increase in wage costs for activities on Sunday are also taken into account. In the stores the shelves for promotional items in the upcoming discount week cannot be stacked earlier because the presentation area is used for items in the current discount week. This means that the promotional items must be stacked on Sunday and therefore the 100% costs increase for handling those items on Sunday does not have to be taken into account.

The transportation costs are defined per hour and per kilometer. The total number of hours was registered, and by dividing the total wage costs by the number of hours the estimated wage costs per hour is obtained. The costs for the equipment (truck, maintenance, fuel, etc.) are assumed to be linear with the total driving distance. The costs increase when trucks are hired beyond the dedicated fleet is assumed to be 10% for both the wage and the equipment costs. For each second delivery per day it will be assumed that it will be performed with a non-dedicated truck.

<table>
<thead>
<tr>
<th>Table 2 - Estimated cost factors</th>
<th>Cost factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
</tr>
<tr>
<td>Wage costs increase on Sunday</td>
<td>100%</td>
</tr>
<tr>
<td>Workload difference</td>
<td>1/10</td>
</tr>
<tr>
<td><strong>DC</strong></td>
<td></td>
</tr>
<tr>
<td>Picking costs</td>
<td>8/10</td>
</tr>
<tr>
<td><strong>Store</strong></td>
<td></td>
</tr>
<tr>
<td>Shelf stacking</td>
<td>1</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td></td>
</tr>
<tr>
<td>Wage costs</td>
<td>1670</td>
</tr>
<tr>
<td>Equipment costs</td>
<td>21</td>
</tr>
<tr>
<td>Cost increase for non-dedicated trucks</td>
<td>10%</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td></td>
</tr>
<tr>
<td>EBI for non-promotional items</td>
<td>1</td>
</tr>
<tr>
<td>EBI for promotional items</td>
<td>0.2</td>
</tr>
<tr>
<td>Instore inventory</td>
<td>6/1000</td>
</tr>
</tbody>
</table>

### 4.1.7 Cost function

The cost function will be used for reducing the total costs related to order advancement and is presented below;

\[
\text{Total Relevant Costs} = 0.1 \sum_{i \in T} |\Delta_t| + 1.8 d_{7,0} + 0.8 d_{7,1} + T \sum_{i \in T} N_t + 0.1 T(N_t - 1)^+ + T_W N_T + \sum_{i \in I} \frac{\sum_{t \in T} n_{it}}{1000/6} + \sum_{i \in I} \sum_{t \in T} (EBI_{it0} + 0.2 EBI_{it1})
\]  

(4)

The first element of the goal function is related to the workload difference. The workload difference \((\Delta_t)\) is defined by the difference between the average demand in period \(i\) and the delivery volume in period \(i\).

\[
\forall t: \Delta_t = \frac{\sum_{i \in I} n_{it}}{7} - \sum_{i \in I} d_{it}
\]

(5)

The second and third element represent the handling costs that increase due to delivering items on Sunday. Thereafter the costs for transportation \((T)\) are given and consist of wage costs \((T_w)\) and equipment \((T_e)\) costs. It will be assumed that loading and unloading per store will take two hours and
the average speed of a truck will be 60 kilometers per hour. This means that the total delivery costs per delivery are equal to;

\[ T = T_w + T_e = \left( 2 + \frac{DD}{60} \right) \times 1670 + DD \times 21 \] (6)

Finally the extra costs related to (backroom) inventory are given.

4.2 Application of the advancement model

In this paragraph the design will be applied to three stores and which were selected based on their weekly demand levels. Not all stores were selected, because this would have been consuming and discussing the results of all stores would be less valuable than discussing the results of three stores more extensively. This paragraph first discusses for which stores the order advancement process will be applied in this thesis. Then the selected data and the current demand pattern per store are discussed. Finally the results of applying the delivery scheduling process and the order advancement model are shown and discussed.

4.2.1 Data selection

For application of the model, three stores are selected and the demand data of ten weeks is collected. These selected weeks from 2015 are 3,4,5,6,7,9,10,11,12 & 13. These weeks are selected because there are no holiday periods, e.g. Christmas, Carnival (week 8), Easter, are included. The potential deviation in the delivery pattern per week due to these events is the reason to exclude holiday periods. To meet the shelf life restriction non-promotional items from the dry groceries and frozen foods categories will only be used for order advancement.

The accuracy of the shelf capacities in the ASO-system are checked for 506 items in three stores, because the accuracy of this parameter could have a large impact on the accuracy of the results. The real mean is 20.16 compared to the 20.20 of the ASO-system. Regression analysis gives an R-squared of 0.903 (Appendix F) and ANOVA shows that the shelf capacity in the ASO-system predicts the real shelf capacity significantly well (0.000). From these results can be concluded that the shelf capacity data from the ASO-system is accurate enough and this accuracy prevents that the amount of backroom inventory after order advancement will be unexpectedly high in practice. It must be noted that there is still room to improve the accuracy of the shelf capacity data.

For implementation of the design the raw data is filtered. First items that have a shelf capacity equal to zero will be excluded, because these items cannot be used for calculation or are direct and outsourced deliveries. Thereafter, items with a discount period in the selected weeks are excluded, because it is hard to determine the effect of discount period on the demand in regular weeks. In practice, the ASO-system takes a longer history than ten weeks and is able to exclude the effect of promotional demand on the regular demand and therefore, in practice, there is no need to exclude this part of the assortment for order advancement. After excluding those items, on average 59.7% of the non-promotional demand in the dry grocery and frozen food categories will be used in the item selection algorithm.
4.2.2 Stores selected for applying the order advancement model

The ID’s of the selected stores are 1800, 3409 and 5900, representing a medium, a high and a low demand level respectively (Appendix D). Store 3409 is chosen because the delivery volume per week is very close to six truckloads, given the current stacking efficiency of RC’s. In the current situation eleven or twelve stops are scheduled in a week per store and the largest costs reduction could be obtained for the 47 stores which can be delivered with in at most six stops, if the delivery volume can be fully smoothed.

