MASTER'S THESIS

Dynamic Three-Dimensional Resource Space Allocation in a Multi-Item Inventory Environment

A research into three-dimensional resource space allocation in the Self-Serve Furniture Area and Warehouse department of the local warehouse store of the IKEA Group in Hengelo, Overijssel.

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”The most dangerous poison is the feeling of achievement. The antidote is to every evening think what can be done better tomorrow.”

Ingvar Kamprad
Founder of IKEA

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Management Summary

Retail selling space is a finite resource that requires frequent decision making about which items to stock and how much space to allocate to these items. The product allocation does not only influence the perceptibility, demand and sales revenue of certain products, it also influences various costs, ergonomics and safety restrictions. The division of this finite amount of retail space is an important decision within an IKEA store. The stores do not purely offer a shopping experience for the visitors, they also operate as a warehouse, where products are received, inventory is held and orders are handled. Currently there are 13 stores operational within the Netherlands, of which one store in Hengelo, Overijssel. The general store layout consists of a Showroom, Markethall, Self-Service Furniture Area (SSFA) and Warehouse (WH). The SSFA and WH departments show similar characteristics as a general warehouse, from the storage of products in racking, to order picking services. Since the opening of the store in Hengelo, the amount of flow through the SSFA and WH departments increased significantly. Furthermore, it is forecasted that this amount of flow will increase even further. The amount of available retail selling space (or Stock Keeping Area (SKA)) in these departments stays the same, resulting in that the current usage of the SKA is not in line with the expected growth in customer demand. This research focuses on increasing the efficiency of the SKA allocation, within the SSFA and WH departments of the store in Hengelo, Overijssel.

Research Objective

The subject of this thesis is the dynamic allocation of the resource space (SKA) among a set of Stock Keeping Units (SKUs), in which the three-dimensional characteristics of both the SKA, and the SKUs are taken into account to create an efficient solution. The research objective is defined as follows:

To develop an efficient, adaptive and generic approach of SKA allocation, within the racking sections of the SSFA and WH departments.

The research objective is three-fold and the objectives are mutually dependent. First the SKA allocation needs to be efficient. Secondly, the allocation needs to be adaptive, such that changes in product range and resources can be included. Finally, the allocation needs to be generic, such that it can be applied to different stores settings.

Method

The developed method is based on the existing goods allocation process and incorporates safety and ergonomic restrictions. Furthermore, it is designed such that it is beneficial to a set of defined Key Performance Indicators (KPIs), namely to the internal damages, handling rate, Customer Service Level (CSL) and fast picking operations. The model is based on the principles of the bin packing problem. The resources can be seen as a set of finite bins, with three-dimensional characteristics. In the regular bin packing problem, these bins are infinite and have identical sizes. In the scope de-

partments the resources are finite, not always identical and, therefore, can have different sizes. The restriction that only identical products are allowed to be placed upon and behind each other, makes it possible that the height and length dimension of the products can be used as a selection criterion for the racking. In this way, the three-dimensional problem is reduced to a one-dimensional problem and the different bin sizes are incorporated with the use of the selection criteria.

A heuristic is designed to obtain the right SKU dimensions to allocate. This heuristic makes use of the dynamic character of product allocation, whereby boxes can be placed upon, behind and next to each other. In every allocation step the resources are checked if the dimensions fit and afterwards the SKU is allocated according to one-dimensional bin packing problem approximate approaches.

Safety restrictions are implemented with the use of adaptive slack variables per resource. This slack includes slack between SKUs, between SKUs and uprights and between SKUs and sprinklers. This slack is also, together with the correct allocation, beneficial to preventing internal damages. Furthermore, the products can be placed according to demand rate, such that fast moving articles are placed closer to the output. The one-dimensional bin packing problem has the goal to place the SKUs in as few resources as possible, therefore increasing the utilization of the resources. In other words, it increases the amount of SKUs that can be allocated within the SKA, therefore increasing the CSL and reducing the buffer movements and handling rate.

Results

The model is programmed into a stand alone executable software program. The outcomes are validated, verified and benchmarked against the manual SKA allocation within the WH. In this manual allocation the safety restrictions are not fully implemented and not all products are allocated according to allocation principles. The model provides an allocation rate of 92.7% of the SKUs currently assigned to the sales locations within the WH and a racking occupation of 81.1%. The model indicates a lack of level 00 locations and an overflow of level 10 locations, resulting in 7.3% not allocated products. Furthermore, the allocation time is reduced from a few hours to a few minutes.

Recommendations

The developed model provides insight into the allocation process. It is a complement to, not a substitute of, the current goods allocation process. The model and study face limitations due to its scope and time window. The output of the model, in combination with the limitations of this research, result in recommendations for further research. The recommendations are summarized below and are both practical, as theoretical based.

- Update the racking layout. The model output indicates a mismatch in location types. Additional level 00 locations can be created by cannibalizing the overflow of level 10 locations. This cannibalization can increase the product allocation rate to 95.1% (+2.4%) and the racking occupation to 87.7% (+6.6%)

- Further verification and implementation of the model. The model is currently benchmarked against the WH allocation. This benchmark can be extended to the SSFA and other store settings. Furthermore, a frequent usage of the model is recommended, in order to obtain the benefits of the model to their fullest.

- Further reduction of the internal damages. Not all the internal damages can be prevented with the use of the model. Further practical implementation of mats within racking and push back protection can result in additional reduction of internal damages.

Preface

In the autumn of 2018, I began to see the final horizon of my masters. This horizon implies the end of an era, an era which I look back at with great pleasure and nostalgia. At long last, all good things come to an end. Fortunately, an ending is always the beginning of something new. I believe that, within every individual, there is an opportunity and a sense of responsibility to turn these new realities into something special. It goes without doubt that I would like to take on that challenge.

