MASTER

Improving freshness
the effects of week patterns and opening terms on outdating at Albert Heijn

Weteling, R.V.

Award date:
2013

Improving Freshness

The effects of week patterns and opening terms on outdating at Albert Heijn

Weteling, R.V.
March 2013

Supervisors

Dr. K.H. van Donselaar | assistant professor at Eindhoven University of Technology
Dr. R.A.C.M. Broekmeulen | assistant professor at Eindhoven University of Technology
M. Biesheuvel | manager Replenishment at Ahold
H. Kevenaar | specialist Replenishment Preparation Albert Heijn at Ahold

Keywords: Food-retailer, Retail, Retailers, Perishables, Opening, Supermarket, Grocery, Inventory, Holiday

Project

Time: September 2012 to March 2013
Field: Operations Planning in Retail
Topic: Perishable Goods
Research: Improving freshness – The impact of opening terms on outdating at Albert Heijn

ACKNOWLEDGEMENTS

After my mentor application with Karel van Donselaar I was lucky that he was willing to guide me through my master and master thesis. Although I guess that the collaboration was slightly unfamiliar at first, he was very supportive from the start.

After a guest lecture by an alumnus of the studies, I wanted to have a shot at graduating within Ahold. During spring 2012 I had the first meeting with Marco Biesheuvel in an attempt to provide myself with a graduation project. From the first meeting on Marco was open for this opportunity and immediately provided me with personal feedback. In this process he explicitly focussed on my personal development for which I am very grateful, immediately translating into defining my own research project. So even without any explicit ideas, except for a research within perishable goods, I was welcome.

Soon Hugo Kevenaar joined the supervising team, as he would be my mentor on a more frequent basis. Weekly meetings and daily informal discussions, as well as arranging any practicalities like appointments, e-mail, and authorizations within Ahold made Hugo irreplaceable in reaching my goals. Clear analysis of my work guided me forward and when I felt I did not move on, he provided means to keep on going.

When finally in December my project plan was defined, Rob Broekmeulen became the second supervisor from Eindhoven University of Technology. Immediately offering help with the simulations, which in the end was necessary, illustrates his involvement with the project.

I would like to take this opportunity to thank both Marco and Karel for the opportunity of defining the project from start to finish, and guiding me through this process. Identifying subjects, prioritizing, deciding and executing made the process challenging from the start, as it was unclear what the end would be. Next to this, I would like to thank Karel for his time, flexibility, and feedback on content. I would like to thank Marco for all his personal guidance and providing not only the opportunity to graduate at the largest retailer of the Netherlands, but also applying for a job there (even though the outcome still is unknown). Hugo was the supervisor most close as I spoke to him no a daily basis, and I would like to thank him for his clear feedback, flexibility, and involvement. Finally I am very grateful for the help Rob gave me, especially after simulations needed to be redone. Not only did it save time and work, but I could also easily speak with him about results and he provided results of different designs before I could ask.

This thesis is not only the finalization of a graduation project, but of completing my entire studies. For that I would like to thank my friends for making my time as a student the best time ever and Marloes for her support throughout the years, and especially the last year. However, I could not have done this without my parents who supported me the entire 6.5 years, not in the least by financial means. The freedom they gave me to make the best of these years was the best support I could get.

Rob Weteling

ABSTRACT

This master thesis reviews the main effects of the number of days per week a grocery store is opened and the week pattern in demand on outdating. The context for this is not only Sunday opening, but also event based closure like Christmas and Eastern. The research was executed at Albert Heijn, the largest supermarket chain in the Netherlands.

Using a regression method and simulation of order methods of both EWA and Albert Heijn the effects of days open and week pattern on outdating were looked into. Apart from this, both methods provided leads to manage outdating in general. The regression model included not only the main effects that were under consideration, but tried to identify the effects on outdating of many variables. Similarly, the simulation showed the effect of not only week pattern and days open, but also several opportunities of improvement.

Keywords: Food-retailer, Retail, Retailers, Perishables, Opening, Supermarket, Grocery, Inventory, Holiday

MANAGEMENT SUMMARY

This master thesis reviews the main effects of the number of days per week a grocery store is opened and the week pattern in demand on outdating. The research was executed at Albert Heijn, the largest supermarket chain in the Netherlands.

From both literature and practice, the general interest in perishable goods is a hot topic. Literature has addressed this topic for many years, but still questions remain like the relationship between promotions and outdating of perishable goods. Practice has the interest of decreasing waste, both from a financial point of view and corporate social responsibility.

The main concern is of the effect of the number of days open and the demand pattern within the week on outdating. From theory especially the week pattern was of interest, as several researchers identify a pattern in demand during a single week without actually addressing its effect on outdating. For practice, the 2013 change in Dutch law on opening stores on Sunday makes this a topic of renewed interest. Apart from that, opening stores on holidays like Christmas and the effects of this, is also of interest

This research especially looked into the following aspects:

- The effect of the amount of days per week opened;
- The effect of week pattern on outdating;
- Opportunities to manage outdating, especially
    - The effect of replenishments on outdating;
    - The effect of case pack size on outdating.

The results identified that the amount of days per week opened and the week pattern had little to no effect on outdating. However several opportunities were identified. Several steps were taken to obtain these results.

Using a regression model these hypothesized effects were first tested on existence. The regression showed that they do, and special attention in managing perishable goods should go to the relative order quantity (order quantity divided by average demand during shelf life), as this factor is of major influence on outdating. Second, promotions showed to have large effect on outdating, not only promotions in the week outdating occurred, but especially promotions in the week before.

The week pattern and number of days open, showed small effects, whereas the replenishment interval can be used to manage outdating although the way to do so was unclear. The target availability showed to have an effect. Several product characteristics, like average demand and variance, but also shelf life and category showed to have effect, and retailers should identify products of high risk. Products with low demand and small shelf life are generally more sensitive to outdating.

Next a simulation was executed to see the precise effects on outdating of the proposed mechanisms, by keeping other factors constant. Also several ideas for improvement were proposed and tested. Outdating was indeed affected by the proposed factors, and again a major effect came from the order quantity. The effects were tested using a

theoretical order model (EWA) and the model from Albert Heijn. The following statements are merely based on the EWA results as the Albert Heijn model did not always provide the intended consistence between the other tested parameters.

When the store was seven days a week opened, similar outdating was found compared to six days open. The week pattern showed diverse effects, but and the precise effect was unclear. Product characteristics like average demand and variance in demand are highly related to outdating. The replenishment interval showed to influence outdating as well, but what the optimal interval is was unclear. However, it was clear that when a store is closed on Sunday it can be beneficial to still deliver on that day.

A remarkable finding was that the above did not differ among shelf lives for the AH model, but did for the EWA model. Although the outdating fractions itself did not have a clear result, the other effects were similar across shelf lives. These products differing in shelf life, did differ in outdating patterns within the week, as the largest outdating percentages were found on different days. However, this was all related, as this day was VT days after Friday (evening), where VT stands for shelf life (verkooptermijn).

Opportunities of improvement were also tested. First of all: adding a single day of shelf life at some moment in the week. As products might stay in the DC for several days, there is an opportunity to distribute products with longer shelf lives than they normally have. It was tested to overcome the Sunday outdating, by adding one day of shelf life. I.e., products that would normally expire on Sunday, now had until Monday to be sold. This resulted in similar to better performance.

The other opportunity of improvement was to order on a later time, without delivering later. I.e. when a store is closed on Sunday, on may order on Saturday evening instead of noon, and still get products delivered on Monday morning. Also for this, similar to worse performance was the result.

Both opportunities of improvement might have been tested on the wrong day, as the outdating pattern within the week showed that the opportunity of improvement lies with the Saturday deliveries.

In general, it seems that, if possible, Sunday opening will have less outdating, but Sunday delivery provides better results. Moreover, opportunities for improvement should be found in the order quantities, the promotional periods (and the week after) and the deliveries. Especially the Friday delivery should be of concern, as these products result in the largest outdating percentages.

CONTENTS

TABLES

FIGURES

DEFINITIONS AND ABBREVIATIONS

To support the reader in translating abbreviations and terms in the text throughout the document, the several definitions and abbreviations are listed below.

	AH	Albert Heijn	Page 1
	AHXL	Albert Heijn XL	Page 18
	DNAH	Albert Heijn store type 'De nieuwe AH'	Page 19
	TU/e	Eindhoven University of Technology	Page 2
	OPAC	TU/e group researching Operations Planning, Accounting, and Control	Page 2
	IS	TU/e group researching Information Systems	Page 2
	HPM	TU/e group researching Human Performance Management	Page 2
	OML	TU/e master program on Operations Management and Logistics	Page 2
Point of Sale	POS	Generally combined with 'data', representing data that is collected at the point of sale, i.e. check-out	Page 3
Out of stock	OOS	Not having inventory during some time	Page 3
On shelf availability	OSA	A fraction denoting the availability of a product	Page 3
Fill rate	P2	A fraction denoting the percentage of demand that was fulfilled	Page 3
Genuanceerde beschikbaarheid	NB	OOS-measurement of Albert Heijn: percentage of consumers that did not have the option of buying a product, despite their intention of buying	Page 4
Winkelbeeld	WB	Store image, measurement of Albert Heijn: Percentage of products in store that have enough products in stock one hour before delivery to fill all facings	Page 4
First-in-first-out	FIFO	Withdrawal order where the oldest product (first in) is used first (first out)	Page 5
Last-in-first-out	LIFO	Withdrawal order where the newest product	Page 5

		(last in) is used first (first out)	
Distribution center	DC	Location where the manufacturer delivers its products to, these products are temporarily stored and then distributed to stores.	Page 7
Vendor managed inventory	VMI	A comaker is a supplier that has the same sales information as AH and uses this information to replenish, instead of AH placing orders. In more general terms, vendor managed inventory is used.	Page 7
Regional distribution center	RDC	Albert Heijn has regional distribution centers that distribute most products. Some products come from a central location.	Page 16
Landelijk vers centrum	LVC	Some fresh products are distributed from a central location to the stores. This is the ‘landelijk vers centrum’.	Page 16
Stock keeping unit	SKU	A product that is different than another in product characteristics (semi-skimmed milk vs. skimmed milk) or packaging (1L vs. 2.5L).	Page 14

1. INTRODUCTION

This first chapter is used to pose the context of the research, by discussing the several stakeholders and how their interests intersect. The remainder of this thesis first discusses the background of the research, including relevant questions from literature and practice. Then the specific topic and the related research design are set. Next the several research methods used are discussed, including their setup and results. The final chapter returns to the research question, discussing the answers found. On the previous pages (VII and VIII) a list of abbreviations and definitions is found.

1.1 | ALBERT HEIJN

The author chose to perform his master thesis within the company of Albert Heijn (AH), largest supermarket chain of the Netherlands ("AH blijft grootste van allemaal ," 2012, "Supermarkten in Nederland," 2011) and the largest subsidiary owned by the holding company Ahold, the largest Dutch retailer ("Ahold verreweg grootste retailer," 2003, "Slechts 4 Nederlandse bedrijven in de top 250 van grooste wereldwijd opererende retailers," 2010). The collaboration of TU/e and AH within this research project was established after a guest teacher of Albert Heijn taught in the Retail Operations course[1].

The thesis will be executed at the Replenishment Preparation department of AH which is in charge of enabling to keep track of replenishment and inventory of the supermarkets, shaping the automated ordering system, and adjusting this ordering system if necessary. Replenishment Preparation is constantly improving the automated ordering by identifying new actors and relationships that are involved in predicting sales, by altering general parameters into parameters for subgroups and adding parameters to the system, in order to obtain as much availability with the least costs. Replenishment Preparation identifies a triangle to control this replenishment trade-off, which is illustrated in Figure 1. Keeping inventory will allow for high availability but also includes high costs. By accurate forecasting, the safety stock can be decreased, leading to less inventory and less outdating. Responsiveness prepares AH to react on unforeseen events and allows for less inventory as well (more deliveries implies that less stock is needed at the time, as this stock needs to overcome a smaller period in time where demand occurs).

[1] Retail Operations course (1CM40) as taught during the fall of 2011 at TU/e.

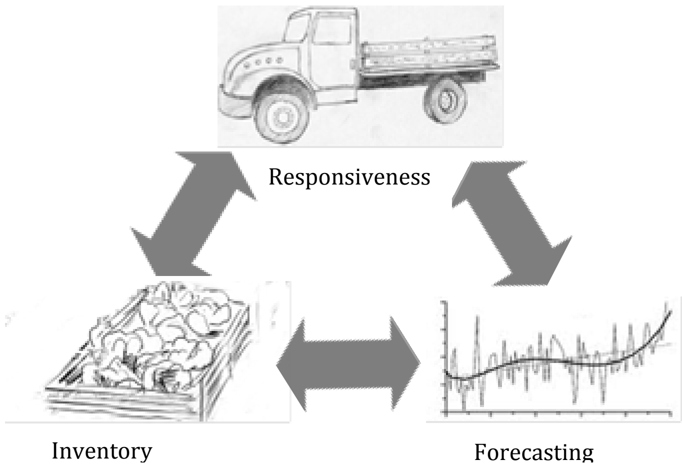


Figure 1 | Illustration of triangle of effects to ensure availability, as defined by Replenishment

It is to the projects interest to identify a project that can fit within this context so AH will be more experienced with the subject, and the outcome can be of value for this retailer.

1.2 | TU/e

The project will be conducted in light of the master program Operations Management & Logistics (OML) at Eindhoven University of Technology (TU/e). This is a 120 ECTS (two years) program focussed on managing operations in a business environment from different points of view. These views are based in the four research groups of the school of Industrial Engineering, where OML focuses on Human Performance Management (HPM), Informations Systems (IS), and Operations Planning, Accounting, and Control (OPAC). The first tries to improve performance by using the main resource of the business: people. The second focuses more on modelling business processes from an IT point of view, redesigning this and simulating the changes. The last research group addresses business processes by mathematical modelling of accounting, and production- and transportation processes.

The master program is completed by a master thesis of 30 ECTS, which can be conducted within the university or in collaboration with a company. The thesis is a research associated with the interests of all parties involved, the student, the company (if applicable) and the mentor, and in this case this is associated with the OPAC group. The research should be scientifically relevant and therefore a balance between business interest and scientific generality should be obtained.