From a transportation perspective, without bundling truckloads, it is cost-efficient to schedule the minimum number of deliveries. In a situation with at least seven deliveries per week, no deliveries on Sunday, and not more deliveries than the required amount, it will definitely lead to two fully loaded trucks in some periods. This means that there will still be a workload difference of one truckload between the peak and non-peak. In the stores a workload difference like that could lead to problems for obtaining sufficient shelf stackers. For the DC and transportation the workload difference will also be large and even more problematic if all of the second deliveries are scheduled in the same periods. To prevent this workload peak it is possible to smooth the workload during the week by scheduling more deliveries than the required number. Because of the costs as defined in the cost function are linear with the number of deliveries, it seems to be very costly to schedule for example two deliveries from Monday until Saturday. However, if the workload can be fully smoothed, every second delivery per period will definitely not be fully loaded, which means that it could be possible to bundle the volume of the second delivery with other store deliveries. In this situation the defined transportation costs are no longer representative and inventory routing must be included to give an accurate estimation of the cost difference between different delivery frequencies and levels of workload smoothing per store. As stated before, the largest cost savings can be obtained for the stores with a minimum of six truckloads per week and only ten stores require more deliveries. To schedule the delivery moments for those ten stores it is complex to determine a cost-efficient delivery schedule from a supply chain perspective without creating new workload peaks. Due to the lack of inventory routing and the complexity that must be added to the model for determining a cost-efficient schedule for those ten stores and the limited cost-savings compared to the 47 other stores, the delivery scheduling process will not be applied to the ten stores which require more than six deliveries.

4.2.3 Demand pattern of the selected stores

For the stores with store ID ‘1200’, ‘3409’ and ‘5900’ the demand pattern is shown in the figure 12, 13 and 14 on the next page respectively. It can be seen that the pattern deviates per store. For the application of the order advancement model it is assumed implicitly that a review period starts just before store opening. Without order advancement and with no deliveries on Sunday the peak delivery volume is 2.18, 2.12 and 1.69 times the delivery volume for the non-peak period for respectively store 1800, 3409 and 5900. During the implementation of the design the delivery times should be determined and it could be the case that the review periods will start later during the day. This could lead to different demand level per review period, but it is an operational planning question to determine the exact shelf stacking times and therefore not in the scope of this thesis. Due to a lack of available data there are some items with an irregular demand pattern that includes at least one day with zero demand. To prevent calculation problems with the days of zero demand
during the ten selected weeks for the non-promotional non-perishables items, the week pattern per item is set equal to the aggregate week pattern of all non-promotional dry groceries and frozen foods per store.

Figure 12 – Demand pattern for store “1800”

Figure 13 – Demand pattern for store “3409”

Figure 14 – Demand pattern for store “5900”

4.2.4 Results of the order and delivery scheduling process

The order and delivery scheduling process consists of three steps. For the three selected stores the process is iterated until no more cost improvements can be obtained and the results are discussed hereafter.

Initial number of deliveries

In the first step it must be decided how many deliveries should be scheduled per week per store. As stated in the conceptual design the starting point is the required number of deliveries as shown in figure 6. For store 1800, 3409 and 5900 the weekly delivery volume is equal to respectively 5.0, 6.0 and 3.1 truckloads, given the current stacking efficiency of RC’s. Also for store 1800 and 5900 the minimum required number of deliveries will be equal to six to enable sufficient replenishment moments for the perishable items. The transportation costs per delivery with a dedicated vehicle are shown in table 3.

<table>
<thead>
<tr>
<th>Store ID</th>
<th>hours</th>
<th>distance(km)</th>
<th>T_w</th>
<th>T_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>3.1</td>
<td>66</td>
<td>5177</td>
<td>1389</td>
</tr>
<tr>
<td>3409</td>
<td>5.5</td>
<td>104</td>
<td>9129</td>
<td>4368</td>
</tr>
<tr>
<td>5900</td>
<td>3.9</td>
<td>112</td>
<td>6513</td>
<td>2352</td>
</tr>
</tbody>
</table>
Reducing the workload difference will lead to a cost increase for holding extra inventory. From the number of used RC’s and the delivery volume in CU’s, is calculated that the RC’s of store 1200 have one of the highest utilization degrees per RC (appendix E). This store on average has a demand of 147500 consumer units per week, which is equal to 9.5 truckloads and therefore an expected utilization rate of 95%. This means that a fully loaded truck transports approximately 15500 CU’s. To compensate for the deviating stacking efficiency an overcapacity of 5% will be used and therefore 14750 CU’s per truck delivery will become a hard design restriction. For store 1800, 3409 and 5900 respectively 4.6, 5.8 and 1.9 deliveries were estimated given the number of RC’s when we divide the total weekly demand per store by 14750. Given the limitation of the maximum truckload it can be concluded that it is not cost-efficient to plan more deliveries than the required number in advance. Even when the driving distance is zero, and the inventory costs do not increase due to order advancement, the workload difference must reduce with 16700 CU’s, but the workload difference is always smaller.

From the perspective of freshness it could be decided to schedule a seventh delivery, with both perishable a non-perishable items on Sunday despite the increase in costs. With a delivery on Sunday less volume will have to be advanced from Sunday to Saturday, which means a reduction in the backroom inventory of at most 1 cost unit per item. A potential reduction due to fewer advanced promotional items is at most 0.6 cost units in case of delivering promotional items on Sunday. The reduction in backroom inventory and workload difference (0.2 cost unit) will not outweigh the costs increase for order picking and shelf stacking on Sunday (1.8) and the extra wage costs for transportation. Thus, the initial number of deliveries for all stores will remain equal to the minimum number of truck deliveries as shown in figure 6. Although it is not efficient from a cost perspective, it could be valuable to differentiate from competitors by delivering fresh products on Sunday and therefore it is recommended to consider this option in the future.

**Target workload and number of deliveries per day**

Scheduling the required number of truck deliveries and the total delivery volume per period is restricted by the cumulative delivery quantity of the expected demand during the planning horizon. To minimize the sum of all reorder level increments, or increase the probability that the target workload will be reached, the deliveries must be scheduled as late as possible during the planning horizon.

From the cost function can be concluded that it is not preferred to deliver non-promotional or promotional items on Sunday. This means that the required number of deliveries must be scheduled from Monday until Saturday. It also means that the lead time for delivering items on Monday will become equal to two days for all stores and the review period that must be covered by the delivery volume on Saturday will also be equal to two days. The planning horizon will start on Monday. In case of six deliveries the goal will be to obtain a fully smoothed workload from Monday till Saturday to minimize the workload difference.