To reach this final horizon of my masters, I had the opportunity to conduct my graduation thesis at the *IKEA Group*. I'm proud to cordially present you this thesis, which marks the end of my time as an *Industrial Engineering and Management* student at the *University of Twente* and the beginning of my career as an industrial engineer. This report includes not merely the technical results of my work, but also breathes the joy and spirit which I felt throughout my entire internship period.

This leap to the final horizon was not possible without the persons who gave me the opportunity to do so. First I want to thank all my fellow co-workers of *IKEA Hengelo*, with a special word of gratitude to all the employees within the logistics department. The open culture, guidance and expertise made it possible for me to complete this thesis and work on it with a big smile. Next, I would like to thank *Thijs Wieffer* and *Kimberly Kruize* for granting me this opportunity. My special thanks goes to *Thijs*, who served as my main supervisor, for his expertise, open mind and feedback. Furthermore, I want to thank *Marlene Martin* for her supervision, time and guidance. I had a great time at *IKEA* and enjoyed working in the logistics department, the activities and, of course, the *IKEA* family and culture. At the university, I had the honor to be supervised by *Peter Schuur* and *Sipke Hoekstra*. I want to thank them both for their constructive feedback, suggestions and open minds. Without the great input from all these people this thesis would not have been possible. I am glad to have had the opportunity to work with all of them.

With the horizon in sight, I look back at the great opportunities that were given. The *University of Twente* enabled me to learn, grow and obtain experiences, throughout my bachelor's and master's degree periods. During my time at the university, I met a lot of inspiring and interesting people, from all over the world, with all sorts of different backgrounds. I enjoyed the open minds and diversity of my fellow students, which made it a pleasure to work and laugh with them during lectures, projects, excursions and association meetings. People to never forget. I would like to conclude with the words of *Ingvar Kamprad*, the founder of *IKEA*: "*Most things still remain to be done. Glorious future!*".

Thijs Bemthuis
Enschede, March 2019

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List of Abbreviations

1D-BPP One-Dimensional Bin Packing Problem. xiii, xiv, 33, 35, 40, 44, 45, 50, 51

2D-BPP Two-Dimensional Bin Packing Problem. xiii, 33, 35

3D-BPP Three-dimensional Bin Packing Problem. xiii, 33, 35, 60

APQC American Productivity & Quality Center. 29

BF Best-Fit. 34

BFD Best-Fit Decreasing. 34

CCSBP Class Constrained Shelf Bin Packing Problem. 34

CEO Chief Executive Officer. 26

CP Customerpack. 56–58, 63

CSL Customer Service Level. vii, viii, 8, 9, 26, 27, 34, 38, 45

CSP Common Store Planning. xiii, 20–22

DC Distribution Center. 3, 11, 17, 18, 26, 27

DD Direct Deliveries. 18, 27

EDS End Date Sales. 24

ELF European Low Flow. 18, 27

EP Euro Pallet. 41

FF First-Fit. 34

FFD First-Fit Decreasing. 34

FPL Full Pallet Load. 24

FTL Full Truck Load. 17

FY Financial Year. xiii, 1, 2, 6, 9

GDP Gross Domestic Product. 29

GUI Graphical User Interface. xiv, 39, 47, 48

HFB Home Furniture Business. 4, 5, 20, 24, 34

IoS Ikea of Sweden. 2

KPI Key Performance Indicator. vii, 11–13, 17, 24, 27, 34, 38, 45, 47, 53, 67

MH Markethall. xiii, 4–6, 9, 10, 20

MP Multipack. 57, 58

NF Next-Fit. 34

NFD Next-Fit Decreasing. 34

SKA Stock Keeping Area. vii, viii, xi, xv, 6, 8–14, 17, 19, 21–24, 26, 27, 29, 30, 34, 38, 39, 45, 46, 60, 61

SKU Stock Keeping Unit. vii, viii, xiii–xv, 6, 12, 18, 22, 23, 26, 30–32, 34, 35, 38–42, 44–46, 49–51, 54, 56–61, 64, 67

SLM Sales Location Management. 24

SOP Standard Operating Procedures. 22

SR Showroom. xiii, 4–6, 10, 20

SS Safety Stock. 29

SSFA Self-Service Furniture Area. vii, viii, xi, xiii, 4–6, 8–13, 17, 19–24, 26, 27, 29, 30, 38, 45, 61, 66

VR Virtual Reality. 26

WH Warehouse. vii, viii, xi, xiii, xiv, 4, 6, 8–13, 17, 19–24, 26, 27, 29, 30, 38, 45, 56, 60, 61, 66

Chapter 1

Introduction

In the framework of completing my master's degree in *Industrial Engineering and Management* at the *University of Twente*, I conducted my graduation project at *the IKEA Group*. This research focuses on the store location of *the IKEA Group* in *Hengelo, Overijssel*. The whole process from the production of raw materials to the finished product in the living room of the end customer implies a complex supply chain. A part of this supply chain is the distribution of products through the local warehouse stores of *the IKEA Group*. With this complexity comes challenges for increasing efficiency and improvements in customer service.

This chapter provides an introduction to this research. Section 1.1 introduces *the IKEA Group*, focusing on both the national and international context of the company. Subsequently, Section 1.2 introduces the local warehouse store in *Hengelo, Overijssel*. Section 1.3 contains the problem identification, in which we identify and state the problem addressed in this research. Section 1.4 contains the research design, including the research objective, scope, questions and approach. Finally, Section 1.5 concludes this chapter with the structure and motivation of the remaining part of this thesis.

1.1 Company Introduction

The IKEA Group is a global home furniture company and was originally founded in 1943 [6]. The name ”IKEA” is an acronym formed from the founder's initials (Ingvar Kamprad), the first letters of the farm he grew up in (Elmtaryd) and his hometown in Smland, southern Sweden (Agunnaryd) [6]. The IKEA Group consist of a group of companies (Ingka Holding B.V. and its controlled entities) that are owned by the Stichting Ingka foundation [7]. Ingka Holding B.V. is one of the 11 franchisees and it exploits the IKEA warehouse stores through franchise agreements with Inter IKEA Systems B.V., the owner of the IKEA concept and the worldwide franchisor of IKEA [8] (Section 1.1.1). Inter IKEA Systems B.V. is owned by the Inter IKEA Group, which operates independent from the IKEA Group [8].