1.3 | Match

Replenish is defined as ‘to fill or build up again <*replenished* his glass>’(“Replenishment,” n.d.), whereas logistics is defined as ‘the handling of the details of an operation’, or in more detail (in military context) ‘the aspect of dealing with the procurement, maintenance, and transportation’(“Logistics,” n.d.). Hence we see that logistics enables the operations of replenishment. Both the master OML, and the research group OPAC, explicitly identify themselves as specialized in Logistics and Operations. In more detail, the replenishment in retail is one of the subjects of interest, and here we find a perfect match between TU/e and AH. Identifying models and relationships, as well as the related parameters to control the operation processes is of interest to both parties. Moreover, TU/e, and especially the department of Industrial Engineering, always tries to handle challenges from practice. Hence we can conclude that the collaboration in this project is a perfect match.

As supervisors, Eindhoven University of Technology is represented by dr. Karel van Donselaar and dr. Rob Broekmeulen. They both have expertise in Operations Planning, Accounting and Control, with a focus on Retail operations. Inventory management, outdating products, store handling and warehouse planning are part of their expertise in research. Ahold will be represented by Marco Biesheuvel, manager Repelenishment, and Hugo Kevenaar, specialist Replenishment preparation, who both have expertise in forecasting demand, adjusting the forecast on a day-to-day basis to meet unforeseen circumstances, and the planning of replenishment in general.

2. BACKGROUND AND LEADS

The second chapter discusses the background of the research by reviewing literature on inventory management (2.1) and perishable items (2.2). After combining the two in section 2.3, the scientific context (2.4) and practical context (2.5) are discussed, which will lead to several opportunities of research (sections 2.6 and 2.7).

2.1 | INVENTORY MANAGEMENT

Grocery stores all over the world are trying to satisfy the demand of the customer on household products. They want to maximize sales, with the trade-off of stock-keeping (Nahmias, 1982). Hansen & Heinsbroek (1979, p. 1) put it differently: "If the customer doesn't see a certain product he can't buy it, and if the customer sees a certain product he may buy it." This results in keeping out-of-stock (OOS) rates as low as possible, as the only way to make a business is to offer the product at any time. Out of stock is simply not having stock, and can be measured and defined in several ways. The main distinctions are types of measurement (e.g. physically or point-of-sale (POS) data) and distinctions in what is actually counted (e.g. instances, units sales or value of sales)(Gruen & Corsten, 2007). Two variants will be highlighted, that distinct in emphasis: on-shelf availability, focussing on providing the opportunity of sale to the customer, and fill rate, emphasizing on the fulfilled demand.

The fill rate equals the fraction of customer demand that is met routinely (K. H. Van Donselaar & Broekmeulen, 2011, Silver, Pyke, & Peterson, 1998, Van Woensel, Van Donselaar, Broekmeulen, & Fransoo, 2007). A different approach is the on-shelf availability (OSA) measure, which is defined by Kent, Kent, & Omar (2003, p. 444) as "having goods that are on the shelf and ready for selection and purchase by the consumer." Formulating this as a fraction leads to the fraction of consumers being able to buy the product as at least one was on shelf, although this is not widely supported in literature; the fraction of time is also used instead of fraction of customers (Gruen & Corsten, 2007). Do note that this is different from the Customer Impact Rate that Gruen & Corsten (2007) define, which is similar to the fill rate as it relates to the expected sales. The difference between the two measures is that the fill rate takes the perspective of missed demand, whereas OSA takes the perspective of not available stock for any customer. As not every customer will have demand, the measures probably have a different result, except if the amount of demand, both missed and total, are equal to the amount of customers, both the customers seeing empty shelves and the total amount of customers.

$$fill\ rate = \frac{fullfilled\ demand}{fullfilled\ demand + missed\ demand} = 1 - \frac{missed\ demand}{total\ demand}$$

$$OSA = 1 - \frac{consumers\ not\ seeing\ the\ product}{total\ of\ consumers\ that\ visited\ the\ store}$$

Within Albert Heijn OOS is defined as the percentage of customers of an individual store that found at least one item of a particular product on shelf (irrespectively of the consumer's intention of actually purchasing the item). Albert Heijn thus uses the OSA measure as defined by Kent et al. (2003), although Ettouzani, Yates, & Mena (2012) claim this cannot be done as the inventory records will not provide information about the specific location of the product in store. The records of AH do include this information as every product arriving in store is immediately shelved – this is the policy and must be act upon due to lack of storage space and the policy overcomes a major cause of OOS (Gruen & Corsten, 2007) – and any sales are subtracted using real time point-of-sale data. A limitation is that products that are delivered but are still in the process of being shelved, or products that are taken from shelf but not yet paid for, are not incorporated (hence there is a slight delay in information). Another limitation is of data accuracy of the point of sale data (Gruen & Corsten, 2007) (for example due to theft) but this is manually checked from time to time (empty shelves are always checked and will be replenished the next day). Despite its limitations, the solution of Albert Heijn seems to counterfeit the argument of Ettouzani et al. (2012).

Apart from this measurement, Albert Heijn also has another measurement concerning inventory management, called store image (´winkelbeeld´, WB). AH defines this as *the percentage of products in a particular store that have enough stock to fill every facing one hour before replenishment*. Next to the same limitations as their OSA measurement, this measurement has the assumption that a product with multiple facings and still carrying enough inventory to meet the requirement, will have an item actually placed on every facing. I.e. a product with two facings should have at least two products and these should be placed next to each other instead of behind each other. It is the store's responsibility to ensure this latter, as that information is not available in the data system.

This measurement does not seem to return in literature as such, however Bloemer & De Ruyter (1998) do mention some kind of store image, they define as "the complex of a consumer's perceptions of a store on different (salient) attributes" (Bloemer & De Ruyter, 1998, p. 3). Within this complex they also include service, assortment and store atmosphere, which can be derived towards the aim of Albert Heijn: ensuring a good looking store by keeping enough inventory for every single facing. Also Baker, Grewal, & Parasuraman (1994) acknowledge that there is some kind of store image, referring to some kind of atmosphere within store. As the store image concept is not widely found in literature, this will not be elucidated later on in the research.

Both the concept of OSA and store image are measures for Albert Heijn to identify performance. Both are based on the inventory level, where the first is continuously monitored and is a strict performance measurement as it will be directly related to not being able to fulfil demand. Store image is periodically reviewed (an hour before replenishment) as either having a fraction of shelf filled (enough to fill all facings of the product) or not and is therefore not directly related to order fulfilment (i.e. orders can be fulfilled without achieving WB). OOS can be prevented by keeping safety stock to cope with fluctuating demand. The store image will even increase this safety stock for goods with multiple facings, as not just the one facing needs to be filled, but also the other facings. Note that in practice especially fast movers will have multiple facings, which will lead to large (measured as an absolute) safety stock for OSA already. Both measurements also imply a risk of having too much on shelf, leaving perishable products to expire.

2.2 | A PERISHABLE ITEM

"A perishable item is characterized by its usefulness over a limited period of time, known as 'life.' Once the 'life' is over, these items spoil, which obviously is a loss" (L. M. Chen, 2009, p. 9). As these products have an expected life time, they are labelled with an expiry date, indicating the date until which the product is guaranteed to be consumable, assuming all requirements are met (for instance keeping cool in the refrigerator). An example is dairy produce, like cheese and yoghurt. The expiry date of perishable products makes the inventory management different from managing inventory of non-perishable products, as a specific item can only be sold for a limited amount of time. The trade-off of inventory management is now extended with unsold items that will never gain any returns as the products need to be disposed (L. M. Chen, 2009, K. Van Donselaar, Van Woensel, Broekmeulen, & Fransoo, 2006, Stanger, Wilding, Yates, & Cotton, 2012). Furthermore Van Woensel et al. (2007) and Broekmeulen & Van Donselaar (2009) identify that there is a huge difference in managing perishables and non-perishables and that there is lots to gain for grocery stores. Please note that the actual date that products are not sold anymore, i.e. will be disposed, can differ from the date the products are actually not allowed to use anymore. This is primarily due to difference in definition and experience. Consumers may have a different perspective from the date on the product, then actually intended, resulting in more waste as the products are either not purchased anymore or thrown away too early (Gunders, 2012). This will be discussed in more detail in section 2.4.

For the context of the research it is should be noted that perishable items make up about half of the sales (Ferguson & Ketzenberg, 2005), covering a large share in sales. For Albert Heijn the turnover figures show a similar ratio.

2.3 | INVENTORY MANAGEMENT OF PERISHABLE PRODUCTS

Several extensive literature reviews are found on modelling perishable inventory, of which Nahmias (1982, p. 2) wrote the first, describing the main effects found in literature when managing perishable inventory: "Most inventory models assume that stock items can be stored indefinitely to meet future demands. However, certain types of inventory undergo change in storage so that in time they may become partially or entirely unfit for consumption." An important note he makes is to distinguish between fixed life time products, assuming units may be retained in stock to satisfy demand until a predetermined date on which it must be discarded, and random life time products, for which the exact lifetime cannot be determined in advance (Nahmias, 1982), which was supported by several authors (e.g. Dave (1991), Raafat (1991), and Karaesmen, Scheller-Wolf, & Deniz (2011)). Earlier Nahmias (1975) makes a second distinction: the withdrawal policy is generally modelled as first-in-first-out (FIFO) or last-in-first-out (LIFO), and in real life might even be a combination of the two (Haijema, 2011). In case of the first withdrawal old products will always be demanded prior to the new products, implying less outdated products than in the latter issuing order (Deniz, Scheller-Wolf, & Karaesmen, 2004). However, Haijema (2011) claims that a mixed model will provide the optimal solution due to better timing of outdating.

The second review was the article Raafat (1991) wrote, addressing papers considering the effect of deterioration as a function of the on-hand level of inventory. In contrast with Nahmias (1982), who focused on fixed-life models, he focused on models for continuously deteriorating products, also known as (exponential) decaying products. He also noticed that almost all published models are devoted to single items, and that an important distinction is made between single and multiple periods, separating products that are outdated within the replenishment period (single period) or will survive at least one replenishment cycle. We might consider this as either a product or a supply property. The newsvendor problem is a typical example of a single period problem, as by the end of the day all stock is unusable (Silver et al., 1998).

Another large review was conducted by Goyal & Giri (2001), who added another major distinction to the classification. The (deterministic) demand could be classified in uniform, time-varying, stock-dependent, and price-dependent demand. Although deterministic demand might not be most realistic, these four distinctions do lead to relevant factors in analysing issuing and withdrawal of (deteriorating) products. This might be allocated to the consumers' behaviour.

2.4 | Scientific context

The first sections of this chapter described general background on the topic of interest and some high-level findings. However, literature provides more interesting ideas that should be taken into account when looking into managing perishable goods.

The aspect of goods perishing results in a worse (perceived) state of quality of the product and leads to a disadvantage compared to fresher products with respect to sales probability. However, it seems that this sales probability can be actively influenced by providing discounts to the customer, leading to either an advantage for the nearly expired product, or an increase in sales overall. Consumer behavior in general seems to be actively influenced by promotional activities (Nijs, Dekimpe, Steenkamp, & Hanssens, 2001). Not only have the promotional activities caught the consumers' attention, but also the expiry date. Several researches suggest that the consumer is unaware of the actual meaning of the date printed on the product and interprets all as the date from which on the product may not be used anymore (Gunders, 2012, Soethoudt, van der Sluis, Waarts, & Tromp, 2012), which will affect withdrawal.

2.5 | Practical context

Perishable goods fulfill a major part in daily grocery sales and, as explained earlier, have the risk of outdating. It seems that half of the turnover made each day is due to sales of perishable items, thus perishable items add sufficient value to the retailer to be of interest for improving inventory management. Besides that, the costs of loss provide an opportunity for the retailer in general.

In general, the last few decades the consumers started focusing on food which is not only healthier for himself, but also for the environment. Waste reduction in any way is more and more of interest for the general public and with respect to corporate social responsibility, a retailer should care. It is both an opportunity and a must to be aware of the impact of waste (of perishable goods)(Gunders, 2012, "Voedselverspilling," 2012).

Week after week, consumers visit the grocery store to buy their daily needs, resulting in quite some predictability in behavior. As explained earlier, uncertainty is affected by promotional efforts, but the large amount of experience fed improvement of supply chain management. However there are exceptions which seem to be hard to cope with. From January 2013 on, the Dutch government has decentralized the choice of Sunday opening ("Koopzondagen en avondopenstelling," 2012), which may affect restrictions Albert Heijn copes with. There are few cases that are excluded from this: Christmas day, Eastern and few other holidays. In both the case of the regular Sunday and of holidays, an interruption in sales (opportunity) occurs, of which the results of any changes are unknown. Or the other way around: the regular sales pattern is interrupted and we are currently unaware of the impact of this interruption, as well as any changes in this interruption (e.g. Sunday opening).

2.6 | Questions from literature

As proposed in the previous section, literature provides several leads to interesting research topics. From an integral supply chain perspective the information exchange and the use of new technologies can be interesting, as well as extending the amount of case studies looking into shortening the supply chain. An extended list of project ideas is accompanied in Appendix B.

On the other hand, when the product leaves the supply chain, it ends up at the consumer. We already discussed that consumers do not always behave as intended or predicted. In line with this opportunity it is interesting to look at how perishability is perceived (what is freshness and how do consumers interpret expiry dates?), how choice and demand can be modelled (especially the effect of the discount for nearly expired products), and diversity amongst shelf lives on out of stock behaviour by consumers. Finally the patterns in consumer demand across the week that are observed still need to be explained.

The effects occurring at the retailer also still provide enough leads, as different ways of discounting nearly expired products can be subject of interest, as well as the effect of outdating right after promotion. The shelving process and especially the lay-out of the shelves are opportunities for research.

2.7 | Questions from practice

Within Albert Heijn some questions concerning goods supply arose, especially what the effect of *comaking* is (i.e. the manufacturer is in charge of stock keeping at the distribution center (DC) instead of the DC itself; vendor managed inventory (VMI)) and how (relative) order quantities affect outdating.

The concept *fresh* is thought not to have a one-on-one relation to *remaining shelf life*, since longer or shorter shelf life does not necessarily make a product fresher. This somewhat vague concept is hard to measure and the first question would be "What is freshness?" But how will this concept affect sales? How fresh are products? Where in the supply chain do fresh products lose freshness?

Assortment and promotion are expected to influence outdating of goods in store, and retailers question how such decisions are made and should be made.

Finally, the development within the Netherlands that from 2013 on the rules on Sunday opening are less strict (instead of governmental regulations local regulations, ("Koopzondagen en avondopenstelling," 2012)) is a major point of interest and resulted in several questions. What will the effects of opening the stores be on outdating and how will the week pattern fit into this? This effect can also be projected on holiday periods like Christmas and Eastern where the regular sales week will be interrupted by a day of closed stores.