**Item selection**

The third step of the order and delivery scheduling process is the item selection algorithm. The parameter $\varepsilon$ is set to 10 CU’s, which is approximately equal to the average case pack size (9.25 CU’s). The minimum advancement quantity (MAQ) per period will be equal to 0.1 CU. A larger value will reduce the available volume for smoothing, but it increases the likelihood of advancing orders and
reaching the target workload pattern. Future research should explore the effect of different MAQ values.

At first a maximum probability of overflow equal to zero is used, and only for store 5900 the target delivery pattern can be obtained. Therefore a maximum probability of overflow of three percent is used for store 1800 and 3400. In table 4 the final workload shortages and surpluses are given after applying the item selection algorithm for the three selected stores. For stores with a high demand rate the shelf capacity per item is lower and therefore there is less excess shelf space available for order advancement. The results show that how lower the demand, the higher the level of workload smoothing that can be obtained. In table 5 the expected backroom inventory after order advancement is given for non-promotional items. A probability of overflow of 3% increases the expected backroom inventory due to order advancement with only a couple of CU’s. It could be argued that the constraint of 3% should be increased, but this could increase the number of items in the backroom, which reduces the handling efficiency significantly. In addition, due to shelf space inaccuracies the actual increase of backroom inventory could be larger in practice.

<table>
<thead>
<tr>
<th>Store ID</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesd.</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>624</td>
<td>623</td>
<td>623</td>
<td>624</td>
<td>-8</td>
<td>-2488</td>
</tr>
<tr>
<td>3409</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>-15</td>
<td>-15</td>
</tr>
<tr>
<td>5900</td>
<td>864</td>
<td>862</td>
<td>862</td>
<td>862</td>
<td>-7</td>
<td>-3442</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Store ID</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesd.</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>350</td>
<td>376</td>
<td>414</td>
<td>482</td>
<td>614</td>
<td>465</td>
</tr>
<tr>
<td>3409</td>
<td>225</td>
<td>229</td>
<td>229</td>
<td>248</td>
<td>261</td>
<td>237</td>
</tr>
<tr>
<td>5900</td>
<td>816</td>
<td>929</td>
<td>1061</td>
<td>1361</td>
<td>2106</td>
<td>1114</td>
</tr>
</tbody>
</table>

In figure 15, 16 and 17 on the next page the new workload patterns are shown. The delivery volume during the peak period has become 1.28, 1.30 and 1 times the delivery volume during the non-peak periods. The workload during the peak was reduced by 6.8, 6.5 and 7.1% of the weekly sales volume for store 1800, 3409 and 5900 respectively. Given the restriction of 14750 CU’s per truck delivery it can be concluded that the obtained workload pattern for store 1800 and 5900 will not lead to more deliveries than scheduled in step one of the delivery scheduling process. For store 3409 the obtained workload exceeds the capacity of one truck by 360 and 3975 CU’s on Friday and Saturday respectively. One could argue that this can be transported within the 5% spare capacity. More appropriate is to shift the delivery volume of the promotional items to prevent an extra delivery on Friday, this will increase the costs due to an increase in backroom inventory. For Saturday an extra delivery must be made, because only some volume (510 CU’s) from promotional items can be shifted towards Thursday but this will not solve the problem. Although the cost function indicates that the transportation costs will increase by 13497, the cost increase can be reduced to a large extent by bundling truckloads, because the remaining volume is only 26% of the truck capacity.
Within the target delivery pattern there is no unique solution for planning the promotional orders. One of the requirements was an inventory build-up of 40% at the start of the discount period and this could be realized by delivering for example 0.05, 0.15 and 0.20 of the expected weekly demand on respectively Thursday until Saturday before the discount period. Note that in these days the entire delivery volume for promotional items is not for the upcoming discount week. The reason to deliver at least some promotional volume for the current discount period is to create some flexibility to respond to forecasting errors in the current discount week. An example of the inventory build-up for promotional items is shown in figure 18. In the presented design, most of the promotional volume will be delivered during the peak. If the discount period would start right after a non-peak period, the overcapacity during non-peaks could be used to build-up the inventory level for the start of the upcoming discount period. The consequence is that less non-promotional orders have to be advanced towards the non-peak period. Therefore it is recommended to analyse the possibility at starting the discount period after a non-peak period.
4.3 Expected workload pattern for the DC and transportation

In the current order and delivery schedule each store receives eleven or twelve deliveries per week and at most two deliveries per day. The peak in delivery volume is 1.70 times higher than the delivery volume on Monday. Moreover, all perishables are loaded and delivered in a time window of 3 hours and all the non-perishables within a separate time window of 5 hours. Both the difference in delivery volume and the delivery of both segments within a small time window creates inefficiencies for transportation. By order advancement both problems can be solved. Due to order advancement the difference between peak and non-peak workload will reduce by 40% on average for the stores with an expected weekly delivery volume of at most six fully loaded trucks. For the ten stores that are excluded in this chapter twelve deliveries will be assumed from Monday until Saturday. This is comparable with the current order and delivery schedule. Because the order and delivery scheduling process was only applied to a limited number of stores, the expected new workload pattern for DC and transportation can only be estimated.

From store 1800 can be concluded that after advancing, the maximum delivery volume will fit the capacity of one truck per day. Therefore all stores with less or an equal demand volume also need 6 deliveries per week and one per delivery day. There are 22 stores with a higher demand level and this means that 22-10=12 stores will receive an extra delivery. The periods in which the extra delivery for those twelve stores will take place will not be determined in this thesis. If the deliveries take place at the latest possibility during the planning horizon the increase in inventory in the store can be reduced, which saves costs for handling. A consequence of scheduling the extra deliveries as late as possible is that most of the stores will receive this extra delivery on the same day. This will create a workload peak for transportation and the DC. If it is possible to schedule some of the extra deliveries earlier, the probability that this delivery volume can be bundled with other stores will increase. Scheduling an extra delivery should outweigh the extra costs of accepting more inventory in the backroom.