Over the Financial Year (FY) 2017 the group registered 817 million store visits worldwide [1]. In total these visits generated a part of the total revenue of 36.3 billion euro's, from which 2.5 billion euro's net profit [1]. The group employed a total of 149.000 co-workers, from which 134.400 in retail, 9.100 in distribution, 2.100 in shoppingcentres and 3.400 in other occupations [1]. Every year the IKEA product range is renewed with (approximately) 2.500 products, which sums up to a total of (approximately) 9.500 products in the IKEA range [1].

At the end of the FY17 the IKEA Group operated 355 IKEA stores in 29 countries [8]. Furthermore, it operated 24 pick-up and order points, 43 shopping centers, 31 store distribution sites and 26 customer distribution sites worldwide [9] (Figure 1.1).

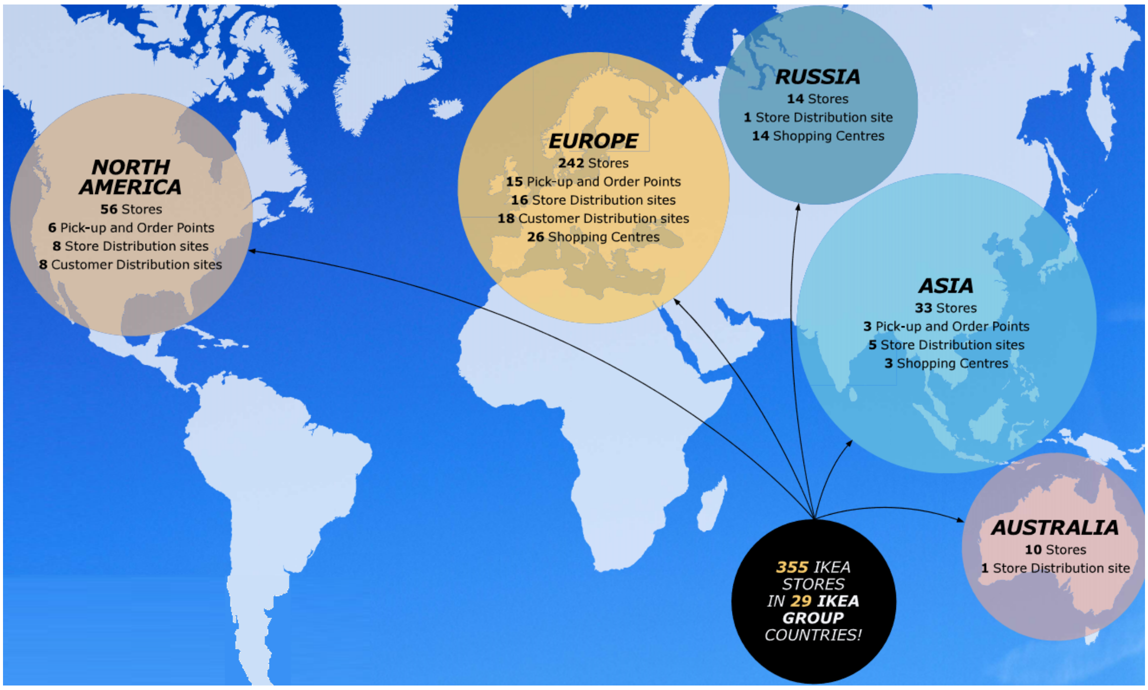


Figure 1.1: IKEA stores worldwide, amended from the IKEA Group yearly summary FY17 [1]

1.1.1 Design, Range and Supply

Design, range and supply are part of the main occupations of the Inter IKEA Group [10]. Furthermore, the focus lies on franchise operations and industry. The franchise operations are located in the Netherlands, the range operations in Sweden and the supply operations in Switzerland [10]. Most of the industry activities are based in Poland [10].

Inter IKEA systems B.V. is a part of the Inter IKEA Group and is owner of the IKEA concept and worldwide IKEA franchisor [10]. It develops the IKEA concept and implements it in new and existing markets [10]. Currently, the IKEA concept is being reviewed with regard to reestablishing different aspects to align multichannel retailing [10] (see Chapter 2). Moreover, Inter IKEA B.V. is occupied with defining a new strategy which will focus on three main areas: health and sustainable living, becoming circular and climate positive, and contributing to a fair and equal society [10].

The range and supply business of the Inter IKEA Group is responsible for developing and supplying the global IKEA range [10]. This includes activities within the whole value chain, from supplier to customer [10]. Within these activities also Ikea of Sweden (IoS) AB, IKEA Supply AG, IKEA Communications AB, IKEA Food Services AB and related businesses are involved [10].

IoS is responsible for developing, designing and producing home furnishing solutions [10]. IKEA Supply AG is the wholesale company that supplies all the IKEA franchisees with IKEA products and it produces and supplies the components solutions used to assemble those products [10]. It is also the owner of the goods within the Distribution Centers (DCs) worldwide [10]. Overall there are 24 purchase and logistic service offices to support external suppliers [10]. IKEA Communications AB is the communication agency that creates and produces IKEA communication for customers and other IKEA organizations, e.g. the IKEA catalogue [10]. IKEA Food Services AB develops the food and beverages product range sold in the IKEA restaurants, cafes, bistros and Swedish food markets in the IKEA stores [10].

1.1.2 Production and Sourcing

The industry business of the Inter IKEA Group focuses on manufacturing the IKEA home furnishing products [10]. In total, it produces approximately 10 to 12% of the total IKEA range. The main focus lies on furniture, in which it is the (self proclaimed) largest producer in the world [10]. The operations are conducted through 40 production sides, including forestry, sawmills and production of board material, wood components and ready furniture [10]. These production units are located in China, France, Hungary, Lithuania, Poland, Portugal, Russia, Slovakia, Sweden and the USA [11]. The remaining products of the IKEA range are supplied by (approximately) 1.000 external home furnishing suppliers in 51 countries [10]. About 20% of products are shipped directly from the suppliers to the IKEA stores [12], the rest through a DC.