3. RESEARCH DESIGN

Chapter three aims at describing in more detail the research topic and how answers to related questions are will be obtained. First the topic will be elucidated in section 3.1, followed by some research support in 3.2. Then specific questions are set (3.3) with hypotheses (3.4), followed by the design of experiments (3.5). The chapter ends with a summary of the above.

3.1 | TOPIC

From the prior questions in sections 2.6 and 2.7 the following project was proposed:

> HOW WILL DIFFERENT OPENING TIMES OF GROCERY STORES AFFECT THE OUTDATING OF PERISHABLE GOODS AND HOW CAN THIS EFFECT BE ACTIVELY MANAGED?

Not able to provide a one-on-one relationship, the effect of opening times is not expected to directly influence outdating. Instead some mechanisms in between are expected, as shown in Figure 2.

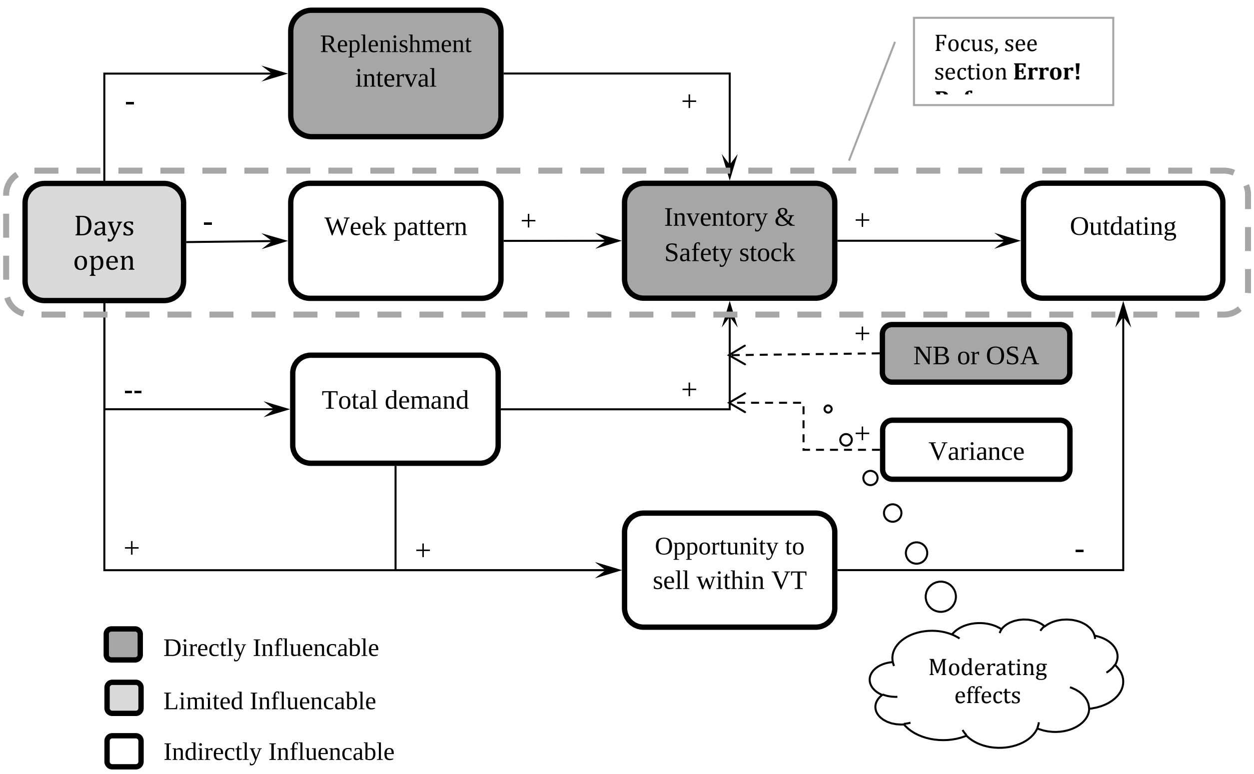


Figure 2 | Expected mechanisms connecting opening times to outdating

The definitions of the mechanisms are as follows:

- Days open identifies the amount of days per week the store is opened, ranging from 0 to 7 in integers (in reality primarily 6 or 7 days);
- Replenishment interval is the average time between two subsequent deliveries in days and is thus calculated by dividing the amount of days opened by the amount of deliveries per week;
- Week pattern is the ratio between average sales per day at the end of the week (= Friday, Saturday) and the beginning of the week (= Monday through Thursday);
- Total demand is the total demand per week;
- Inventory & Safety stock is the amount of consumer units of a particular item that is held on shelf in store;
- Opportunity to sell within VT is the opportunity to sell within shelf life, which is derived from several mechanisms. A slow moving product has less chance of being able to be sold before it expires, than a fast moving product. Moreover a product with a shelf life of 4 that is delivered in a store that is opened 7 days a week, always has 4 days to be sold. If it is delivered to a 6 days opened store, it may occur that the product has only 3 days to be sold (e.g. on Friday, Saturday, and Monday considering the store is closed on Sunday and the product is delivered right before opening on Friday). As this mechanism is excluded from the remaining analysis, an exact definition is omitted.
- NB or OSA is the on shelf availability;
- Variance is the variance in demand;
- Outdating is the amount of products expiring divided by average demand.

It is proposed that both week pattern and demand are influenced by the number of days a store is opened (Keuchenius, Cohen, L. Fedorova, Van Hinte, & Jakobs, 2009). AH deducts its inventory levels and the related safety stock from several actors and we see that these levels are (obviously) primarily influenced by demand per day. Moreover it is influenced by the replenishment as the inventory should be enough to serve demand up to the next replenishment. It is easy to imagine that the amount of days open might influence these replenishments; closing the store provides less opportunity to replenish, but opening the store an extra day does not automatically mean it will be replenished on that day (e.g. Sunday opened stores are rarely replenished). From the model we see high relation between inventory characteristics (safety stock, order-up-to level, etc.) and outdating which was already shown by K. H. Van Donselaar & Broekmeulen (2012). The factor of opportunity to sell within shelf life is deduced from the idea that older products have less probability of being bought (Nahmias, 1982) and the opportunity of sale will decrease over time. However, when shelf life is relatively long, this day of closure might only slightly distinguish products while short shelf life could make a large difference (i.e. when remaining shelf life is 63 versus 65 days, having 54 versus 56 days of sales respectively, will have less effect than when shelf life is 3 or 4 and sales days are 2 or 3 respectively). The week pattern is chosen in the current definition, to enhance effects, whereas Kahn & Schmittlein (1989) poses more smoothed increase of demand during the week.

3.2 | RESEARCH SUPPORT

Several factors support this project. First of all there is a scientific gap; in several articles there is spoken of non-stationary demand (e.g. K. H. Van Donselaar & Broekmeulen (2011), Ferguson & Ketzenberg (2005), and Goyal & Giri (2001), Matsa (2011)), but no-one ever seems to identify what the precise effect of non-stationary on outdating is. Seasonal demands are explicitly researched (e.g. Taylor (2007) and F. Chen & Ou (2009)), but although it is recognized by researchers, this intra-week seasonality is not further investigated.

Next there is the public support; in general the management of perishable goods is of interest as decreasing waste is of public interest (e.g. Gunders (2012)). More specifically to this project is the support that within the Netherlands grocery stores probably will be allowed to extend their opening times from six to seven days a week (e.g. Novum (2012a) and Novum (2012b)). This extended opening term, or especially the Sunday opening, has several implications, which will (directly or indirectly) influence outdating. According to Keuchenius et al. (2009), there is a direct relation between this extension of opening terms and smoothening the demand. Hence, stationary demand might be actively altered to non-stationary demand, and possibly vice versa. As such, we derive a weekly seasonality pattern as identified by Kahn & Schmittlein (1989), but define it slightly different as argued before. This pattern will smoothen out over the week to a more stationary pattern after extending opening times. However, Keuchenius et al. (2009) also identify that total sales increases when stores are opened seven days a week, which has another relation with outdating.

The company would like to have identified where the strengths and opportunities are to cope with the previously described effect of interrupting sales and supply. Especially exceptional periods like Christmas are of interest to identify how to prepare for omitting days. Finally we should mention the higher purpose: reducing waste is of interest, because basically waste is loss.

We identified a scientific gap and some public support which only vaguely hints to outdating, but change in demand (per day and in total) will affect outdating (e.g. Arentshorst (N.d.), K. H. Van Donselaar & Broekmeulen (2012)). The project should aim at identifying the constructs that are influenced by the opening terms and eventually will lead to a change in outdating so actions can be initiated to prepare for a change in opening terms, if this is either expanding or constraining.

3.3 | RESEARCH QUESTIONS

The main question includes the influence of opening times on outdating, but Figure 2 shows that this is probably an indirect influence. Some of the properties are described as 'influenceable', implying that these might provide management opportunities. Others are described as 'uninfluenceable', and are external circumstances we have to cope with. Hence we would like to know

- The effect of the number of days per week opened;
- The effect of week pattern on outdating;
- What opportunities can help managing outdating;
    - The effect of replenishment interval of outdating;
    - The effect of order quantity on outdating.

3.4 | HYPOTHESES

In light of these questions, the following is hypothesized:

- Increasing the number of days per week opened will result in less outdating – there is a negative effect.
  Considering a store that is six days open, inventory that remains at the end of Saturday will have one day in which it cannot be sold (Sunday). When the store will open seven days a week, considering stable week demand, the items have a higher probability of being sold within shelf life. The decrease in demand on the other days will lead to a decrease in inventory overall, as well as safety stock, and will have nog effect on outdating.
- A larger week pattern (i.e. average sales on Fridays and Saturdays compared to average sales on Mondays through Thursdays increases) will result in more outdating – there is a positive effect.
  A more constant demand pattern will be easier to tune inventory and safety stock, whereas little demand followed by high demand (even though it is predicted) will lead to adaptation of inventory (increase of inventory before the peak in demand), which will then be set back to the original. However, safety stock that is provided for the high demand days, might lead to high remaining inventory and overstocking for the low demand days.
- A smaller replenishment interval (schedule with more frequent opportunities for delivery) will lead to less outdating – there is a positive effect.
  As inventory is meant to cope with demand up to the next replenishment, a smaller period of time between two replenishments should lead to both less inventory to cope with expected demand and less safety stock. Hence, the probability of overstocking will become less. Although this is expected to be the general effect, too frequent delivery might increase outdating as there is always a better product available (in an extreme case would any sale be immediately replaced by a new product and, considering that consumers will not always withdrawal according to FIFO, the old product will remain in safety stock until expiry).
- Smaller order quantity will result in less outdating – a positive effect

A small case pack provides the opportunity to closely follow demand, whereas large case packs will be less flexible to cope with variance in demand. Next to this, large order quantities will result in overstocking and therefore outdating.

It is expected that the effects will be mediated by the (target) availability, average demand and variance in demand. The availability and variance will be positively mediating, while the average demand will have negative effects.

3.5 | DESIGN OF EXPERIMENTS

The above statements are first tested to see if they exist, by using real life data. Then the surroundings will be contained to find the specific effects in specific circumstances and what theoretical adaptations will lead to. Hence the research will be divided into two parts.

REGRESSION

First a regression analysis will be performed to identify if the above propositions truly exist. The regression analysis should backup the above mentioned ideas, but also other possibilities will be incorporated to simultaneously provide ideas for future research.

SIMULATION

Second a simulation study will be designed in order to contain the circumstances and provide insights in the effects of a particular mechanism. Also several ideas for managing the outdating can be tested.

3.6 | SUMMARY & GOALS

The main question was: How will different opening times of grocery stores affect the outdating of perishable goods and how can this effect be actively managed?

Following Figure 2 we identified several questions to obtain both the effect of opening times, and of possible mechanisms to actively manage this effect:

- The effect of the amount of days per week opened;
- The effect of week pattern on outdating;
- The effect of replenishment interval of outdating;

To identify these effects it was chosen to first perform a regression analysis to identify if the above propositions truly exist. A simulation analysis should identify in a more constant environment the specific effects.

4. Regression

This next chapter will describe the regression analysis. It will start by setting the objectives (section 4.1), followed by some definitions and hypotheses (4.2). Then the dataset used will be discussed in section 4.3, followed by the results in 4.4. The chapter will be concluded with discussion (4.4), conclusions (4.5) and limitations (4.6).

4.1 | Objectives

To the knowledge of the author, no research has been looking into general causes of outdating and it was difficult to find where the main opportunities for decreasing outdating in the supermarket should be. Using a regression analysis several leads to manage outdating should be identified.

4.2 | Dataset

The analysis previously described, was conducted using POS-data of Albert Heijn stores. More specifically, it included Albert Heijn Baarn II (old type neighbourhood stores), De Nieuwe Albert Heijn (new type neighbourhood stores, called DNAH), and Albert Heijn XL (AHXL) stores. It excluded AH to Go stores, as these largely differ in assortment and target group, limiting the analysis by means of data limitations (only few SKU's overlapping and excluding many common products).

In 2012 Albert Heijn had about eight hundred stores (but was expanding its presence during the year with acquisitions and new stores), of which 34 AHXL, 340 DNAH, and 440 Baarn II stores. Of these a subset was chosen of 9 AHXL stores, 33 DNAH stores and 38 Baarn II stores, adding up to 80 stores. To ensure diversity in parameters of the regression model, these were selected in order to obtain stores that are six days opened, seven days opened and one times a month opened on Sunday throughout all categories. Also variance in crowdedness was ensured, ranging from an average of 0.50 to 10.75 customers per square meter per day.

For the products, five hundred products were randomly picked out of the three thousand five hundred fresh products. The sales data per SKU k per store W per week t for weeks 29 to 40 were used. The data was available per day, but that level of detail was only specifically used to identify mean demand, variance, and week patterns. Products had a maximum shelf life of thirty days, but later on in section 4.4 will be described that this will be stricter.

The products resulting from this ranged from several dairy products (like milk, butter, yoghurt and pudding), cookies and chips (which will later on be excluded due to shelf life), meats, (lunch) salads, cheeses, fresh vegetables, packed vegetables and flowers. For the fresh vegetables a distinction should be made as not all are sold per piece, which makes the analysis harder. This finally resulted in 491 SKU's.