To give an approximation of the difference between the peak and non-peak workload for transportation and the DC, order advancement is also applied to five other stores with different sales levels. One of these selected stores is the store with the highest sales level (store 1200). Due to the assumption of twelve deliveries and no deliveries on Sunday, the goal was to obtain a fully smoothed workload given the maximum probability of overflow of 3%. For store 1200 the peak workload can be reduced by at least 3.9% of the weekly sales volume compared to a just-in-time approach. Given the workload differences of four stores it is possible to estimate the expected workload difference for DC. In figure 19 on the next pages the expected difference in delivery volume between peak and non-peak is plotted for eight stores. From the figure can be concluded that is it reasonable to assume that the difference can be estimated by linear regression. The estimation of the workload difference is not only determined by the weekly sales level but also by the demand pattern per store. The larger the peak demand, the less the workload difference can be minimized. Given the linear formula the workload difference between peak and non-peak delivery volume is estimated. The peak workload in the DC and transportation will become on average 1.18 times as high as the non-peak workload, compared to 1.70 times in the current situation.
4.4 Effect on transportation costs

In figure 20 the delivery costs per CU is shown given the current costs factors per hour and per kilometer. The total driving distance from the DC to the current stores varies from 1 to 120 kilometers. The effect on the costs per unit in case of a 20% increase or decrease is also shown and the effect of using non-dedicated vehicles is excluded. For stores with a large distance from the DC to the store it is less beneficial to smooth the workload by planning extra deliveries. Because of the linearity of formula 6, it is easy to draw conclusions about the effect on the costs per CU by a 20% increase or decrease of both the costs per hour, costs per kilometer, or utilization degree.

In figure 20 the expected cost reduction from the new design can be obtained. The average distance to a store is 50 kilometers. Therefore, it can be concluded that the average costs per unit of a fully loaded truck will be equal to 0.56. For stores with a demand level of six truckloads per week and therefore six or seven deliveries a utilization degree of 70.2% will be obtained without bundling truckloads. This means that the expected delivery costs per CU will become 0.79. From the operational costs in figure 4, the ratios between handling store, transportation and handling DC is 1:0.9:0.8 respectively. This means that the new design will reduce the transportation costs for stores with a maximum weekly demand level of six truckloads by 12.2%. For the ten stores with a volume larger than six truckloads twelve deliveries will be scheduled and this means that for those stores the workload can also be smoothed. Given twelve deliveries for these ten stores, the expected number of stops will reduce from 636 towards 420, which is a reduction of 34.0%.
5 Sensitivity analysis

In this chapter a sensitivity analysis is performed on two input parameters. Because it could be a large risk for the performance of the design, one of the research questions is to do a sensitivity analysis about the stacking efficiency of RC’s. Besides a sensitivity analysis for the stacking efficiency of RC’s, a sensitivity analysis is also executed for the effect of deviations in the shelf capacity per item on the potential level of advancement.

5.1 Stacking efficiency of RC’s

It was shown in paragraph 2.3 that the delivery quantity in RC’s could vary greatly due to different stacking efficiencies. A large variation in the stacking efficiency of the RC’s could lead to a difference between the expected and realized truckload. In the worst case scenario this could lead to extra unscheduled deliveries and therefore a large increase in transportation costs. This is why it is necessary to perform sensitivity analysis.

The change in delivery volume by changing the stacking efficiency is compared to the current stacking efficiency per store. When the stacking efficiency improves with 10% the total required number of deliveries or stops reduces of 1.9%. A decrease in stacking efficiency of 10% will increase the minimum number of stops with 4.7%.

In figure 21 is shown what the effect of a change in stacking efficiency on the number of stores with a weekly demand volume of at most six truckloads is. From figure 21 can be concluded that an increase in stacking efficiency of 10% will increase the number of stores with six deliveries by 3 and an increase in stacking efficiency of 10% will reduce it by 8. In this thesis it was assumed that stores with a total weekly delivery volume larger than six truckloads will still have 12 deliveries or stops and therefore it could have a significant impact on the potential savings of the design.

In figure 21 is also shown that decreasing or increasing the stacking efficiency by 10% could change the utilization rate for stores with a minimum number of six deliveries with respectively plus 3.4% and minus 4.9%. In this research bundling of store delivery volumes is not included and therefore a more accurate approximation cannot be given. A decrease in the utilization degree by improving the stacking efficiency will increase the probability that store delivery volumes can be bundled, which can also lead to a further reduction in the total driving distance.

Figure 21 – Effect of stacking efficiency on the transportation performance
Store 1200 is the store with one of the highest utilization rates per RC (Appendix G, figure 26). If the same stacking efficiency would be reached for every store, the required delivery volume in truckloads will reduce by 10.5%. The number of stores with a required number of six truckloads per week will reduce by one and the utilization degree for these stores will reduce by 8.5%. At this moment there is hardly any restacking performed for store 1200 at the start of the week due to the planned overcapacity in transportation. This means that achieving the same average stacking efficiency as store 1200 for all stores seems to be feasible. For both reducing the probability of extra unscheduled deliveries and for obtaining significant cost savings in transportation it is recommended to investigate the possibilities of improving the stacking efficiency in such a way that it do not lead to a disproportional increase in DC’s handling costs.

5.2 Shelf capacity

Due to a constraint on the probability of overflow the shelf capacity significantly affects the potential level of order advancement. In paragraph 4.2.1 was concluded that there is a good fit between the measured data and the data in the ASO-system. However, the actual shelf capacity was a bit lower than the data measured. During the last decade the depth and width of the assortment has grown dramatically and this has reduced the shelf capacity per item. It is not ruled out that in the future the assortment will be expanded further. On the other hand it is also possible that the number of items in the assortment will decrease in the future. Both developments make it worthwhile to investigate the effect of an increase in the systems shelf capacity on the advancement potential per day.