1.2 Warehouse Store Introduction

Within this research, we focus on the IKEA Group within the Netherlands, with a more narrow focus on the warehouse store location in Hengelo, Overijssel. In Section 1.2.1 we first introduce the different store locations in the Netherlands and briefly highlight the history of IKEA within the Netherlands. Afterwards we define the store location in Hengelo in Section 1.2.2.

1.2.1 Warehouse Stores Within the Netherlands

IKEA has over 35 years of history within the Netherlands. In 1978 the first IKEA store opened in Sliedrecht. In the years after, more stores opened, till the opening of the latest store in Zwolle (2015). In 2001 the new DC in Oosterhout opened. This DC, together with the DCs in Genk (Belgium) and Dortmund (Germany), are the main DC suppliers for the stores within the Netherlands and Belgium. In 2006 the store in Sliedrecht closed, because it became to small for the IKEA product range. A summary of the different IKEA stores, with the corresponding store floor surfaces and year of opening, can be found in Table 1.1.

Table 1.1: IKEA stores within the Netherlands

Location	**Surface** m^2	**Year of opening**
Amersfoort	31,000	2006
Amsterdam	37,700	1982
Barendrecht	38,000	2001
Breda	32,000	2003
Delft	39,000	1992
Duiven	39,000	1983
Son (Eindhoven)	31,800	1992
Groningen	41,000	1997
Haarlem	32,300	2005
Heerlen	38,000	1994
Hengelo	30,000	2002
Utrecht	40,000	1996
Zwolle	29,700	2015

1.2.2 Local Warehouse Store

The warehouse store in Hengelo opened in 2002 (see Table 1.1). It is located in the north of Hengelo, in the shopping area ”Plein Westermaat”, nearby the motorway A1 and close to the Dutch-German border. Due to the location of the store, the majority of the visitors come from both the Netherlands and Germany. Ten years after the opening of the store, the store increased their customer service with the built of a parking garage and increased their parking capacity with 650 places [13]. Furthermore, at the same time, they started to increase their floor capacity with almost 4000 m^2 [13] to (approximately) 30.000 m^2 (see Table 1.1).

The warehouse store is divided into different departments, namely the Showroom (SR), Markethall (MH), Self-Service Furniture Area (SSFA) and Warehouse (WH). Within these sections different areas are located based on product categories, or ”Bubbles”. A product category is called a Home Furniture Business (HFB). A list of the HFB groups can be found in Table 1.2.

Table 1.2: Home Furniture Businesses

HFB group	Products Categories
01	Living room
02	Store and organise furniture
03	Work spaces
04	Bedroom furniture
05	Beds and Mattresses
06	Bathroom
07	Kitchen
08	Dining
09	Children
10	Lighting and home decor
11	Bed and Bath Textiles
12	Home Textiles
13	Rugs
14	Cooking
15	Eating
16	Decoration
17	Oudoor
18	Home Organisation
19	Secondary Storage
20	Other Business Opportunities
92	Family

1.2.3 Store Layout

In the previous section we defined the different departments within the IKEA store. These different departments have an important influence in the layout of the store, since products are located according to the HFB groups (see Table 1.2). Figure 1.2 shows the floor plan of IKEA Hengelo, as available for the customers visiting the store. The figure shows that the different HFB groups are categorized in sections within each department, except for the SSFA.

Figure 1.2: Floorplan IKEA Hengelo

The Showroom (SR)

On the first floor of the store the SR is located. The SR is the first sales area the visitor enters, when entering the store according to the floor plan (Figure 1.2). Within the SR the range of IKEA furniture and furnishing accessories are represented. It enables customers to see the products of IKEA displayed. Afterwards the products can be picked up in the SSFA or be ordered online. Examples of HFB groups that are represented here are 01 (living room), 03 (work spaces) and 07 (Kitchen) (Table 1.2). A visual example of the SR of IKEA Hengelo is given in Figure 1.3.

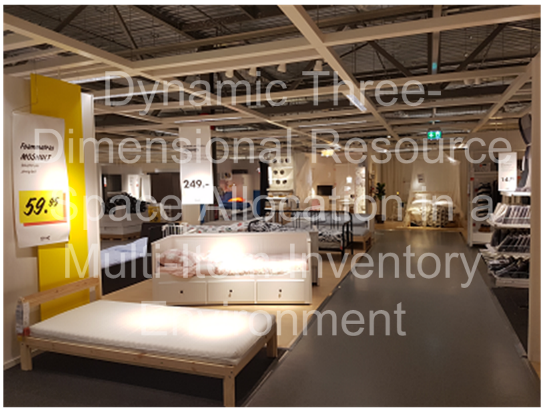


Figure 1.3: SR of IKEA Hengelo

The Markethall (MH)

The MH is located on the ground floor of the store and is entered by the visitor after leaving the SR (according to the floor plan (Figure 1.2)). The MH is similar to the SR, except the products located in the MH are more accessories, instead of furniture. The products can be picked directly or be ordered online. An example of the MH department of IKEA Hengelo is given in Figure 1.4.

Figure 1.4: MH of IKEA Hengelo

The Self Service Furniture Area (SSFA)

The SSFA is located on the ground floor and is entered by the visitor after leaving the MH. The SSFA is a sales area, in which the full height of the building is used to get maximum efficiency for storage, display and availability. The SSFA enables visitors to pick-up products that were displayed in the SR or MH. Furthermore, a small range of products are displayed that enable visitors to see the products of IKEA. Figure 1.5 shows an example of the SSFA of IKEA Hengelo. The idea of the SSFA was originally created in the 1960s. Large volumes of customers caused long lines at the merchandise pick-up areas, resulting in lost sales, unhappy customers and a low customer service. To fight this problem the idea of the SSFA was created, whereby customers can pick up the majority of the purchases themselves. This resulted in lower checkout lines, less staff necessary, eased capacity problems and higher customer service. The idea behind the SSFA is not changed, enabling customers to serve themselves in the same matter as in the 1960s.