4.3 | Design

In the previous chapter, several hypotheses were made and this regression is used to find out if these effects actually exist. Apart from the main goals, identifying the effect of week pattern and days open on outdating, many other variables were included in the regression, and in Appendix C all input variables suggested are shown, including an explanation of the hypothesized effects. The dependent factor, average outdating for a particular item in a particular store, was defined as

THE FRACTION OF BOTH GIVEN DISCOUNT AND WASTE, RELATIVE TO DEMAND.

$$AB = \frac{discounted\ products\ + wasted\ products}{sales}$$

The discounted products were measured as if they were waste. This contradicts with the method used by AH, but this is a more general measurement. Moreover, when moving on to the simulation it will be the best way to measure as consumer behaviour will not be corrected by discount.

The proposed variables did have a few limitations as several could not be measured: AF_{rel} (order quantity of DC to manufacturer), M_{tkW} (altered orders), e_k (self-service item), g_{tkW} (sales part in group), d_k (date type), w_W^p (store performance), and w_W^t (fraction of inventory counts). None were available in the data, except the self-service factor but that factor is so rare in the current Albert Heijn business that it was excluded. The date type was not stored and unfortunately not too straightforward for all of the products (i.e. all products in group X have an open code), resulting in no easy access to this data and exclusion in the regression.

It was chosen to use the Stepwise method in SPSS to perform the regression, so the possible factors would be added in order of relevance (strength of correlation) and the irrelevant factors, not per se adding value to the model, will be left out of the model. Up front, some variables were transformed into dummy variables (especially the promotional variables) in order to obtain linearity. After a first run, several factors needed to be corrected for independence of the error terms and a few variables needed to be corrected for outliers (e.g. the replenishment interval was ranging between 0.3 and 1.3, with an outlier at 6.0). Both the transformations and restrictions are shown in Appendix C. A major restriction was on the shelf life VT. To enhance explanatory strength, this factor was limited to products up to six days of shelf life.

4.4 | RESULTS

In the first model several factors showed VIF>10 and were posed for exclusion (conform Hair, Black, Babin, & Anderson (2010)). Variables DT, WB_tkW, and VT showed VIF>50. As DT and VT showed high multicorrelation factors, it was tried to remove only one of them first, DT and this showed to be sufficient (see Appendix D). After the removal of variables, the resulting regression model showed only VIF<10. The analysis after removal of intercorrelated variables showed an explained variance (R^2) of 53.7%.

DESCRIPTIVES

The descriptives (see Appendix D) reveal that the average relative outdating is [redacted] with standard deviation [redacted]. The dataset considered shows 12% XL stores, and the remaining were regular convenience stores. Of all products, 63% was delivered by a comaker (VMI). The availability norm was [redacted] and the store image norm only [redacted]. The average amount of deliveries is rather low but the average interval is near to 1. About 93 percent of the product-week combinations considered was not in promotion, while 4.6% had shelf promotion. The relative order quantity (BE_rel) is 0.43, implying that the case pack size is nearly half the expected demand during shelf life. An average week pattern of 1.6 is seen in the dataset with a standard deviation of 0.7. Finally the transformed data is shown, as well as the days open which was transformed into a dummy, 1 meaning 7 days open. Hence we see that on average the seven day opened stores were slightly better represented than six days stores.

Resulting model

The final model is shown in Appendix D, but a summary is provided in Table 1. The model showed that the most important factors are average demand and the shelf life. Where average demand has a remarkable positive effect, shelf life has an expected negative effect. Higher shelf life has more opportunity to be sold than small shelf life, explaining this result. The result of the average demand is odd, as it can only be explained by relatively high safety stock. Otherwise, high demand may also imply frequent replenishment of the goods, providing the consumers with fresh products and leaving the old products on shelf.

The DT/VT parameter has a small positive correlation with the outcome, implying that when DT is rather high compared to VT, more relative outdating is found. As expected, the standard deviation also has a positive correlation with outdating – more uncertainty in demand means both higher safety stock and higher probability of remaining with goods.

The factor of crowdedness shows a small negative effect, which can be explained by the higher opportunity of sales in a busy store. The comaker has a small positive effect which could either be because products with high risk of outdating frequently have vendor managed inventory, or the supplier provides too many items. The relative order quantity (BE_rel) also has a positive effect. This was conform expectation as high order quantities lead to high stocks as more products than necessary will be replenished. Moreover, large order quantities make it hard to precisely follow pace of consumers demand, leading to more uncertainty.

Both the store image norm and the availability norm show up and both have a negative relation. The question here is, if these norms are set accordingly to outdating or vice versa. Probably the first one holds, as this would mean that products with high outdating will be allocated lower norms, obtaining a negative correlation.

The replenishment interval as well as the amount of deliveries from RDC have a positive relation. This slightly contradicts as the first implies that less deliveries will lead towards high outdating, where the latter implies more deliveries to lead to high outdating. Note that the VIF factor is rather high, although within the limit of 10 (Field, 2009).

Table 1 | Variables included in the model

Variable		Short explanation	Included?
w_W^f	≔	Store formula of W	Yes
$FASG$	≔	Assortment group	No
BE	≔	Order quantity	Yes
PT	≔	Production term	No
DT	≔	Distribution term	No
VT	≔	Shelf life	Yes
NB	≔	On shelf availability	Yes
WB	≔	Norm for store image	Yes
c	≔	Comaker	Yes
w_W^o	≔	Days of the week open	Yes
$CROWD$	≔	Average crowdedness	Yes
FSC_{kW}	≔	Shelf capacity	No
s_{corr}	≔	Corrected average stock	No
$REPL_{del}$	≔	possible deliveries a week	No
$REPL_{del}^{lvc}$	≔	possible deliveries LVC	No
$REPL_{del}^{rdc}$	≔	possible deliveries RDC	Yes
$REPL_{del}^{int}$	≔	delivery interval	Yes
DT/VT	≔	Ratio between DT and VT	Yes
BE_{rel}	≔	Relative order	Yes
mu_{kW}	≔	Average demand per week	Yes
sd_{kW}	≔	Standard deviation of demand	Yes
CV_{kW}	≔	Coefficient of variance	Yes
p_{kt}	≔	Presentation/visualization	Partly
$p_{k(t-1)}$	≔	Presentation last week	Partly
D_m	≔	Fraction of missed demand	No
sQ_Qmu	≔	$\left\lceil \frac{s}{BE} \right\rceil * \frac{BE}{mu}$	No
AF_{rel}	≔	Relative order quantity by DC	Unavailable
M_{tkw}	≔	Percentage of orders adapted	Unavailable
e_k	≔	Self-service item (ego)	Unavailable
g_{tkw}	≔	Sales part within group	Unavailable
w_W^p	≔	Store performance	Unavailable
d_k	≔	Date type (open versus closed)	Unavailable
w_W^t	≔	Fraction of counts	Unavailable
u_k	≔	Unit (pieces versus weight)	Unavailable

The amount of days open have a small negative effect, implying that seven days a week open will have slightly less outdating than six days a week open. This can be explained by the increase in sales opportunity when opened seven days a week.

The transformed absolute order quantity (BE_log) has a small positive effect. The explanation is similar to relative BE, but it is clear that the relative BE has a stronger result and might more accurately reflect the effect.

The week pattern has a small negative correlation on outdating. It was expected that a higher week pattern would lead to more outdating, as the peak in demand at the end of the week leads to high inventory, which then should be decreased right after the peak with only small demand. Possibly, the increase in demand at the start of the peak (Friday) may compensate this effect, leading to small outdating figures.

Several promotion mechanisms are included, but especially the promotion of last week seems to be of concern. Both Prom2_X1 and Prom2_S1 show a positive effect. Prom2_B1 shows a small negative effect, possibly because this type is partly promotion (either X or S) and partly non-promotion. So this within week change may cause small inventory but high demand. Of the promotion in the current week, only promotion type X remains in the model.

The AHXL stores seem to have slightly less outdating than other stores, as the effect is slightly negative. In general AHXL stores attract more consumers due to the larger offer and large parking space, possibly explaining this result.

Finally the CV^2 was incorporated in the model, showing a slightly negative result. It states that when standard deviation is relatively high compared to demand, less outdating occurs. Possibly this compensates for the effects already found by the individual variables.

4.5 | Discussion

In light of the research, both the amount of days open and the week pattern were found to influence outdating. The main objective of the regression was to identify leads to manage outdating. From the regression a major impact would be the effect of promotions on the outdating in the week after promotions, possibly diversified to type of promotion. Moreover the relative order quantity might help reduce outdating as it is of major importance. The several measurements for product life can be interesting, but are hard to influence. The amount of replenishments is of influence but it is unclear in what way they may help in controlling outdating due to somewhat contradicting results. Finally, the availability measurements showed to be related to outdating.

4.6 | Limitations

The above showed several factors that influence outdating. However, the dataset was limited to products with short shelf lives (up to six days), limiting the generalizability of the results. Apart from that, sever factors were proposed that could not be tested, which could make the model stronger.

5. SIMULATION

After the regression showed that the identified effect indeed exists, this was tested in a more controlled environment by simulation. The next section will describe the simulations that were executed. First the objectives are set in section 5.1, then the design in order to identify the several steps in the process (5.2). Next the results of the simulations are shown and discussed (5.3 to 5.6) and the chapter will end with a summary (5.7).

5.1 | OBJECTIVES

From the regression is continued to the simulation. The simulation should identify results on outdating of specific behaviour. The week pattern and days opened are of interest, as argued in chapter 3. The objective of the simulation is to

- Identify key differences and opportunities between the EWA model (Broekmeulen & Van Donselaar, 2009) and the ordering model of Albert Heijn;
- Identify effects of the week pattern;
- Identify effects of the amount of days opened;
- Identify effects of possible solutions.

These diverse objectives should hold under different circumstances and the simulation will distinguish the cases for several product types. The possible solution is provided by differing the replenishment frequency (see also Figure 2), but also to differ in relative order quantity as shown in the regression. The order process as well as the withdrawal in store should be simulated.

5.2 | DESIGN

The dataset used for the regression analysis will be the lead for the choice of parameters for the simulation model to obtain the scenarios to test. In the regression the focus was already scoped to products with shelf life up to 6 days and for the simulation we will focus on shelf lives 3-5. These include several dairy products, some fruit and vegetables (e.g. grapefruit and spinach), and especially cakes and prepared meals (e.g. pizza and 'maaltijdsalade'). Values for the parameters are chosen to best match current data, as depicted in Appendix E.

i. **Differ in products:**

Simulate for different products to see if this results in different behaviour. As with the regression analysis, focus is on short shelf lives (VT). Moreover the mean demand per week (μ_{week}) and variance-to-mu-ratio (σ^2/μ) will be differed. As also the service levels (NB & WB) are expected to have influence (see also the regression model) the availability norm will be altered. The fill rate (P_2) will be used as the model will not simulate customers, but demand. It is expected that an increase in availability leads to an increase safety stock and remaining stock, hence outdating. Considering that the realized service level by Albert Heijn varied a lot (see Table 13 in Appendix E), several targets are tested to find the best fit.

a. $VT \in \{3, 4, 5\}$

b. $\mu_{week} \in \{3, 6, 18\}$

c. $\frac{\sigma^2}{\mu} \in \{0.7, 1.5\}$
d. $P_2 = \{0.75, 0.80, 0.85, 0.90, 0.95\}$

ii. Differ in replenishment characteristics

Simulate for different replenishment characteristics to identify improvement possibilities. First of all, the replenishment interval as described in section 4.2 will be differed by altering the number of replenishments per week (R). The option of six days delivery will be discussed as it is rather common to deliver Monday through Saturday. Next also the Sunday is included. Finally it was tested what would happen if on a particular day two moments for delivery are selected. If this would have any improvement, it would be best during the peak days as the demand in between two review periods will be split (see also section 5.4) at the moment in time that this is the highest. Hence, Friday and Saturday are both tested to have two moments to replenish. Secondly we differ in order quantities relative to demand during shelf life (Q), which will influence the safety stock (as replenishment quantities depend on this).

a. $R = \{6, 7, 8_{Sat}, 8_{Fri}\}$
b. $Q = \{\left\lceil \frac{1}{4} * VT * \mu_{day} \right\rceil, \left\lceil \frac{3}{4} * VT * \mu_{day} \right\rceil\}$

iii. Differ in daily demand behaviour throughout the week

Finally we will come back to the initial question: the difference for different opening terms, as well as diversity in week pattern. Week pattern is defined as the average sales per day on Friday and Saturday, divided by the average sales per day on Monday through Thursday.

a. Week pattern $\in \{1, 1.5, 2, 3\}$
b. Days open $\in \{6, 7\}$

DESIGN CHOICES

Several design choices for the simulation analysis are made.

- The simulation reflects the ordering procedure of both AH and EWA, and excludes forecasting (i.e. there is expected demand, but this is not adapted due to previous results, but static across weeks);
- The effect of discounting (e.g. 35% discount for nearly outdated products) is excluded;
- The withdrawal policy is FIFO;
- Order moments are fixed and every day the same (except when the number of ordering moments per week is eight). This will be on midday, and when the number of order moments equals eight, the extra order moment will be on the proposed day after closing time;
- Delivery moments are fixed and every day the same (except when the amount of ordering moments per week will differ from the amount of days opened). When ordered in the middle of the day, the goods are delivered just before next opening of the store. Deliveries can only be made prior to and on days the store is open. When ordered at the end of the day, the delivery is made half way the next day the store is opened;

- Demand distribution throughout the day is uniform (i.e. the probability of having demand in the afternoon is equal to the probability that demand occurs in the morning);
- When opened six days a week, the store is closed on Sunday;
- Shelf life is valid from the day of delivery and will be wasted at the end of the day that the remaining shelf life equaled 1;
- There is no shortage at DC, orders will always be delivered on the intended moment;
- Demand is stochastic, discrete and positive;
- Demand for Sunday will behave as demand for Monday, Tuesday, Wednesday and Thursday and the expected demand for Sunday is equal to that of Monday to Thursday;
- The variance-to-mu ratio is considered to hold on a daily basis;
- Inventory is only influenced by demand and replenishment, hence theft etc. does not occur;
- No promotions, influencing withdrawal and demand, occur.

MODELING DECISIONS

To obtain a stochastic distribution for the demand that has the same parameters as the input, we use Adan, van Eenige, & Resing (1995). However, this does result in some issues when splitting the week in two ('high' demand and 'low' demand). To illustrate, an example is included.