To analyze the effects of changes in the available shelf capacity on the potential level of order advancement the shelf capacities are simulated from minus 10% to plus 10% for the three selected stores. In the presented model the maximum reorder level increment is limited by \( A_i \) and the available advancement volume from the period with the largest workload surplus. The advancement potential is approximated by taking the minimum of all maximum reorder level increments and the sum of the expected demand for all periods with a workload surplus (\( \mu_i^* \)). This approximation slightly overestimates the advancement potential, because it is not always necessary to use all advancement volume from the periods with a workload surplus to obtain the target delivery volume.

\[
\forall i: AP_i = \min[A_{i,1}, ..., A_{i,5}, A_{i,7}, \mu_i^*], \quad \text{with} \quad \mu_i^* = \sum_{\forall t, w_t \geq 0} \mu_{it} \tag{13}
\]

In figure 22 on the next page the effect of a change in the size of the shelf capacity on the change in advancement potential is shown. The effect is not linear, because an increase in shelf capacity will only be utilized when there is sufficient advancement volume available. From the figure can be concluded that a small change of the shelf capacities could have a large impact on the order advancement potential. A decrease in the shelf capacity will have a larger impact on the advancement potential than an increase. This disproportional effect indicates a misalignment between the demand and available shelf capacity per item.

In figure 23 on the next page the fit between the maximum demand during the review period and the shelf capacity minus safety stock is shown. In the figure can be seen that for some item-store combinations even the safety stock cannot be stored in the shelf. To reduce store handling costs and backroom inventory, the alignment between case pack size, shelf capacity and reorder point is critical (Eroglu et al., 2013). An R-squared of 0.03 as a result of linear regression indicates a misalignment between demand level and shelf capacity. The regression line shows that for most
items there is sufficient shelf capacity. Both the capacity shortages and surpluses indicate that a better alignment is possible and therefore the store handling costs can be reduced. Improving the alignment could have a positive as well as a negative effect on the level of order advancement. When the shelf capacity of the problematic items is increased it could increase the advancement potential for those items. On the other hand, to increase the shelf capacity for specific items, this must be compensated by reducing the shelf capacity of others. This will reduce the backroom inventory, but it will also reduce the available shelf capacity of other items and therefore it reduces the advancement potential for the items with a shelf capacity reduction.

From figure 22 can be concluded that in the current situation the level of order advancement is quite sensitive to a change in the shelf capacity. Even for store 5900 with a low demand level a 5% reduction of the shelf capacity will reduce the advancement potential by 7%. Therefore it is recommended to improve the accuracy of the shelf capacity data in the system, before implementing order advancement, to prevent unnecessary inventory in the backroom.

![Figure 22 – Effect of the change in shelf capacity on advancement potential per store](image1)

![Figure 23 – Alignment between shelf capacity and the average demand per day](image2)
6 Implementation

The last step of this thesis is discussing the implementation of the design. First the effect on the order and delivery scheduling process will be discussed. For transportation, as well as the stores and the DC, the findings will be summarized. Also the effect on operations will be discussed and recommendations for implementation will be provided. Finally the limitations of the research that should be taken into account by implementation will be summarized.

6.1 Order and delivery scheduling process

The current complex order and delivery schedule is a result of local optimization in the supply chain. The underlying decision rules were lost and maintaining the current order and delivery schedule is very time consuming. This makes it hard to optimize supply chain processes. In this thesis a model has been presented that provides fundamental guidelines for making scheduling decisions. The starting point for order and delivery scheduling is workload smoothing by order advancement and will lead to an efficiency improvement in the supply chain. It does not mean that a fully smoothed workload will minimize costs. For stores with a high demand level, it is not beneficial to smooth the workload completely, because this would lead to a significant increase in backroom inventory and corresponding handling costs. The concept of workload smoothing and the results of the thesis can be used to structure the political discussion between transportation, the stores and the DC about the replenishment schedule.

The order advancement model was built in Excel and the calculation time is about half an hour per store. Before the model can be implemented it is required to reduce the calculation time by using another software tool and perhaps rewriting the software code. A direct integration with the ASO-system might be necessary, because it could contribute to making the scheduling process less time consuming.

It is expected that the model is not sensitive to the deviation in the demand, because the total volume does not differ significantly per week (Appendix B). In the design an overcapacity of 5% is taken into account, given the same stacking efficiency as for store 1200. To make the system less sensitive a larger amount of overcapacity can be scheduled. This will increase the costs, however the more static the new schedule is, the more it reduces complexity of scheduling resources in the supply chain.

6.2 Transportation

Optimizing the current transportation schedule was restricted by two limitations. Currently each store receives eleven or twelve deliveries per week, which results in a low delivery volume per stop and therefore a low utilization degree. An important limitation of the current schedule is that the perishables and non-perishables are delivered separately and in a small time window. For obtaining a utilization degree of 78.8%, 1.73 stops per route are scheduled in the current situation.

In the presented design inventory routing was not included, which is one of the main limitations of this research. Because it could reduce the driving distance per stop, inventory routing could reduce the costs per stop and per CU significantly. Without inventory routing, and with the current stacking efficiency of RC’s, the utilization degree will become 70.2% for the stores with a demand level of at
most six truckloads per week. The utilization degree of 70.2% means that the transportation costs are expected to reduce by 12.2% for this set of stores.

In the presented design 12 deliveries will still be scheduled for stores with a larger weekly demand volume than store 3409. Given this limitation the number of stops reduces from 636 now towards 420, which is a reduction of 34%. The utilization degree is measured by the number of loaded RC’s and due to the reduction in the number of stops per route the decrease in utilization rate is actually smaller. A large reduction in the number of stops means that the final transportation schedule will become less complicated. Moreover, through this reduction stores can be delivered easily within a time-window of 8 hours, given the current number of dedicated trucks. The more the time window is widened, the more it will be possible to use the dedicated trucks, which means a further reduction in transportation costs.

The difference in delivery volume between peak and non-peaks reduces from a factor 1.70 to 1.18. From this can be concluded that less non-dedicated trucks need to be hired compared to the current situation. An important improvement that is counterproductive with workload smoothing is that 40% of all promotional demand for the upcoming discount period will have to be delivered during the peak (Thursday till Sunday) in the new design. To improve the level of workload smoothing it is recommended to evaluate the possibility of starting the discount period after a non-peak period, so that the non-peak period can be used for building up the inventory level.

An important recommendation for a further reduction of the transport costs is improving the stacking efficiency of RC’s. The current stacking efficiency varies a lot among stores, because restacking before unloading is not performed every store on all days. If the stacking efficiency of all stores becomes as high as that of store 1200 the required number of stops will reduce by 2.1% and the delivery volume in truckloads will reduce by 10.5%. Even for store 1200 there was hardly any restacking at the start of the week, which means that this stacking efficiency is not infeasible to achieve for all stores.