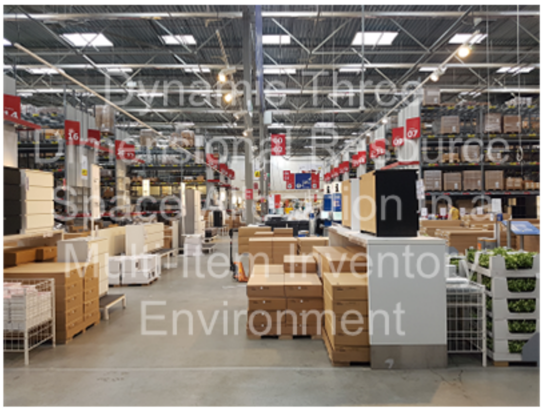


Figure 1.5: SSFA of IKEA Hengelo

The Warehouse (WH)

The WH is a department that is not accessible to visitors. The WH is located in the same area as the SSFA, but separated by flexible gates that can be removed. Furthermore, the WH is connected to the docking, forklift charging area and merchandise pick-up area, such that it can be operational during opening hours and visitors are not bothered. Figure 1.6 shows an example of the WH department of IKEA Hengelo. The general store layout of the SSFA and WH departments is further outlined in Chapter 2.

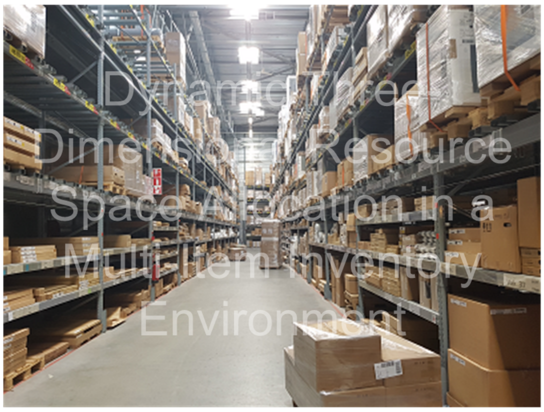


Figure 1.6: WH of IKEA Hengelo

1.2.4 Capacity

Capacity is an important aspect within the IKEA supply chain. The IKEA concept is based on selling large volumes of products and making them available to customers at the lowest possible price. The total space capacity of an individual IKEA store has an important impact on the inventory allocation within the supply chain.

Since the opening of the warehouse store in Hengelo in 2002, the sales turnover grow significantly from (roughly) XX million euro's in the FY02 to (roughly) XX million euro's in the FY18. In 2002 the original floor space concerned (approx.) 26.500 m^2. This includes the floor space of all the different departments and walking areas within the store. In 2013 the floor space increased to (approx.) 30.000 m^2. This additional floor space contribute primarily to the SR and MH departments, the floor space of the SSFA and WH did not increased by this upgrade. The actual space used for storing Stock Keeping Units (SKUs), the so-called Stock Keeping Area (SKA), is only a part of the total floor space. The SKA per department is shown in Table 1.3.

Table 1.3: SKA per department

Department	SKA m^2
Total MH	x,xxx
MH-Entrance	x,xxx
MH-Bath	x,xxx
MH-Bed Textile	x,xxx
MH-Cooking & Eating	x,xxx
MH-Decoration	x,xxx
MH-Home Organisation	x,xxx
MH-Home Textile	x,xxx
MH-Lighting	x,xxx
MH-Rugs	x,xxx
MH-Glass House	x,xxx
Total SSFA/WH	x,xxx
SSFA (Incl. Activity Areas)	x,xxx
WH	x,xxx
Activity Areas	x,xxx
Total SR	x,xxx
SR-Childrens IKEA	x,xxx
SR-Kitchen Accessories	x,xxx
SR-IKEA Familiy	x,xxx
Total Store	x,xxx

Sales space capacity, or SKA, is the total number of sales locations in the SR, MH, SSFA and WH (measured in m^2). Sales locations in the racking are also called floor picking locations when products are sold on paper pallets and loading ledges, and shelf picking locations when products are sold on the shelves. The locations in the racking above the sales locations are storage capacity (in m^3) (see Figure 1.7 for a visual example). The overall space capacity of an IKEA store is determined according to range size and expected sold volume. Individual sales locations are determined according to sales frequency and in-delivery quantities (see Chapter 2 and Appendix A for more details).