EXAMPLE

The expected demand per day is corrected for the week pattern as follows:

The demand per week equals 18, the week pattern is 2, the store is 6 days open. This means that the expected demand on Friday and Saturday is twice as high as the expected demand per day on Monday through Thursday. Hence, demand on Monday through Thursday is expected to be $\frac{18}{4+2*2} = 2.25$. For Friday and Saturday this is $\frac{2*18}{4+2*2} = 4.5$. The formulae are $E[X_1] = \frac{E[X_{week}]}{(days-2)+2*pattern}$ and $E[X_2] = \frac{pattern*E[X_{week}]}{(days-2)+2*pattern}$ where X_1 is the demand per day on Monday through Thursday, X_2 the demand per day on Friday and Saturday. When the store would be 7 days open, the results would be $E[X_1] = \frac{18}{5+2*2} = 2$ and $E[X_2] = \frac{2*18}{5+2*2} = 4$ and the expected demand for Sunday will be $E[X_1]$.

For the EWA policy, the following steps are taken:

1. Identify the day and the expected demand for all days of the week.
2. Identify stock necessary to reach service level for ODD-period (order-to-delivery-to-delivery).
3. Identify the inventory for products with remaining shelf life of 1 day and subtract expected demand of current day (i.e. from the moment of ordering up to

delivery; order-to-delivery (OD)). If demand is greater than inventory, proceed with inventory with remaining life of 2 days, etc.

4. Correct inventory position for expected outdating.
5. Repeat step 2 for the demand of the next day (i.e. between the next two deliveries; delivery-to-delivery (DD)).
6. Identify remaining inventory level.
7. Order a multiple of the order quantity to surplus the remaining inventory to the inventory level needed for the ODD-period.

The Albert Heijn model performs slightly different.

1. Identify demand per day for the entire week
2. Identify stock necessary to reach service level for ODD-period
3. Identify the inventory restriction to minimize outdating
4. Identify the shelf capacity
5. Prioritize and weigh inventory levels obtained in step 2 to 4 to set the desired inventory level;
6. Subtract expected demand during OD-period from current inventory
7. Order a multiple of the order quantity to surplus the remaining inventory to the desired inventory level.

We see the following key differences:

- EWA uses detailed shelf life information, in order to correct the inventory position for expected outdating. So EWA has a more accurate inventory position and reacts on outdating before it happens. AH uses general inventory information and copes with outdating by defining a restriction. This could lead to lower inventory, but may influence service as actual inventory at delivery may be decreased due to outdating. AH will respond later to this outdating than EWA.
- EWA uses detailed demand distributions for setting the desired order-up-to-level (necessary for the service level), where AH uses a less specific method. EWA may have an advantage in covering safety stock, while AH may have an easier implementation (having such information for twenty thousand products in eight hundred stores for different periods in time (e.g. promotional activities, seasonal activities, etc.) may lead to performance issues).
- AH tries to optimize for multiple restrictions (service level, outdating, and capacity), while EWA merely considers the service level (which may be adapted for outdating in advance).

For the EWA simulation, the same model was used as Broekmeulen & Van Donselaar (2009) and K. H. Van Donselaar & Broekmeulen (2012). In Table 2 an example of the AH simulation is shown. For every week and every day, three moments in time are defined: Opening (receiving ordered goods and start inventory), Midday (ordering, midday inventory and possibly receiving goods) and Closing (end inventory and possibly ordering). The inventory is split over the remaining shelf lives (1 to 3, from right to left) and will move up day to day as the remaining life will decrease. Demand per day is shown in column 4, and is subtracted in a FIFO way from the current inventory either during the morning or during the afternoon or a combination in case demand exceeds 1 (e.g. week 122, day 4). When ordered on day 6 and closed on day 7, the delivery is made on the first moment after the intended moment, hence day 1 of the next week. The inventory with 1 day that is left when the store closes will be the amount of items outdated.

Table 2 | Example of simulation, revealing the steps in time

Week	Day	Forecast	Demand		Total stock	3 day	2 day	1 day	order
121	1	1	0	Opening	4	2	2	0	
				Midday	[illegible]	2	2	0	0
				Closing	4	2	2	0	-
	2	1	1	Opening	4	0	2	2	
				Midday	3	0	2	1	2
				Closing	3	0	2	1	-
	3	1	1	Opening	4	2	0	2	
				Midday	4	2	0	2	2
				Closing	3	2	0	1	-
	4	1	1	Opening	4	2	2	0	
				Midday	3	2	1	0	1
				Closing	3	2	1	0	0
	5	1	0	Opening	4	1	2	1	
				Midday	4	1	2	1	1
				Closing	4	1	2	1	-
	6	1	1	Opening	4	1	1	2	
				Midday	3	1	1	1	2
				Closing	3	1	1	1	-
	7			Opening	2	0	1	1	
				Midday	2	0	1	1	-
				Closing	2	0	1	1	-
122	1	1	2	Opening	3	2	0	1	
				Midday	1	1	0	0	3
				Closing	1	1	0	0	-
	2	1	1	Opening	4	3	1	0	
				Midday	4	3	1	0	0
				Closing	3	3	0	0	-
	3	1	0	Opening	3	0	3	0	
				Midday	3	0	3	0	1
				Closing	3	0	3	0	-
	4	1	2	Opening	4	1	0	3	
				Midday	3	1	0	2	1
				Closing	2	1	0	1	1
	5	1	1	Opening	2	1	1	0	
				Midday	3	2	1	0	1
				Closing	2	2	0	0	-
	6	1	1	Opening	3	1	2	0	
				Midday	2	1	1	0	2
				Closing	2	1	1	0	-
	7			Opening	2	0	1	1	
				Midday	2	0	1	1	-
				Closing	2	0	1	1	-

Stock is represented per remaining shelf life. Moving to the next day, shelf life decreases.

Demand is subtracted during the day conform FIFO withdrawal. Demand can occur during morning or afternoon with equal probability.

Orders are placed during midday and sometimes at the end of the day. These are replenished half a day later.

Orders placed on the day prior to the day the store is closed will be delivered the next day the store is opened.

5.3 | RESULTS

This result section will discuss only the high level results of the previously described design. The next section will take a deeper dive, trying to explain and identify other effects.

The outcome of the simulation is measured in relative outdating; the outdating relative to the average demand. For this we obtain the following formula:

$$relative\ outdating = \sum_{\forall i} \left(\frac{o_i}{d_i}\right) / (\#i) * 100\%$$

With:

i ≔ scenario (product-store combination)

o_i ≔ average amount of products per time period outdated for scenario i

d_i ≔ average demand per time period

The following results are based on the EWA simulations and are average results over all observations within the provided boundaries. The results of Albert Heijn are included in 5.5. These results are compared to the EWA results in section 5.6.

First the target fill rate will be shown, as it can be identified from Table 3 that both the realized service and the relative outdating are most in line with the empirical data (see also Appendix E). Therefore all other results shown will be filtered for target fill rate 75%. Next the results will be shown per design and in the discussion any interesting effects will be discussed as well as the research questions formulated.

Table 3 | Outdating and fill rate for different target fill rates

Target fill rate	Realized fill rate	Relative Outdating
75%	88.9%	28.8%
80%	90.6%	31.8%
85%	92.6%	36.8%
90%	95.0%	45.6%
95%	97.5%	61.7%

DIFFER IN PRODUCTS:

Different shelf lives were tested and Table 4 shows that longer shelf lives will result in less outdating. This negative effect is weaker when going from 4 to 5 days than when going from 3 to 4 days. The table also shows a negative effect; the higher the demand per week, the less outdating. For the variance-to-mean ratio a positive effect is shown, as there is more outdating when the variance is relatively high.

Table 4 | Average relative outdating for different shelf lives

		Average relative outdating
Shelf life	3	42.2%
	4	25.0%
	5	19.2%
Demand per week	3	51.9%
	6	23.7%
	18	10.8%
Variance-to-mean ratio	0.9	24.3%
	1.5	33.3%

DIFFER IN REPLENISHMENT CHARACTERISTICS:

Next the replenishment characteristics of order quantity Q and the amount of deliveries per week R are discussed. Table 5 shows that the amount of deliveries primarily results in less outdating when every day in the week has a delivery opportunity (seven or eight deliveries) than for less deliveries (six). An order quantity Q that was dependent on the shelf life and average demand per day was used. The table shows that the smaller Q results in far less outdating.

Table 5 | Average relative outdating for different replenishment characteristics

		Average relative outdating
Possible Deliveries	6	31.8%
	7	28.0%
	8 Sat	27.6%
	8 Fri	27.7%
Q	$1/4 * VT * \mu_{day}$	21.9%
	$3/4 * VT * \mu_{day}$	35.8%

DIFFER IN DAILY DEMAND BEHAVIOUR THROUGHOUT THE WEEK:

The third design differed in daily demand behavior, i.e. in demand per day and the amount of days open per week. The results are shown in Table 6 and it shows that the week pattern has some result on outdating but rather small. The same holds for the amount of days open.

Table 6 | Average relative outdating for different within week behaviour

		Average relative outdating
Week pattern	1	26.9%
	1.5	28.0%
	2	28.8%
	3	31.6%
Days open	6	29.2%
	7	28.5%

5.4 | Discussion

The same structure as with the results section will be used.

Differ in products:

The results showed that all product characteristics relate to differences in outdating. Both the shelf life and the demand per week reflect a negative effect, which can be explained by the increased opportunity of sales. Longer shelf life will result in more days in which the product may be sold, and in addition the current FIFO-modelling make the opportunity that a product will be sold before outdating even greater. The variance-to-mean-ratio as well as the intended fill rate will in general ask for higher safety stock. This stock will on average not be sold and expire, explaining the positive effect. Looking slightly deeper (see Figure 3) it can be seen that weekly demand interacts with the shelf life as for the higher demand patterns the difference between shelf life 4 and 5 are really small. So it seems that when demand is high enough, shelf life is of little influence on outdating.

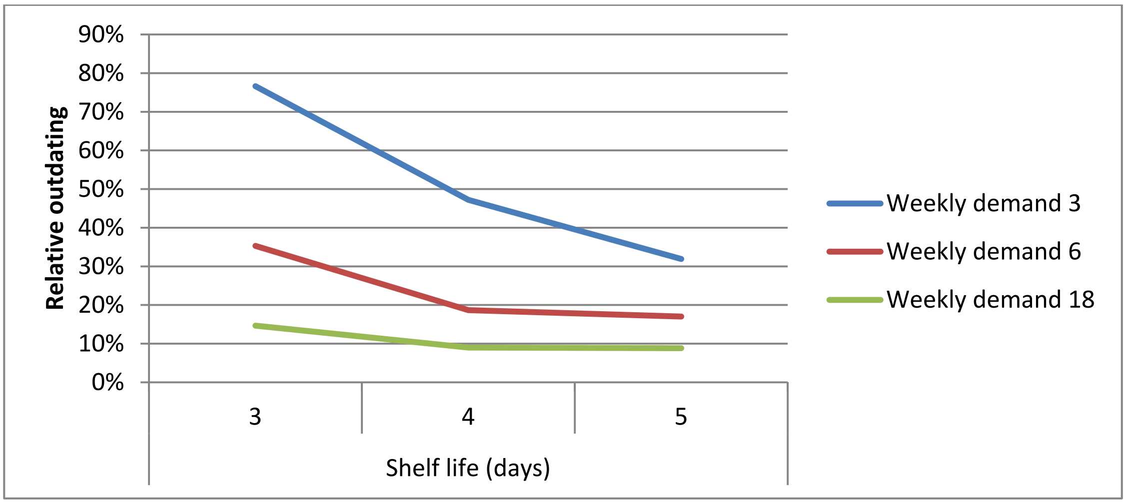


Figure 3 | Interaction effect between weekly demand and shelf life

DIFFER IN REPLENISHMENT CHARACTERISTICS:

The amount of replenishments and the case pack showed negative effects, where the amount of replenishments showed only improvement from 6 to 7 deliveries, and no result from 7 to eight deliveries. A question that arises is if a store should have replenishments when closed. Figure 4 shows that indeed for six days open, seven deliveries are beneficial and that for both six and seven days open, multiple deliveries a day do not seem to have an effect.

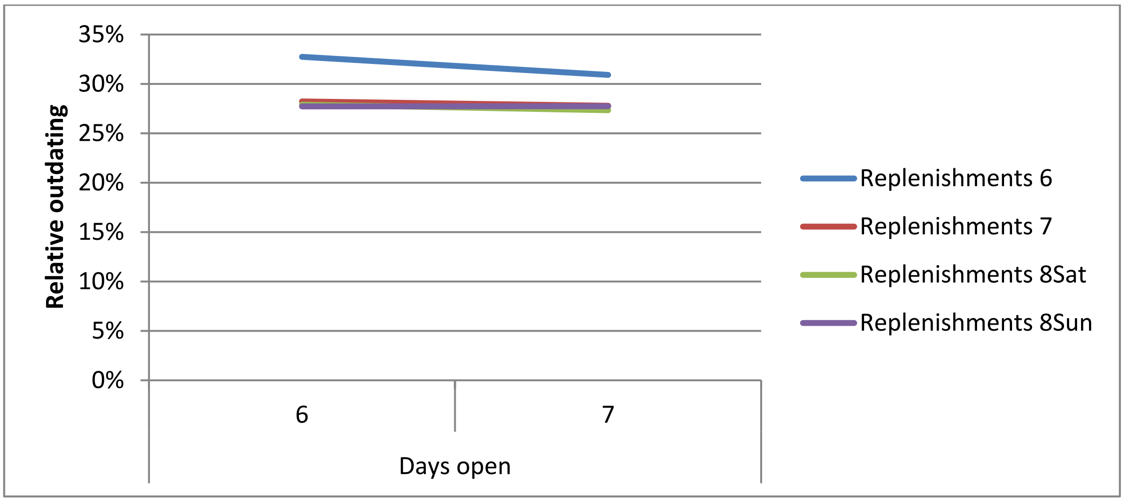


Figure 4 | Interaction effect of replenishments and days open

In more detail it shows that on average per week less products are delivered (see Table 7). In case of six deliveries, the last order-up-to-level is based on the demand during Saturday afternoon and Monday. So products arrive relatively early (one day before sales), which decreases the opportunity of sales. In case of seven deliveries, the supply on Saturday is merely focussed on recovering from sales during Saturday afternoon, and the Sunday delivery is for the entire Monday. Although in total this seems to be equal, the Monday demand has one day extra to be on shelf, not only reducing the probability of not being sold, but also decreasing the amount of products that are ordered to correct for outdating. Note that it was not tested for six days replenishment, leaving out Saturday as this may have similar results to the seven replenishment design.