6.3 Stores

Due to order advancement the inventory level in the stores will increase. The target level of availability for the non-perishables is set of 99% and due to order advancement the level of availability will improve, which could lead to more sales. To prevent a large cost increase for instore handling and to keep the number of items in the backroom restricted, a maximum probability of overflow of at most 3% is used. In addition, in the new design the promotional delivery volume for the upcoming discount period is delivered more just-in-time, which reduces the amount of inventory in the backroom. At this moment the number of items under promotions is around 500 per week and 55% of the items under promotion account for 6% of the promotional demand. It is important to note that these items cannot be used for order advancement during the discount period. These numbers indicates that it could be valuable to perform an analysis about the commercial contribution of those items, because a reduction in the number of items under promotion could improve the potential level of workload smoothing.

Although the inventory level of many items will increase by order advancement, this does not mean that a presentation stock is no longer needed for the non-promotional items. If there is sufficient smoothing volume available, items with a low demand level will not be used and the inventory level
during the week will not be increased. To stimulate the potential sales of items with a low demand, it could be decided to increase the inventory level by adding a constant presentation stock during the week. Note that a constant presentation stock can be added if there is some remaining excess shelf space after order advancement each moment in time.

An important parameter for the amount of backroom inventory and the potential level of order advancement is the shelf capacity. It was concluded that the accuracy of the shelf capacity data can be improved. Improving the shelf space data will reduce the amount of backroom inventory, because each overestimation of the shelf capacity could lead to extra backroom inventory. In the sensitivity analysis it was found that there is a misalignment between the expected demand and the available shelf capacity per item. A better alignment will reduce the store handling costs, and could have a positive and negative effect on the amount of workload smoothing. Before implementation it is recommended to improve both the alignment between demand and the shelf capacity and the data in the ASO-system.

Due to order advancement the delivery schedule per store will change and therefore the workforce should be rescheduled. The exact arrival times are not determined in this thesis. To determine the arrival times per store the labour costs and available workforce must be taken into account. It is already mentioned that the available workforce and wages during the day could deviate because the availability of, for example, young people with low wages is limited during school hours. The deviations in labour costs per hour should be investigated and the results can be used as input for planning the order and delivery times per store. In the current order and delivery schedule the shelf stacking times in the system and in the store are not aligned with the arrival times of the truck. Some of them are even before the truck arrives. In this situation the review period used in the ordering system is actually too short and could result in a lower availability level than expected. Note that the alignment of the shelf stacking and the truck arrival times could have a large influence on the amount of backroom inventory.

A last recommendation is on the influence of store managers on the order quantities. The store managers adjust 14.1% of the proposed orders. Van Donselaar et al. (2010) also found that store managers modify automated order advices by advancing orders. Implementing order advancement for determining the automated order advices therefore supports the behavior of store managers. For implementation the effect of store managers on the automated order advices must be reduced to prevent significant deviations in the workload pattern or amount of backroom inventory.

6.4 DC

The effect on operations for the DC is comparable to the effect of order advancement on transportation. For the DC it is important to investigate the possibilities of improving the stacking efficiency, because it could result in large cost savings. Improving the stacking efficiency also reduces the required capacity in the outbound zone.

The final time window that a delivery could be collected will depend the loading times that will follow from the transportation planning. The loading and unloading times of trucks will depend on the costs and availability of shelf stackers and order pickers. To reduce supply chain costs it is required that the preferences of all involved logistic subsystems are taken into account for
determining the exact delivery time windows. Determining the loading time in DC and the unloading time per store is an operational and short-term planning’s question and was not in the scope of this research.

6.5 Deliveries on Sunday

In this thesis it was concluded that it is not cost-efficient to schedule deliveries on Sunday. However, there are different arguments that make it likely that Sunday will be used in the future. To support Jan Linders’ distinguishable performance in the segment of fresh products, it could be valuable to deliver also fresh products on Sunday. Therefore the management of Jan Linders could decide to deliver goods on Sunday despite of the costs increase. If this would be the case, there is already a delivery with not a fully loaded truck and therefore it will be less costly to deliver also non-perishable items.

In addition, it is not ruled out that in the future the wage-cost increase of 100% will be eliminated in new collective labour agreements (In Dutch; cao). In this case there is no longer a need to distinguish Sundays from other days for scheduling deliveries. This could change the target workload per period and the goal could be to smooth the delivery volume and the number of stops during from Monday until Sunday. This could mean that stores with six deliveries could get different delivery patterns. For the stores with seven deliveries it could be cost-efficient to smooth the workload completely over all days.

In case of one replenishment moment per item per day and deliveries on Sunday, the peak workload could reduce even further. To be able to say at least something about the level of workload smoothing the item selection algorithm has been applied to store 1200 and store 3409. After using the algorithm the peak workload was respectively 1.32 and 1.09 times higher than the non-peak workload. This is a large reduction compared to a factor 1.64 and 1.30 in case of smoothing over six days. This means that using Sunday as a delivery day will have a considerable impact on the level of order advancement.

6.6 Limitations of the design

There are several limitations of this research that could affect the integration of the design. All of them will be discussed in short.

Planning promotional orders

For items under promotion the target workload per store per day will be determined in the order and delivery scheduling process. This means that for reaching the workload a more detailed replenishment policy must be defined that defines the replenishment quantities per period per item. The minimum amount of inventory build-up was set at 40% of the expected weekly demand. In the current situation the amount of inventory build-up of non-perishables is 96%(!) of the expected weekly demand and the delivery quantity is mostly determined manually and based on best-practices. To reach the obtained target workload pattern a replenishment policy for the promotional demand must be developed.
Inventory routing
Vehicle routing is not included in this research and the order advancement model is applied per store. Taking into account bundled truckloads will significantly reduce the fixed transportation costs per delivery and thereby affect the level of workload smoothing. To further optimize the order and delivery schedule an aggregate model should be developed which should take into account dependencies between stores due to bundling truckloads.