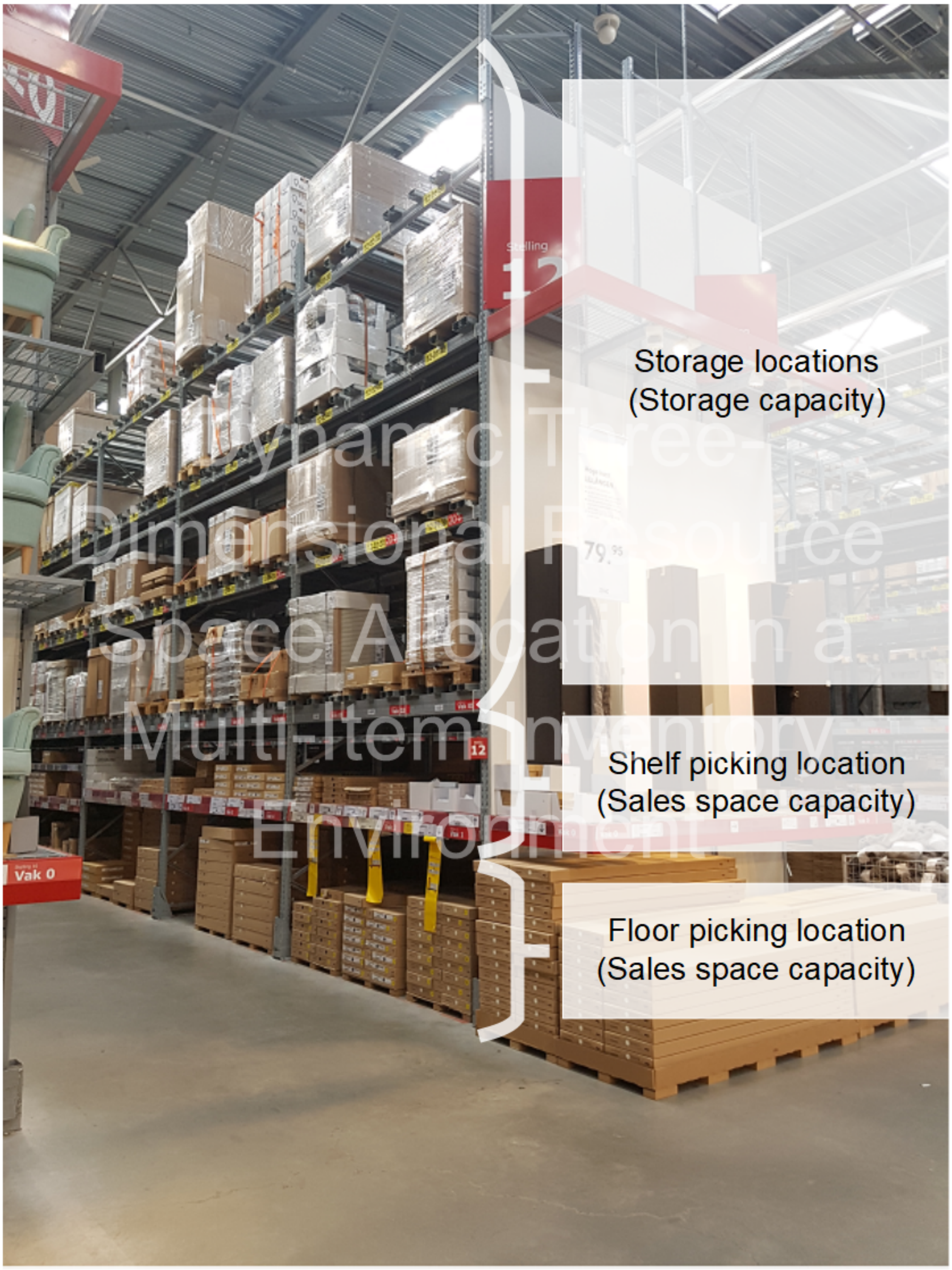


Figure 1.7: Racking locations of IKEA Hengelo

1.3 Problem Context

This section provides the context analysis of the problem studied in this thesis. In Section 1.3.1 the background of the problem is discussed and explained. Consecutively, in Section 1.3.2 the actual problem is identified and discussed. From this problem identification a concrete problem statement is subtracted and formulated.

1.3.1 Background

In Section 1.2.2 it is explained that over the last decade the sales turnover is increased from roughly XX million euro's to roughly XX million euro's (approximately XX% increase). This increasing sales turnover (in euro's) is correlated to the increasing sales volume (measured in m^3) and, therefore, to the corresponding product flow through the warehouse store. For the upcoming years it is forecasted that the sales volume will increase further (see Figure 1.8).

Figure 1.8: Forecasted sales volume

As addressed in Section 1.2.2, the capacity of the local warehouse store is divided into different departments. Since the original opening of the warehouse store in 2002, the floor space of the SSFA and WH departments is not increased. The product flow through the SSFA and WH is increased in correlation with the increased sales turnover. Within the SSFA products are located that customers can pick themselves. The available space to place products within the SSFA is limited. When the demand of a product per day is higher than the available space to place this particular number of products (within the SKA), it causes out-of-stock options and a reduced Customer Service Level (CSL). During customer hours it is not possible to shift products from the storage locations to the picking locations within the SSFA (Figure 1.7), due to safety restrictions.

Products within the WH are not accessable for customers, but are collected by employees. The time this collection takes is increased when products are not located on the floor picking locations, but instead need to be picked from the buffer locations. As mentioned before, within the WH it is possible to move products from the buffer to the floor locations during opening hours, nevertheless the buffer locations are also limited and out-of-stock options can occur. Furthermore, longer picking times imply longer waiting times for customers and a reduced customer service. Efficient usage of the SKA is necessary to cope with this increasing sales volume in a fixed SKA availability. Moreover, efficient SKA usage implies benefits for both the customers, as the local warehouse store. Efficient usage of the SKA implies:

- A better availability and a higher customer satisfaction. It can result in fewer non-central shortages, because more weeks of stock can be hold upon store level.
- An improved bottom line. The direct delivery share can be increased, resulting in reduced costs (less handling) and a positive impact on the bottom line (financial result).

- Lower prices for IKEA customers. A positive bottom line can have a positive effect on the costs that can results in lower prices for the IKEA customers.
- Lower supply chain costs. An efficient SKA result in fewer shortages, that reduces extra and shortage deliveries.
- More sales. Less shortages implies more sales.
- An improved home delivery and picking with delivery services. A faster and more efficient operation for external partners and customers.

An important notice that has to be made is that, according to the IKEA group, a lack of storage space does not always mean extra capacity is required. Shortage locations can sometimes be rationalized.

Capacity Determination and Allocation
Within the IKEA store a special sales-to-range-to-space tool is used to determine the right amount of space requirements (in m^2) per department to meet the expected sales volume (in m^3), as forecasted (Figure 1.8). Furthermore, the size of each sales area within an IKEA store is determined by the forecasted sales space need for every product sold (see Chapter 2 and Appendix A).