Table 7 | Supply per week for several delivery schedules

		Supply per week
Possible Deliveries	6	9.94
	7	9.68
	8 sat	9.58
	8 fri	9.62

As discussed in the previous section, the smaller case pack size results in less outdating. This is most likely due to the necessity of rounding orders to a multiple of the case pack, which will at least equal the intended amount of products one would like to order. The rounding will lead to higher average order quantities and supply, resulting in high left-overs. Note that the highest outdating is found in lowest demand and shelf life, but that this combination of factors already results in the smallest case pack size (i.e. in case of 7 days demand μ_{week}= 3 and VT=3 results in $\frac{1}{4} * VT * \mu_{day} = 1$ and $\frac{3}{4} * VT * \mu_{day} = 1$, while $\mu_{week} = 18$ and VT=5 results in $\frac{1}{4} * VT * \mu_{day} = 4$ and $\frac{3}{4} * VT * \mu_{day} = 9$).

DIFFER IN DAILY DEMAND BEHAVIOUR THROUGHOUT THE WEEK:
It was shown that the relative outdating for the stationary weekly demand was slightly smaller than for higher week patterns. The differences were really small, with the most outdating for week pattern 3. This result also holds when the week pattern is set out to other variables.

Looking at the inventory for the several week patterns in Figure 5, it shows that Sunday has the largest inventory. As the peak in demand occurs on Friday and Saturday, the deliveries for Thursday evening and Friday (evening) are largest, as would be the safety stock for those days. Considering that these are not expected to be sold, these items remain on shelf. Only after this peak in sales, this can be corrected by sales and ordering less, explaining the peak in inventory. Considering that EWA also corrects for expected outdating, inventory can increase even more on Sunday (or after Saturday delivery) to correct the outdating of Saturday, while no products will be sold on Sunday. But this still does not explain why the average outdating is more or less equal across week patterns. Figure 5 also shows that the inventory for each day of the week is similar for the week patterns, with especially difference for Saturday. This day also has higher demand, which will correct for the high inventory. Figure 6 shows that the average safety stock does change per week pattern, but that the difference is at most 0.1 product – on Saturday. It seems that due to the small discrete demand and inventory, the peak in demand can be covered without altering the order-up-to-level too much.

The amount of days open had a small negative effect, and can be explained similar to the explanation of the amount of deliveries – higher opportunity of sales.

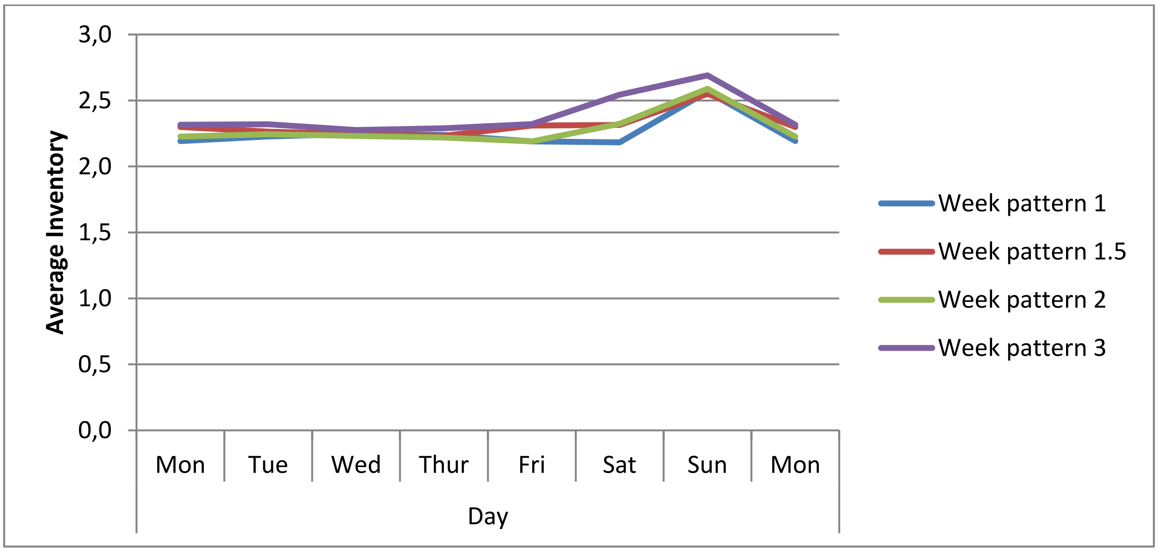


Figure 5 | Inventory per week day for different week patterns

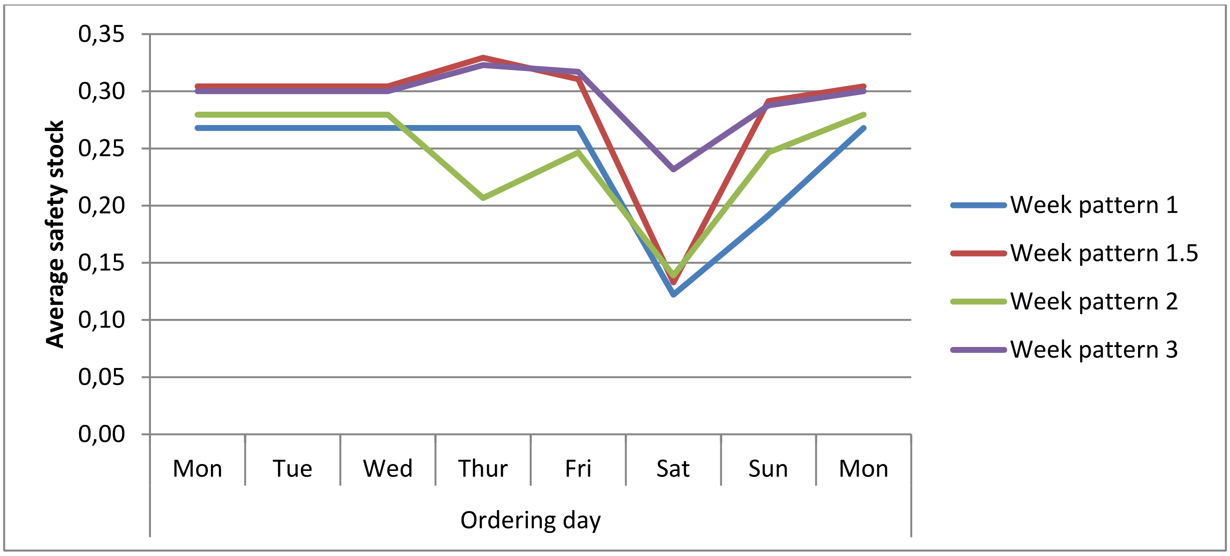


Figure 6 | Average safety stock per order moment

OTHER

Table 8 shows that there is also a pattern in outdating when traced back to the day of delivery. For each shelf life, the peak in outdating occurs VT days after Friday, i.e. the Friday delivery has most outdating in all cases. On this day $E[D_{L+R}]$, that is used to find the order-up-to-level for a pre-specified fill rate, equals half the Friday demand and the Saturday demand and is on average highest. However, it arrives after Friday sales, and $E[D_L]$ has past. On the Friday this demand is relatively high compared to other days (except Saturday), as is the variance. Hence, the error is largest. Underestimating demand has a restriction on inventory (i.e. it will equal less than zero), but overestimation does not (i.e. the demand is less than expected), leaving most safety stock. Moreover, the Friday delivered products all miss a day of sales when considering 6 days delivery, whereas for example Monday delivery does not. So the most inventory is obtained at the end of Friday, with the largest possibility of being incorrect and less opportunity of sales for the six days sales model. This is likely to explain why the outdating results from the Saturday delivery.

Note that in the number of replenishments, it was tested to split up this Friday delivery, but it showed only small benefits. Although the demand during review period will differ less from the expected value, a period of uncertainty is added ($E[D_L]$), possibly balancing out this gain.

Table 8 | Average outdating per shelf period for different shelf lives

Shelf life								
3			4			5		
Shelf period		%	Shelf period		%	Shelf period		%
Mon	Thu	52.5%	Mon	Fri	18.3%	Mon	Sat	11.9%
Tue	Fri	32.2%	Tue	Sat	17.4%	Tue	Sun	14.1%
Wed	Sat	20.0%	Wed	Sun	21.2%	Wed	Mon	16.8%
Thu	Sun	46.0%	Thu	Mon	23.1%	Thu	Tue	21.1%
Fri	Mon	60.8%	Fri	Tue	41.4%	Fri	Wed	31.5%
Sat	Tue	55.5%	Sat	Wed	39.0%	Sat	Thu	30.4%
Sun	Wed	28.5%	Sun	Thu	14.2%	Sun	Fri	8.8%

5.5 | RESULTS OF ALBERT HEIJN

Table 9 shows the results of the Albert Heijn simulations on a high level. It shows that the shelf life has barely any effect which may be explained as the order model calculates a limit of inventory by considering outdating. The week pattern is of influence on outdating although it is unclear what the precise effect is.

Only two delivery opportunities were tested, once every day and an extra delivery on Friday. Here it is shown that for the Albert Heijn model this indeed is beneficial. Probably the split-up of the DD demand makes the information when ordering more accurate, resulting in this decrease.

The amount of days open does not return different results but the weekly demand does. As expected, high demand is related to low outdating percentages. Similar to the regression and EWA it is found that the relative order quantity can be used to reduce outdating. The variance-to-mean has only little effect in the outdating of Albert Heijn, Considering the general method to calculate the variance, the inventory will be managed similarly in both occasions, explaining this effect. However, as demand behaves differently the obtained service level may differ.

Finally two extra opportunities are tested which will first be explained.

iv. Opportunities

Within the differentiation in products (see Design i), another opportunity is tested, only for the AH model: prevent products from outdating on the day the store is closed by delivering products with a longer shelf life. Thus when $VT = 4$, the shelf life of the products delivered on Thursday equals 5, starting from Thursday. This should compensate for the 'opportunity of sales' as mentioned in Figure 2. In real life this could be possible as products have at least a certain shelf life when arriving in store, but the life might be longer than necessary as these items are already on stock in the DC. It is chosen to prevent outdating on Sunday, as the last day of the life span is the most critical day. The other parameters are set to $R = 1, Q = \left\lceil \frac{1}{4} * VT * \mu\_day \right\rceil$, $P_2 = 0.95$, week pattern = 1 and the store is 6 days per week open.

For the same set of simulations, it is tested what will happen if we would include more information in the order: if we postpone the order of Saturday to the end of the day, we still have more than the proposed 18 hours to deliver as the store is closed the next day. This actual inventory position is expected to decrease outdating at day $VT - 2$ (Saturday + shelf life).

It shows that both opportunities act as expected, as both return less outdating than the overall model.

Table 9 | Average relative outdating results for Albert Heijn simulations

		Average relative outdating
	Overall	
Shelf life	3	
	4	
	5	
Week pattern	1	
	1.5	
	2	
	3	
Delivery opportunities	7	
	8Fri	
Days open	6	
	7	
Weekly demand	3	
	6	
	18	
Q	1/4*VT*mu	
	3/4*VT*mu	
VTM	0.7	
	1.5	
P2	0.95	
Other	Shelf life +1 on d=8-VT	
	Saturday order later	

5.6 | ALBERT HEIJN VERSUS EWA

In section 5.5 the results of the Albert Heijn model are shown and these are summarized in Table 10 in order to compare the results with EWA. Many results are similar to one another, but the most remarkable result would be the effect of shelf life that has no influence in the AH model. Possibly step 3 in the model (identify stock for minimizing outdating) causes this, as it may reduce inventory. EWA in this case tries to forecast the expected outdating and will send in extra goods, while AH first of all limits its inventory for outdating, and reacts on outdating instead of preparing for possible events. Furthermore several slightly less strong effect for different cases, which is probably explained by the general way AH copes with demand distribution, leading to more spread in meeting the required service level.

Table 10 | Comparison of results EWA and Albert Heijn in a qualitative way

	EWA	AH
Shelf life	- - -	0
Week pattern	+ especially wp 3 has effect	+ especially wp 1.5 and 3 have effect
Possible deliveries	- - only 6 deliveries vs. 7 or more had effect	- - only tested 7 vs. 8Fri situation
Days open	-	-
Demand	- - -	- -
Order quantity	+++	++
Variance	+++	+
Other	Major outdating from Friday delivery	Major outdating from Friday delivery

5.7 | SUMMARY

Discussing the main questions, the week pattern and amount of days open resulted in only small gains. As expected, an increase in week demand did show a positive effect, while the number of days open showed a negative effect, but both were really small.

It showed that the major influence on outdating is caused by factors that are hard to influence: product characteristics shelf life, demand, and the variance-to-mean-ratio. A way of coping with this, is using the right relative case pack size as it was shown that of the two options used, the smaller relative case pack size performed best, but not per se the smallest absolute case pack size. Moreover the gain from decreasing the case pack size is likely to decrease as for some cases (e.g. when VT=5 and $\mu_{week} = 18$, the case packs of 4 and 9 were used, resulting in 2% and 16%. Using smaller case pack size than 4 will not decrease outdating by 14% again, if there is any gain at all).

The amount of replenishments per week also showed to be helpful in decreasing outdating. Especially all days replenishment results in less outdating than not all days replenishing, even when the store is not open every day. It was not tested if six deliveries per week, leaving out Saturday, would result in similar outdating figures.

Finally it showed that the major delivery to look into would be the Friday delivery, and although it was tested to split up this delivery, only very small benefits were found.

6. RESEARCH DISCUSSION

6.1 | OBJECTIVES

The main objective of the research was to improve the freshness in the supply chain, especially by looking into the effects of opening terms of stores on outdating. Using Figure 2 the intermediate mechanism of a week pattern was identified, which would be of major importance on the outdating. Apart from this, a regression analysis was performed to identify if the proposed effects truly exist. The major questions were to identify:

- The effect of the amount of days open on outdating;
- The effect of week pattern on outdating;
- The effects of possible solutions to contain outdating.

6.2 | INSIGHTS

First a summary of the general insights of the research is provided. The next section will explicitly discuss the objectives.

From the regression we derived that the relative order quantity (order quantity divided by average demand during shelf life) was of major importance for outdating. The simulation model showed the same, as relative large order quantities resulted in higher outdating and suppressed the effects of other parameters.

Furthermore effects of (shelf) life of products were derived (PT, VT, DT/VT), but these results where affecting one another. Probably the effect of the shelf life itself (VT) was largest, and the (relative) stay in DC would provide opportunities of improvement. This effect of the shelf life was backed-up by the simulation model, as a negative effect was observed.

Looking at the regression, many effects were found of the promotional activities. In the simulation this was excluded, but whether or not a product is in promotion would highly influence these results. As promotion is expected to influence demand, there would be a major effect in the simulation models.