Minimum advancement quantity
In the order advancement algorithm a minimum advancement quantity (MAQ) of 0.1 CU is used. A lower volume does not contribute significantly to a change in the total workload. In addition, a too low MAQ will not change the reorder levels and the order pattern significantly. The effect of different values for the MAQ on the real level of advancement is not analyzed. The larger the MAQ-value, the more accurate the order pattern can be forecasted. It will require further research to analyze the effect of different values of the MAQ. If the MAQ value needs to be increased it is an option to smooth orders across different planning weeks. In this way the cumulative demand of multiple peak days can be accumulated, which will increase the reorder level increment and thereby it will meet a satisfy higher MAQ values

Cost drivers
Sternbeck and Kuhn (2014) have indicated that in practice it could be a difficult task to derive accurate volume dependent process times and costs and this finding is confirmed during this project. For example the approximation of the store handling costs were defined per CU and related to the delivery volume and the volume in the backroom. Van Zelst et al. (2006) have found that the stacking costs and order picking costs are related to respectively seven (figure 7) and five cost drivers. To give a more accurate order advancement cost approximation more cost drivers could be included (e.g. number of case packs and order lines).
7 Conclusion and recommendations

In this chapter the answers to the research questions are summarized. Then the potential performance improvement and the academic relevance is shortly discussed. Finally the recommendations for future research and for Jan Linders Supermarkten B.V. are presented.

7.1 Answers to the research questions

In this paragraph first the answer to the main research question is provided and thereafter the answer to the related sub questions are given.

What is a cost-efficient order and delivery schedule per store for Jan Linders Supermarkten B.V.?

For a costs-efficient order and delivery schedule it was determined that the workload within the supply chain must be balanced. To balance the workload a new approach has been developed. This new approach is called order advancement and does not excluded delivery moments for specific items, which is an improvement compared to previous research. Order advancement is embedded in the developed order and delivery scheduling process. For decision making during this order and delivery scheduling process a cost function is used. The process starts with determining the initial number of deliveries. Then the target workload per period is defined and finally the item selection algorithm is applied, which determines the order quantities per item. In every iteration a new target workload will be defined and the iterating process stops if the costs per store are minimized and the constraints are met.

How to determine the order quantities per item?

For determining the order quantities per item a new approach was developed. This new approach advances orders from peaks to non-peaks without excluding delivery moments per item. An item selection algorithm was developed and this algorithm selects items for order advancement and determines new reorder levels per selected item. The algorithm stops when the target volume is obtained or when there is no more smoothing volume available.

What is the effect of fluctuations in the utilization degree per RC?

From the sensitivity analysis about the stacking efficiency of RC’s it is concluded that improving and stabilizing the load per RC is required and could lead to large cost saving for transportation. If the RC’s of all stores are stacked as efficient as for store 1200 the total delivery volume in truckloads will reduce by 10.5%. The potential reduction in the delivery volume will increase the probability that delivery volumes can be bundled, which reduces the transportation costs per CU. In addition, to reduce the risk of unscheduled extra deliveries it is required to obtain a more constant load per RC.

7.2 Performance improvement

In this thesis a design is presented that provides a new approach for order and delivery scheduling. With order advancement, a new principle is provided to make cost-efficient and integrated planning decisions and it could contribute to structure political discussions between different logistical subsystems. Moreover, by order advancement without excluding delivery moments for specific items, the responsiveness on deviations in consumer demand will improve and the availability level can increase.
The performance improvement differs per logistical subsystem and per store. For stores with a maximum weekly demand level of six truckloads the cost savings in transportation are expected to be 12.2%. Due to the reduction in the number of stops by 34.0% the transportation planning will become less complicated. After applying order advancement to all stores the peak workload in the DC and transportation will reduce from 1.7 to 1.18 times the non-peak workload. The level of workload smoothing differs significantly per store.

7.3 Academic Relevance

From the literature review (Kuijvenhoven, 2015) was concluded that there is a lack of research about an integrative approach to determine the delivery quantities and the store delivery patterns by taking into account stochastic and seasonal demand, the relevant costs for transportation, as well as the stores and the DC. Sternbeck and Kuhn (2014) were the first authors that came closest to an integrative order and delivery scheduling approach. Compared to this most recent research, this research came up with several improvements

- No delivery moments are excluded to advance orders and it thereby increases the responsiveness on fluctuations in consumer demand.
- Promotions, perishables and non-perishables are all taken into account, which provides a more realistic view of the potential cost savings of order advancement.
- The new system cares more about product availability and instore labour requirements and thereby improves the alignment between the incentives of store managers and the ASO-system.

7.4 Recommendations for future research

The recommendations for future research can be obtained from the limitations of the design. The recommendations for future research are summarized below.

- For items under promotions only the target workload pattern per store is determined in the order and delivery scheduling process. This means that for reaching the workload a more detailed replenishment policy must be defined.
- Include inventory routing and bundling truckload across stores. For a further reduction of the supply chain costs, the order and delivery scheduling process should be extended with inventory routing. Including inventory routing will affect the delivery costs per store and could affect the level of order advancement that should be obtained.
- In the order advancement algorithm a minimum advancement quantity (MAQ) of 0.1 CU is used. The effect of different values for the MAQ on the actual level of advancement is not analyzed. The higher the MAQ, the more accurate the order pattern can be forecasted. On the other hand it could reduce the available smoothing volume. Future research should analyze the effect of different values of the MAQ.
- For a more accurate approximation of the effect on order advancement in terms of costs, more cost drivers should be defined. (e.g. number of case packs and order lines).
- A reduction in the number of order lines will reduce the handling costs in both the stores and the DC. The number of order lines can be reduced by advancing orders from multiple peak days and smooth them together towards a non-peak day for example, but it require an adjustment of the item selection algorithm.
7.5 Recommendations for Jan Linders Supermarkten B.V.