Products are allocated according to their size and selling volume. Furthermore, the allocation of products is subjected to the dimensions of the sales location. The best-selling furniture products are allocated to the SSFA to make them more accessible. Within the SSFA there are special locations that are appropriate for selling large volumes. For example, the end of aisles, including end podia, and the activity area (see Appendix A for more details). Within the SSFA this allocating best-selling product to easily accessible sales locations is used and can also be applied to the MH department. In Chapter 2 the allocation principles are further outlined. The in-store logistics and sales space determination are discussed in Appendix A.

1.3.2 Problem Identification

In the previous sections we introduced the local warehouse store and the available capacity within the store. Although that since the opening of the store in 2002 the floor space within the SSFA and WH is not increased, the sales turnover increased significantly. This increased sales turnover resulted in an increased product flow through the warehouse store and the corresponding departments. This flow is measured in m^3 as explained in Section 1.3.1. This flow in m^3 corresponds with a space required in m^2 (SKA), which differs per department and department section. Table 1.4 shows the current SKA, the corresponding SKA needed as forecasted till FY22 (see Figure 1.8, based on XX m^3 flow) and the lack or surplus per department based on this scenario. Within departments it is possible, but not preferable, that lack of capacity in one section is covered by a surplus of capacity in another section. Table 1.4 shows that the total SKA of the store incorporates a lack of space of XX m^2. Furthermore, it can be seen that the major sources of this lack of space are the SSFA and WH departments, that shows a lack of SKA of XX m^2. This lack of space results in increasing out-of-stock options for the customer and a lower CSL.

We define a problem as a situation in which there is a discrepancy between the desired situation (norm) and the actual situation (reality) [14]. From Table 1.4 we can see that it is forecasted that there would be a lack of SKA within the warehouse store. If we look further within this problem, we see that this lack is mainly located within the SSFA and WH departments. This is a clear problem, in which in the desired situation this lack of SKA is not present. Due to the long-term implementations it is currently not desirable to extend this SKA with new to build capacity. The focus lies on a short-term solution, that can increase the efficiency of the SKA usage and reduce the amount of SKA needed to meet the expected customer demand. Therefore can reduce or resolve the problem and the corresponding effects to the customers. We define the problem statement below.

Problem statement: *The current usage of the SKA, within the SSFA and WH departments, is not in line with the expected growth in customer demand.*

As explained above, the problem focuses on two specific departments within the warehouse store, namely the SSFA and WH departments. Furthermore, the focus lies on the current usage of the SKA and does not include extending the SKA. In the next section this problem statement is further operationalized and the research design is outlined.

Table 1.4: Needed capacity per department, by scenario of XX m^3 product flow

Department	**Actual floor Space** m^2	**Space needed** (by XX m^3 flow) m^2	**Lack/surplus** m^2
Total MH	x,xxx	x,xxx	x,xxx
MH-Entrance	x,xxx	x,xxx	x,xxx
MH-Bath	x,xxx	x,xxx	x,xxx
MH-Bed Textile	x,xxx	x,xxx	x,xxx
MH-Cooking & Eating	x,xxx	x,xxx	x,xxx
MH-Decoration	x,xxx	x,xxx	x,xxx
MH-Home Organisation	x,xxx	x,xxx	x,xxx
MH-Home Textile	x,xxx	x,xxx	x,xxx
MH-Lighting	x,xxx	x,xxx	x,xxx
MH-Rugs	x,xxx	x,xxx	x,xxx
MH-Glass House	x,xxx	x,xxx	x,xxx
Total SSFA/WH	x,xxx	x,xxx	**x,xxx**
SSFA (Incl. Activity Areas)	x,xxx	x,xxx	**x,xxx**
WH	x,xxx	x,xxx	**x,xxx**
Activity Areas	x,xxx	x,xxx	**x,xxx**
Total SR	x,xxx	x,xxx	x,xxx
SR-Childrens IKEA	x,xxx	x,xxx	x,xxx
SR-Kitchen Accessories	x,xxx	x,xxx	x,xxx
SR-IKEA Familiy	x,xxx	x,xxx	x,xxx
Total SKA	x,xxx	x,xxx	x,xxx

1.4 Research Design

This section outlines the design of this research. In Section 1.4.1 the scope of this research is demarcated, building upon the demarcation made within the problem statement. Consecutively, in Section 1.4.2 the research objectives are outlined, followed by the research contribution in Section 1.4.3. Finally, in Section 1.4.4 the research questions, and the methodology used to answer them, are outlined and discussed.

1.4.1 Demarcation

In the previous sections the scope is already partly defined. To cope with the complexity of this study, we define the boundaries in more detail in this section. This demarcation is based on the preliminary research, the problem context and the input of stakeholders. Although some aspects are not within the scope of this research, these still can be mentioned within this thesis and the further recommendations, nevertheless no extensive research is done upon these aspects.

Although the supply chain of IKEA is an factor to notice within this research, we do not focus on the supply chain processes of the IKEA Group and Inter IKEA Group (i.e. production facilities and DCs), but only address them briefly. For the aim of this research we focus on the supply chain part that directly affects the local warehouse store, as explained in Section 1.2.2, since the internal logistics within the store are the main focus of this research. More specifically, we demarcate our scope even further to the specific SSFA and WH departments within the store. Since these departments are interlinked with the other departments, we also briefly address the other departments and overall store picture. Within the SSFA and WH we focus on the racking sections and not on the activity areas and end podiums, due to the complexity of the resource allocation within these sections. Furthermore, the other departments and sections are not explicitly mentioned and are not part of the solution we provide.

For the local warehouse store it is of importance that the customers are the main target of interest. All possible solutions should be in line with the needs of the (potential) customer. Therefore, we also need to include the needs of the customer to be able to define a potential solution. However, due to time limitations, it is not realistic to do an extensive customer research. For that reason, we focus on previous conducted research and the Key Performance Indicators (KPIs) of the local warehouse store, that are subjected to the needs of the customer. Next to the view of the customers, the view of the employees are also taken into account within this research. In the end, the employees should be able to adapt the solution. Therefore, we include the view and opinions of the dedicated employees within our research scope.