The amount of replenishments was another factor depicted relevant to outdating. The replenishment interval had a positive effect in the regression, but the amount of deliveries did as well so it was unclear. The simulation showed that the option of more replenishments per week decreased outdating although EWA only returned this outcome moving from six to seven opportunities of delivery.

The week pattern did show to be slightly negative correlation in the regression, and the simulation study showed no clear result. Where the regression showed different influence for different shelf lives, this did only resulted from the EWA simulation model while the AH simulation showed little to no differences between shelf life of products at all.

Another effect found in the regression, was the effect of the (intended) availability, and store image. This would have a positive influence on outdating, but the effects were not too strong. The simulation analysis showed a similar result, where outdating in general did increase.

Variance and demand were both found in the regression models, but the direction of the effects was ambiguous. The simulations showed more clear results as these product-store characteristics showed that mean demand has a negative relation and the variance a positive relation.

6.3 | Conclusions

Referring back to the main questions, we find the following:

- The effect of number of days open on outdating;
  The regression analysis showed a very small negative effect for the number of days open, as did the simulation models.
- The effect of week pattern on outdating;
  The week pattern has a small effect on outdating, but the simulations showed that this depends on product characteristics, such as shelf life and order quantity. The strongest effect was found by the largest week pattern, while the results of the other week patterns where really close to one another.
- The effect of possible solutions to contain outdating;
  By altering the replenishment interval, the outdating can be contained. However, this research was inconclusive on the best method of using the amount of deliveries to decrease the outdating. The major insight from the simulation was to deliver on Sunday, even when the store is closed. For Albert Heijn it showed that multiple deliveries per day would be beneficial. A second opportunity is ensuring the order quantities, or case packs, to best fit with the demand during shelf life.
  Finally for the Albert Heijn model, two other opportunities were tested, both resulting in less outdating. First of all, avoiding Sunday outdating by delivering products with a shelf life of one day more, showed to be beneficial. Second, delaying Saturday ordering was also beneficial, as the delivery moment did not change, but the knowledge of inventory at the moment of ordering did.

6.4 | Limitations

Limitations of the research are first of all that this was only a single case study. Data from other convenience stores might have different outcomes of the regression, and different results for the simulations.

Second, as described in 4.7 the regression had some limitations as seen in the multicollinearity statistics. Especially the effects of the lifetimes and of the availability factors were not identified clearly.

The major limitations of the simulation results, are that currently FIFO was used, and the effect of discounting nearly outdated products was ignored, leading to incorrect numbers of outdating. Besides this, the AH model did not always meet the intended availability, making it hard to draw conclusions.

6.5 | RECOMMENDATIONS AND PRACTICALITIES

Considering the conclusions, the amount of days open have only little to no effect on outdating. However, it is suggested by literature that Sunday open may increase total sales, so in another way it can be beneficial. Apart from that, the amount of deliveries clearly is of importance to manage outdating. Unfortunately it still should be identified what interval is optimal. A second recommendation is to ensure the order quantity is not out of proportion with its average demand during shelf life. Finally the regression showed that there are still many products with small shelf life and demand, of which one might reconsider of including these products in the assortment.

Apart from this, several other opportunities were tested, but the results should be set in perspective some results are currently not suitable for practice. First of all, the improvement of Sunday delivery highly relies on the assumption that the delivered shelf life is the same every day. In practice, the supplier will deliver the DC batches of products. If no fresh batch is delivered every day and in this case especially Sunday, this opportunity will not be beneficial.

In light of this, the opportunity of extended life time to avoid Sunday outdating (in case of Sunday closure) also has its limitations for practice. However, it was shown that crowdedness and demand are of high influence on outdating and one might consider trying to ensure that the oldest batch of products at DC will be delivered to stores with many consumers, while the stores where the product is a slow mover receive fresher products.

Finally the opportunity of delaying the last order of the week is only beneficial if the DC is already opened at Sunday. Moreover, it would only be beneficial within the current design (midday ordering, delivery in between days) because in this particular case it will not affect any other orders. I.e. when one would delay morning orders, the previous order (in this case Friday morning) needs to cover a longer period.

6.6 | FURTHER RESEARCH

This research left several opportunities to investigate in light of managing outdating. First of all, an opportunity to look into is the deliveries on the day right before closure, as here most outdating comes from. In the simulation model, several possible improvements were proposed, but as these focused on different delivery moments, these improvements did not return the intended results.

Also further research needs to be performed on what the best replenishment interval is, as it seems to depend on the order method. Moreover the effects of relative order quantities are found, but an optimum is not yet identified.

Third topic to look into is promotional effect, as promotions are found to have major effect on outdating, but these effects are not yet specified.

Finally, the regression model that was executed within this research still has opportunity of improvement. The explained variance is not too high, but also several possible effects were not yet tested.

Appendix A. References

Adan, I., van Eenige, M. & Resing, J. (1995). Fitting discrete distributions on the first two moments. *Probability in the engineering and informational sciences*, *9*, 623–632. Cambridge Univ Press.

AH blijft grootste van allemaal . (2012). Retrieved from http://www.retailnews.nl/rubrieken/meer/vastgoed/35978/ah-blijft-grootste-van-allemaal.html

Ahold verreweg grootste retailer. (2003). Retrieved from http://www.marketingfacts.nl/berichten/ahold_is_verreweg_grootste_retailer_van_nederland

Arentshorst, J. (n.d.). Inventory modeling of perishable goods.

Baker, J., Grewal, D. & Parasuraman, A. (1994). The influence of store environment on quality inferences and store image. *Journal of the Academy of Marketing Science*, *22*(4), 328–339. Springer.

Bloemer, J. & De Ruyter, K. (1998). On the relationship between store image, store satisfaction and store loyalty. *European Journal of Marketing*, *32*(5/6), 499–513. MCB UP Ltd.

Broekmeulen, R. A. C. M. & Van Donselaar, K. H. (2009). A heuristic to manage perishable inventory with batch ordering, positive lead-times, and time-varying demand. *Computers & Operations Research*, *36*(11), 3013–3018. Elsevier.

Chen, F. & Ou, T. (2009). Gray relation analysis and multilayer functional link network sales forecasting model for perishable food in convenience store. *Expert Systems with Applications*, *36*(3), 7054–7063. Elsevier.

Chen, L. M. (2009). *On the joint price and replenishment decisions for perishable products*.

Dave, U. (1991). On probabilistic scheduling period inventory system for deteriorating itemswith instanteneous demand. *Optimization*, *3*(22), 467–473.

Deniz, B., Scheller-Wolf, A. & Karaesmen, I. (2004). Managing inventories of perishable goods: The effect of substitution.

Van Donselaar, K. H. & Broekmeulen, R. A. C. M. (2011). Fill Rate Approximations for a Perishable Inventory System with Positive Lead Time and Fixed Case Pack Size Using a Modified (R, S, Nq)-Replenishment Policy in a Lost Sales Environment.

Van Donselaar, K. H. & Broekmeulen, R. A. C. M. (2012). Approximations for the relative outdating of perishable products by combining stochastic modeling, simulation and regression modeling. *International Journal of Production Economics*. Elsevier.

Van Donselaar, K., Van Woensel, T., Broekmeulen, R. & Fransoo, J. (2006). Inventory control of perishables in supermarkets. *International Journal of Production Economics*, *104*(2), 462–472. Elsevier.

Ettouzani, Y., Yates, N. & Mena, C. (2012). Examining retail on shelf availability: promotional impact and a call for research. *International Journal of Physical Distribution & Logistics Management*, *42*(3), 213–243. Emerald Group Publishing Limited.

Ferguson, M. E. & Ketzenberg, M. E. (2005). Information Sharing to Improve Retail Product Freshness of Perishables (ed. 3). Georgia Institute of Technology.

Field, A. (2009). *Discovering statistics using SPSS*. Sage Publications Limited.

Goyal, S. & Giri, B. (2001). Recent trends in modeling of deteriorating inventory. *European Journal of Operational Research*, *134*(1), 1–16. Elsevier.

Gruen, T. W. & Corsten, D. S. (2007). *A comprehensive guide to retail out-of-stock reduction in the fast-moving consumer goods industry*. Grocery Manufacturers of America.

Gunders, D. (2012). Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill.

Haijema, R. (2011). Optimal issuing of perishables with a short fixed shelf life. *Computational Logistics*, 160–169. Springer.

Hair, J. F., Black, W. C., Babin, B. J. & Anderson, R. E. (2010). *Multivariate Data Analysis - A Global Perspective* (7th ed.). Pearson.

Hansen, P. & Heinsbroek, H. (1979). Product selection and space allocation in supermarkets. *European Journal of Operational Research*, *3*(6), 474–484. Elsevier.

Kahn, B. E. & Schmittlein, D. C. (1989). Shopping trip behavior: an empirical investigation. *Marketing Letters*, *1*(1), 55–69. Springer.

Karaesmen, I. Z., Scheller-Wolf, A. & Deniz, B. (2011). Managing perishable and aging inventories: review and future research directions. *Planning Production and Inventories in the Extended Enterprise*, 393–436. Springer.

Kent, A. E., Kent, T. & Omar, O. (2003). *Retailing*. Palgrave MacMillan. Retrieved from http://books.google.nl/books?id=fIyFQgAACAAJ

Keuchenius, C., Cohen, L. Fedorova, T., Van Hinte, P. & Jakobs, E. (2009). Effecten zondagsluiting winkels. *Dienst Onderzoek en Statistiek Gemeente Amsterdam*, (project 9106).

Koopzondagen en avondopenstelling. (2012). Retrieved from http://www.rijksoverheid.nl/onderwerpen/winkeltijden-en-koopzondagen/koopzondagen-en-avondopenstelling

Kök, A. G. & Fisher, M. L. (2007). Demand estimation and assortment optimization under substitution: Methodology and application. *Operations Research*, *55*(6), 1001–1021. INFORMS.

Logistics. (n.d.). Retrieved from http://www.merriam-webster.com/dictionary/logistics

Matsa, D. A. (2011). Competition and product quality in the supermarket industry. *The Quarterly Journal of Economics*, *126*(3), 1539–1591. Oxford University Press.

Nahmias, S. (1975). Optimal ordering policies for perishable inventory—II. *Operations Research*, *23*(4), 735–749. INFORMS.

Nahmias, S. (1982). Perishable inventory theory: A review. *Operations Research*, 680–708. JSTOR.

Nijs, V. R., Dekimpe, M. G., Steenkamp, J. B. E. M. & Hanssens, D. M. (2001). The category-demand effects of price promotions. *Marketing Science*, 1–22. JSTOR.

Novum. (2012). Gemeenten vrij in keuze voor koopzondagen. Nu.nl. Retrieved from http://www.nu.nl/economie/2930017/gemeenten-vrij-in-keuze-koopzondagen.html

Novum. (2012). Kritiek op verruimen koopzondagen. Nu.nl. Retrieved from http://www.nu.nl/politiek/2941145/kritiek-verruimen-koopzondagen.html

Raafat, F. (1991). Survey of literature on continuously deteriorating inventory models. *Journal of the Operational Research Society*, 27–37. JSTOR.

Replenishment. (n.d.). Retrieved from http://www.merriam-webster.com/dictionary/replenishment

Silver, E. A., Pyke, D. F. & Peterson, R. (1998). *Inventory management and production planning and scheduling* (Vol. 3). Wiley New York.

Slechts 4 Nederlandse bedrijven in de top 250 van grooste wereldwijd opererende retailers. (2010). Retrieved from http://www.supermacht.nl/keten-in-kaart-othermenu-29/43-levensmiddelen/257-slechts-4-nederlandse-bedrijven-in-de-top-250-van-grootste-wereldwijd-opererende-retailers

Soethoudt, J., van der Sluis, A., Waarts, Y. & Tromp, S. (2012). BO-Voedselverspilling.

Stanger, S. H. W., Wilding, R., Yates, N. & Cotton, S. (2012). What drives perishable inventory management performance? Lessons learnt from the UK Blood Supply Chain. *Supply Chain Management: An International Journal*, *17*(2), 1–1. Emerald Group Publishing Limited.

Supermarkten in Nederland. (2011). Retrieved from http://zakelijk.infonu.nl/detailhandel/72950-supermarkten-in-nederland.html

Taylor, J. W. (2007). Forecasting daily supermarket sales using exponentially weighted quantile regression. *European Journal of Operational Research*, *178*(1), 154–167. Elsevier.

Voedselverspilling. (2012). Retrieved from http://www.rijksoverheid.nl/onderwerpen/voeding/voedselverspilling

Van Woensel, T., Van Donselaar, K., Broekmeulen, R. & Fransoo, J. (2007). Consumer responses to shelf out-of-stocks of perishable products. *International Journal of Physical Distribution & Logistics Management*, *37*(9), 704–718. Emerald Group Publishing Limited.

Appendix B. RESEARCH PROJECTS

Q1. What is the difference in write-offs between 'co-makers' and suppliers?

Co-makers might abuse their responsibility of the stock at the DC's as they can store unwanted products at the distribution centre, whereas regular suppliers only supply ordered products.

Q2. What is the relationship between write-offs (both store and DC) and the occurrence of holidays?

Holidays often incorporate free days (e.g. Christmas, Eastern, etc.), disrupting the flow of goods towards the stores, as well as the demand from the stores. Where you could regularly view the safety stock as 'reusable' stock, this will increase and possibly lead toward more write-offs.

Q3. What is the relationship between write-offs (both store and DC) and the occurrence of promotion?

Promotions increase demand, but it is hard to predict the lift factor. Following the 'winkelbeeld' (store image) and out-of-stock guidelines, you might be inclined to overstock.

Q4. What is the relationship between write-offs and the type of promotion?

Different promotion types and themes might have different effects on forecasting, sales and resulting outdating. According to Replenishment Preparations Specialist Frank Janssen, this largely depends largely on the group of promotions and the accuracy of the prediction of promoters.

Q5. How is deterioration of products (and write-offs of perishables) distributed along the supply chain?

Fruit will deteriorate in store due to moistly weather at the start of the chain. It might also be interesting to show what percentage of waste is disposed in store, what percentage in DC, etc.

Q6. What is the definition of quality? And of fresh?

During the store visit, Willem threw away a mango that was only slightly wrinkled and probably had a very good taste. Similarly there can be differences in opinion on what defines freshness of a product, the remaining shelf life, or the 'intended' shelf life? The first one might imply that lengthening the shelf life will improve freshness, while the second might mean that shorter intended shelf life means it was produced later on and is therefore fresher.