In this thesis several recommendations are provided for Jan Linders and these are summarized below;

- Bundle perishable and non-perishables per store delivery to obtain significant cost savings. Those are currently delivered separately and lead to a large number of stops.
- Implement the order advancing algorithm and replace the current order and delivery schedule to reduce the complexity of managing the supply chain.
- Improve the stacking efficiency of RC's to reduce the transportation costs significantly.
- Improve the accuracy of the shelf capacity data in the ASO-system to prevent an unexpected high level of backroom inventory.
- Improve the alignment between truck arrival times and shelf stacking times to prevent an unexpected low availability level or unnecessary inventories in the backroom.
- Investigate the possibilities for starting the discount period after a non-peak period to reduce the promotional delivery volume during the peak period.
- Reduce the inventory build-up at the start of the discount period, because the current inventory build-up of 96% is more than the required 40%.
- Investigate the store and the DC preferences to determine the exact loading and unloading time windows, because the available workforce and the wage levels could deviate during the day and during the week.
- Improve the definition of the utilization degree for trucks by including the total driving distance as parameter for a more representative performance indicator for transportation.
Bibliography


Appendices

Appendix A; Order advancement and out-of-stocks

Table 6 – Order advancement and out-of-stocks 12-01-2015 till 22-02-2015

<table>
<thead>
<tr>
<th>% turnover</th>
<th>Fresh</th>
<th>Dry Grocery</th>
<th>F&amp;V (cutted)</th>
<th>Fresh meat</th>
<th>Fresh meat (sliced)</th>
<th>Frozen food</th>
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</thead>
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<td>3,0</td>
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<td>4,3</td>
<td>76</td>
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<td>% adjusted order lines</td>
<td>7,6</td>
<td>6,4</td>
<td>15,8</td>
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<td>18,6</td>
<td>4,4</td>
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<td>% out-of-stocks</td>
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<td>98,9</td>
<td>92,8</td>
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Appendix B; Current weekly order and delivery schedule

Table 7 – Small part of the current weekly order and delivery schedule of one store

<table>
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<tr>
<th>Segment</th>
<th>Ordering day</th>
<th>Time</th>
<th>Delivery day</th>
<th>Time</th>
<th>Shelf stacking day</th>
<th>Time</th>
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<td>Vr</td>
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<td>Vr</td>
<td>1600</td>
<td>Vr</td>
<td>2100</td>
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<td>FNF Blauw VVV</td>
<td>Vr</td>
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<td>Vr</td>
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<td>Vr</td>
<td>1600</td>
<td>Vr</td>
<td>2100</td>
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<td>1600</td>
<td>Za</td>
<td>1800</td>
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<td>FNF LB2 VVV</td>
<td>Vr</td>
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<td>Vr</td>
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<td>Za</td>
<td>1800</td>
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<td>1600</td>
<td>Vr</td>
<td>2100</td>
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<td>1600</td>
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<td>1800</td>
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<td>1700</td>
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<td>0830</td>
<td>Di</td>
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<td>1800</td>
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<td>2030</td>
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<td>1400</td>
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<tr>
<td>Vers Geel VVO</td>
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<td>1130</td>
<td>Di</td>
<td>0600</td>
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<td>1400</td>
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<td>Etc.</td>
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<td>……</td>
<td>……</td>
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## Appendix C: Analysis deviations (non-) promotional weekly demand

### Total demand

#### Test of Homogeneity of Variances

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<thead>
<tr>
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<th>df1</th>
<th>df2</th>
<th>Sig.</th>
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#### ANOVA

<table>
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<td>51950,114</td>
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<td>5772,235</td>
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<tr>
<td>Within Groups</td>
<td>957949327,655</td>
<td>113671</td>
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<td>Total</td>
<td>958001277,769</td>
<td>113680</td>
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### Non-promotional demand

#### Test of Homogeneity of Variances

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<td>0.480</td>
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<td>Within Groups</td>
<td>527512424,223</td>
<td>107042</td>
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<tr>
<td>Total</td>
<td>527527802,422</td>
<td>107051</td>
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### Promotional demand

#### Test of Homogeneity of Variances

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<td>Within Groups</td>
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<tr>
<td>Total</td>
<td>397846843,229</td>
<td>6653</td>
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#### Robust Tests of Equality of Means

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<th>Statistic</th>
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<tr>
<td>Welch</td>
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<td>Brown-Forsythe</td>
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a. Asymptotically F distributed.
Appendix D; Demand in CU’s per store

Figure 24 – Demand level per store as a percentage of the total weekly demand for Jan Linders.
Appendix E; Relationship between mean and standard deviation

Example of the results of regression analysis for the relation between mean and standard deviation on Friday

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>Durbin-Watson</th>
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<td>.936</td>
<td>.876</td>
<td>.876</td>
<td>.28482</td>
<td>1.654</td>
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a. Predictors: (Constant), ln(mean(Friday))
b. Dependent Variable: ln(stdev(Friday))

Coefficients

<table>
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<tr>
<th>Model</th>
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<th>Standardized Coefficients</th>
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<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
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<tr>
<td>1</td>
<td>(Constant)</td>
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<td>.004</td>
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<td></td>
<td>ln(σ)</td>
<td>.545</td>
<td>.003</td>
<td>.936</td>
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a. Dependent Variable: ln(stdev(Friday))

Regression results for all days

Table 8 – Results regression analysis for relationship between mean and standard deviation

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<tr>
<th></th>
<th>R square</th>
<th>ln(σ)</th>
<th>ln(μ)</th>
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<tr>
<td>Monday</td>
<td>0.885</td>
<td>0.117</td>
<td>0.555</td>
</tr>
<tr>
<td>Tuesday</td>
<td>0.886</td>
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<td>0.553</td>
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<tr>
<td>Wednesday</td>
<td>0.882</td>
<td>0.118</td>
<td>0.554</td>
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<td>Thursday</td>
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<td>0.544</td>
</tr>
<tr>
<td>Friday</td>
<td>0.876</td>
<td>0.104</td>
<td>0.545</td>
</tr>
<tr>
<td>Saturday</td>
<td>0.878</td>
<td>0.101</td>
<td>0.543</td>
</tr>
<tr>
<td>Sunday</td>
<td>0.879</td>
<td>0.136</td>
<td>0.561</td>
</tr>
</tbody>
</table>
Appendix F; Accuracy of the shelf capacity data

![Regression analysis between the measured shelf capacity and the ASO-system data](image)

Figure 25 – Regression analysis between the measured shelf capacity and the ASO-system data

Appendix G; Relative stacking efficiency of RC’s

In figure 26 the relative shelf stacking efficiency is compared with store 1200 (100%). The store with a value of 130% is unrealistically high and therefore an outlier.

![Stacking efficiency per store, relative to store 1200.](image)

Figure 26 - Stacking efficiency per store, relative to store 1200.