Q7. What is the stock period of products for the different product types and how does this relate to the write-offs?

If some products have items in stock for three days, while they have a daily replenishment, this might be worth evaluating.

Q8. What is the difference in write offs of 'shortly fresh' products and 'regular fresh' products? Or other differences within perishable products (e.g. milk vs meat)

Short fresh products probably are more sensitive to sales and leftovers than other fresh products. This would be helpful to identify critical products.

Q9. What is the difference in write offs for products going out of the system, new in the system, and continued in the system.

Identifying the write-off relation to 'life cycle stage' would help identifying critical products.

Q10. How are sales distributed during the day and do opening times influence the amount of write-offs?

It is considerably easier to manage a 7 days a week open store than one that is closed on Sunday, as it must decrease its inventory by the end of Saturday, and restore this on Monday (Peter). On behalf of opening times, it really depends on the type of product: category 'maaltijdgemak' (convenience dinner) is sold primarily between, say 5PM and 8PM, whereas bread is sold early in the morning.

Q11. Is deterioration *experience* continuous or in stages, and if in stages, how many and what are these?

This question is best explained using the following theorem:

Any product containing an expiry date will have the following quality distribution: first rather equal (good) then suddenly poor. Still, the majority of people will buy the newest (freshest) product. Any product not containing an expiry date will continuously decline in quality. However, people will distinguish stages 'too early', 'acceptable', 'good', 'acceptable', 'too late', which is very subjective, and will only purchase the 'good' products' and possibly 'acceptable'. See also literature on consumer's perception on expiry dates.

Q12. How are the causes of write-offs distributed (e.g. milk can be expired or poorly cooled, fruit overripe or mildewy)?

Gunders (2012) claims that also reduction of quality in the supply chain is of major influence on the expiry of products in store. A research that tries to trace causes of outdating back to supply chain issues (e.g. staying too long in docking which is poorly cooled) or sales issues (few customers/bad forecasting) can be helpful to identify critical products.

Q13. How will shortening the supply chain influence freshness (i.e. let the supplier directly deliver at the stores, like bread is currently managed)

Shortening the supply chain will probably increase flexibility and decrease stocks and overstocking (see literature review).

Q14. What is the trade-off between expanding the assortment and write-offs?

This is a question from Replenishment Preparation Specialist Lars Krommendijk. The example given is of prepared meals (e.g. salads). Going from 8 to 10 flavours will barely increase sales. However, as all need to be in stock and have a very short date, you will throw away more (demand from 14 meals to 15, all stocked 3, expire date 2, then you will remain about 10-15 items).

Q15. What is the relationship between the number of facings allocated/shelf space and the amount of write-offs?

Facings/shelf space and sales are positively correlated, however as extra facings/shelf space does also mean more products to meet 'winkelbeeld' it probably affects write-offs. Where's the optimum?

Q16. What is the effect of relocating nearly expired products (in case of AH discounted products) on the demand distribution

THEOREM: in case of some product types (e.g. salad meals), relocating the discounted products to a particular place might increase the consumption of these products as the consumer will consume these products right away and might prefer price over choice/flavour. However for other products, that are characterised by long term use, like milk and cheese, this will probably decrease sales of these products. There are also product categories that might neither benefit nor counterfeit from this. These are products that typically can be purchased to consume right away or for long term (e.g. fruit and vegetables).

Q17. How does discounting influence the de customers' choice between 'fresh' and 'less fresh' products?

Why does Albert Heijn use 35% discount (why not more, why not less)? What will happen if you would introduce 15% discount for goods that are over their shelf life?

Q18. How can alternative ways of promotion help?

It seems that different ways of promotion might help customers to understand the meaning of dates better, and this should improve the issuing method and the resulting outdating (Gunders, 2012).

Q19. What collaborations can help?

The nearly expired products that are not sold in time, are currently waste. However, one might consider using this for the benefits of the less wealthy, like the Salvation Army. Also, ensuring leftovers will end-up in a local restaurant to be used, can reduce the actual waste (Gunders, 2012).

Q20. What is the effect of location and is there a difference in write-offs between short dates and 'regular' dates?

It might be wise to have products with short dates on a particular location on shelf (e.g. middle height) as this will increase sales (see van Nierop et al, 2008).

Q21. What are the opportunities of postponement?

Postponement means delaying the process of making goods customer specific. For example the introduction of Grill&Steak, where fresh steak is cut in-store and divided in-store over 'no flavour' and 'marinated', is postponement as you combine orders of all steak flavours (as well as their safety stock).

Q22. How will new technologies, like longer barcodes, influence the inventory accuracy and the related remaining goods?

New technologies will certainly make life more easy as all products are traceable. However, currently all goods are manually checked, implying little room for improvement of inventory accuracy. It might help in combination with question Q12.

Q23. How is assortment breadth related to write-offs?

Decreasing the choice of prepared meals probably does not/barely affect sales, but will decrease left-overs.

Q24. How do consumers behave when facing an empty shelf?

For bread is already researched that they will substitute about 80-85% of the time, this might be different for other products. However, high substitution potential will reduce write-offs, just like bread (not all bread is left in store by the end of the day, hence only little write-offs).

Appendix C. Reasoning of regression variables

Variable		Short explanation	Possible effect on outdating
$\boldsymbol{w_W^f}$	:=	Store formula of W	Slightly different assortment and presentation might influence consumer behaviour. Hence XL might differ from regular stores.
$\boldsymbol{FASG}$	:=	Assortment group	FASG can be useful to identify products of risk.
$\boldsymbol{BE}$	:=	Order quantity	High order quantities might lead to overstocking and waste.
$\boldsymbol{PT}$	:=	Production term	If the time between production and sales (and especially between production and arrival at DC) is rather long, this might affect (perceived) quality. Also it leads to rather high inventory, which is less adaptive to actual demand (especially low demand) than short inventory period.
$\boldsymbol{DT}$	:=	Distribution term	Reasoning similar to PT. If the time between arrival at DC and sales (and especially between arrival at DC and shipping to store) is rather long, this might affect quality. Also it leads to rather high inventory, which is less adaptive to actual demand (especially low demand) than short inventory period.
$\boldsymbol{VT}$	:=	Shelf life	Short shelf life might have more chance of outdating before sales, due to relatively low demand. It is also useful to identify products of risk.
$\boldsymbol{NB}$	:=	On shelf availability	The intended availability will require certain safety stock, which might expire.
$\boldsymbol{WB}$	:=	Norm for store image	Intended store image will require certain safety stock, which might expire.
$\boldsymbol{c}$	:=	Comaker	Comaker is in charge of availability at DC and therefore indirectly for availability in store. It is argued within AH that comakers have high stocks at DC, which would lead to high outdating at DC.
$\boldsymbol{w_W^o}$	:=	Days of the week open	Relative high part of the week closed would lead to low sales opportunity, as well as high stocks due to high demand (think of Christmas). Hence high outdating.
$\boldsymbol{CROWD}$	:=	Average crowdedness	Busy stores can have high inventory and more outdating. The other way around, a product that is in stock in a calm store has high risk of outdating.
$\boldsymbol{FSC_{kW}}$	:=	Shelf capacity	Shelf capacity has effects on both store image and average stock due to current replenishment rules. Hence it indirectly might influence outdating.
$\boldsymbol{s_{corr}}$	:=	Corrected average stock	Relative high average stock increases the chance of a product not to be sold.
$\boldsymbol{REPL_{del}}$	:=	possible deliveries a week	The amount of deliveries a week affects the period to bridge with your inventory and can influence remaining stock, but also makes it more or less easy to synchronize replenishment with demand.
$\boldsymbol{REPL_{del}^{lvc}}$	:=	possible deliveries LVC	See $REPL_{del}$. It might be different for different types of products.
$\boldsymbol{REPL_{del}^{rdc}}$	:=	possible deliveries RDC	See $REPL_{del}$. It might be different for different types of products.

Variable		Short explanation	Possible effect on outdating
$\boldsymbol{REPL_{del}^{int}}$	:=	delivery interval	See $REPL_{del}$ but now put in perspective with amount of days opened.
$\boldsymbol{DT/VT}$	:=	Ratio between DT and VT	A relative long stay at DC leaves less possibility of sales.
$\boldsymbol{BE_{rel}}$	:=	Relative order	See BE. When this is put in perspective with sales during shelf life, it might be more accurate.
$\boldsymbol{mu_{kW}}$	:=	Average demand per week	Low demand, combined with inventory required for NB or WB can lead to large remaining inventory and expiry.
$\boldsymbol{sd_{kW}}$	:=	Standard deviation of demand	High uncertainty might lead to high stocks and low demand, hence to outdating.
$\boldsymbol{CV_{kW}}$	:=	Coefficient of variance	Relative high uncertainty might better explain the behaviour than just the standard deviation.
$\boldsymbol{p_{kt}}$	:=	Presentation/visualization	Promotion is less predictable and increases demand, stock and variance. This might result in more outdating.
$\boldsymbol{p_{k(t-1)}}$	:=	Presentation last week	The effect of promotion might be postponed to right after promotion as the outdating itself does not take place in that particular week, due to shelf life.
$\boldsymbol{D_m}$	:=	Fraction of missed demand	This factor is proposed by K. H. Van Donselaar & Broekmeulen (2012) and has a reasoning similar to NB.
$\boldsymbol{sQ\_Qmu}$	:=	$\left[\frac{s}{BE}\right] * \frac{BE}{mu}$	This factor is also proposed by K. H. Van Donselaar & Broekmeulen (2012), reasoning similar to s_{corr}, but now calculated using the relative order level (relative toμ).
$\boldsymbol{AF_{rel}}$	:=	Relative order quantity by DC	A factor similar to BE_{rel}, but for DC orders. It probably only affects DC waste. However, when the quantity is not too high, it might be tried to sell anyway and that might result in outdating.
$\boldsymbol{M_{tkw}}$	:=	Percentage of orders adapted	If the store actively adapts (increases) the automatically obtained orders, this might result in more outdating.
$\boldsymbol{e_k}$	:=	Self-service item (ego)	Self-service items are available for the customer. When an item is not self-service, it can be customized and stocks can be combined for several end-products.
$\boldsymbol{g_{tkw}}$	:=	Sales part within group	Can identify products of risk.
$\boldsymbol{w_W^p}$	:=	Store performance	Store performance might reflect how good the replenished products are actually showed in store. If goods are available but not shelved, this should lead to bad performance ratings. These items will not be sold as they are in store, but unavailable to the customer.
$\boldsymbol{d_k}$	:=	Date type (open versus closed)	Open dates are readable for consumers and might affect their behaviour; for closed dated products the consumer doesn't know the product nearly expires.
$\boldsymbol{w_W^t}$	:=	Fraction of counts	If a store often checks its inventory, the theoretical inventory (in the system) and the real inventory are more aligned, leading to less faulty replenishments.
$\boldsymbol{u_k}$	:=	Unit (pieces versus weight)	In line with the date type, the quality of 'weight' products might be perceived differently than of packed products.

Restrictions

The following variables were restricted in order to exclude outliers. A filter variable *FILT* was included to split the file.

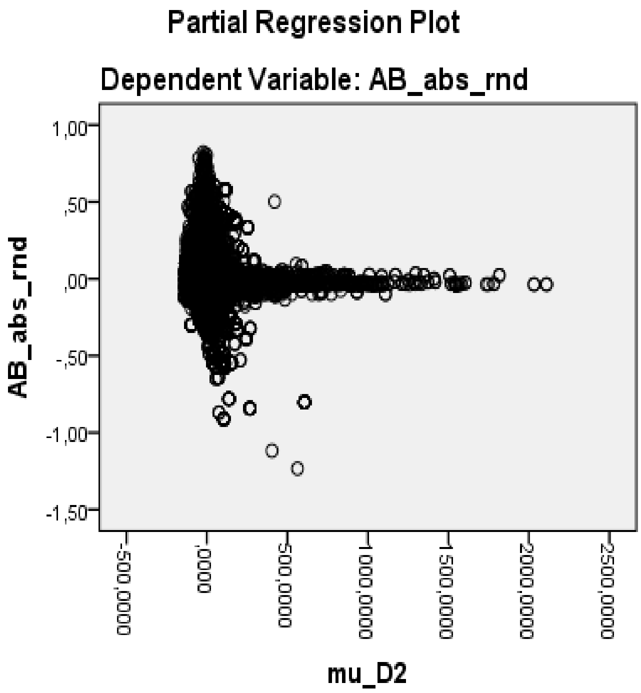
Variable	Minimum restriction (outlier if < value)	Maximum restriction (outlier if > value)	Percentage excluded
Weekpattern	0	5	0.7%
Replenishment_interval		2	1%
Relative outdating		1	2%
Promotion_B		0	0.9%
$\boldsymbol{CV^2}$		1.25	0.2%

Also the shelf life VT was limited to six days, to enhance explained variance. This reduced the dataset from 350,000 cases to 105,000.

Transformations

Several variables needed to be transformed to correct for heteroscedasticity. Figure 7 shows an example.

Variable old	Variable transformed
$\boldsymbol{Mu\_week}$	$Log(mu\_week)$
$\boldsymbol{Sd\_week}$	$Log(sd\_week)$
$\boldsymbol{CV}$	CV^2
$\boldsymbol{DT/VT}$	$Log(DT/VT)$
$\boldsymbol{Crowd}$	$\sqrt{(Crowd)}$



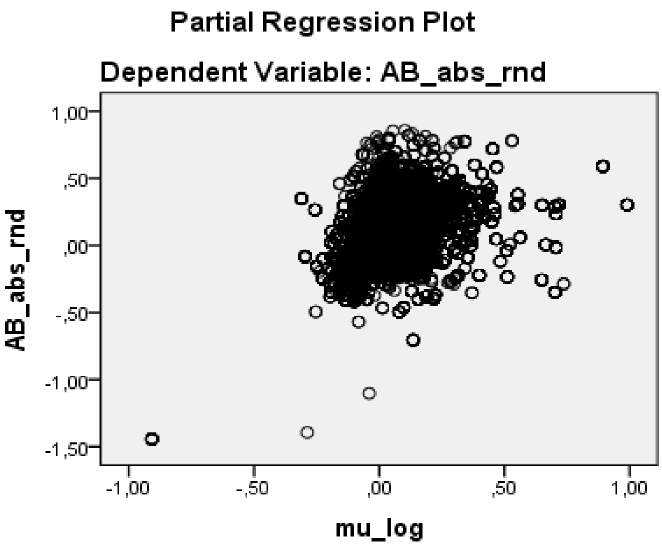


Figure 7 | Variable transformation