Within the IKEA range every year several products are changed and becoming obsolete (approximately 2.500 items annually, see Section 1.1). This changing range is important to meet the chancing customer's needs. Furthermore, the demand of the customers is stochastic. Within this research we do not explicitly focus on this chancing range and stochastic demand, but we implement it as a part of the solution.

In 2002/2003 the local warehouse store increased their overall store capacity. Within this research we do not focus on the extension of the current capacity with rebuild or new to build capacity space. We explicitly focus on the current available SKA. When no feasible solution can be achieved by this research, the potential extension or redesign of the SKA can be part of the recommendations.

1.4.2 Research Objectives

The objective of this research is to create a solution in line with the defined problem statement, as discussed in Section 1.3.2. Furthermore, in the research objective several aspects are important to include within its scope, as demarcated in the previous section (Section 1.4.1). First the solution should be able to achieve an efficient SKA usage within the racking of the SSFA and WH departments. Secondly, the solution should be adaptive and needs to be able to include the stochastic behaviour of the product demand, the changing range of products and the opinion of employees. Thirdly and finally, the solution should be able to provide insight into the performance of the SKA in relation to different allocation configurations. The three defined aspects are mutual dependent. In other words, an efficient SKA usage is dependent on including the stochastic behaviour, product range changes and employees' opinions. Furthermore, the evaluation of the efficiency of different strategies is dependent on the design of the strategies. We formulate the research objective below.

Research objective: *To develop an efficient, adaptive and generic approach of SKA allocation, within the racking sections of the SSFA and WH departments.*

Within the research objective the scope is explicitly demarcated. (1) First we look at an adaptive and generic way of SKA allocation. The model should be adaptive and generic in the sense that the model should be applicable in all similar store settings. A warehouse store in another city should be able to use the model in the same way as the local warehouse store in subject. The model should be adaptive, i.e. store specific settings should be able to be set and the model should be generic, i.e. applicable for similar store settings. (2) Furthermore, the objective specifically looks at the SKA allocation within the SSFA and WH departments. (3) The current SKA allocation method is unknown and has first to be defined in order to look for inefficiencies and potential improvements. The focus on increasing efficiency is based on increasing the SKA utilization and KPI values. The current situation, including the current allocation methodology, restrictions and important KPIs are discussed in Chapter 2.

1.4.3 Research Contribution

The allocation of resources within a warehouse setting is a widely discussed subject in literature. In this research we build upon this foundation of warehouse literature and include the dynamic character of both SKU, and racking resource dimensions. In the current literature there is a lack of involvement of the dynamic dimensions of SKUs and racking resources. Most warehouse designs and slotting strategies do not include the dimensions of both the SKUs, as well as the corresponding racking resources, or focus singly on correlated storage of SKUs, without involving restrictions in resource dimensions. This lack of involvement could cause inefficiencies in the resource allocation. In this research the dynamic dimensions are an important factor within its scope, due to the lack of resource space and the need to optimize the resource space utilization. In this research we focus on developing a method to dynamically allocate the SKUs into available racking resources, in order to increase the resource space utilization and the SKU availability. The dynamic allocation is benchmarked against the current allocation setting of the warehouse, to investigate, and to be able to discuss, the potential effects of the allocation method developed.

1.4.4 Research Questions

In Section 1.4.2 we defined and explained our research objective. This research objective includes different aspects, which need to be researched in order to obtain a potential solution for the defined problem statement. Within the explanation of the research objective, we defined several research topics. To reach our objective, we composed a succession of research questions which we have to answer. The main research question is the leading theme of this research and can be answered through answering the several research questions. These research questions are defined in a logical sequence of activities, which covers the entire scope of this project.

The questions are defined into four main parts, namely (i) mapping of the current situation (context analysis), (ii) analyzing of the current situation and identification of opportunities based on literature (literature review), (iii) creation and validation of a solution based on the identified opportunities (model design and validation) and (iv) implementation plan. Since the implementation of the solution is, due to time limitations, without the scope of this research, we also include an implementation plan. With the introduction of every question a short description is given, based on the planned approach of answering and the motivation for the question.

We have formulated the main research question below.

Main research question: *How should an adaptive and generic SKA allocation method be designed, such that it provides an efficient SKA usage within the racking sections of the SSFA and WH departments?*

The main research question is in line with the defined research objective and includes the demarcated scope, as discussed in Section 1.4.1. The main research question is answered with the use of the sequence of research questions, as discussed above.

(i) Context Analysis

To get more insight in the current way of working within the local warehouse store, with a explicitly focus on the material handling from the arriving of products till the purchase by the customer, a thorough analysis of the current way of working is needed. Within this part we familiarize ourselves with the existing logistic processes within the store and potential future changes. Furthermore, we go more in depth into the characteristics of the SKA within the scope departments and identify the corresponding KPIs. Our approach of answering this question consists of examining documents from the IKEA group and the local warehouse store. Besides that, we conduct interviews with employees to obtain additional information and to ensure validity of our documentation. Furthermore, we conduct field research to obtain the correct characteristics of the scope departments. The first research question is defined below.

Research Question 1: *How are the logistic flows, processes and information flows currently organized?*

a) What are the characteristics of the distribution network and the internal material handling?
b) What are the characteristics of the SSFA and WH departments, including the SKA allocation?
c) What are the KPIs involved and how can these be operationalized?
d) What are the expected upcoming changes in the supply chain?

(ii) Literature Review

The literature review provides the theoretical framework for this research. Research question 1 provides the context analysis of the current situation. After the current situation is known, literature is used to get familiar with existing methods to find possibilities for improvements, within the current situation. The literature study focuses on the SKA allocation methods and strategies within comparable settings and situations. In this literature review we focus on both peer-reviewed scientific articles (i.e. journal papers), as also on books, newspapers and other relevant articles, that include relevant literature. We start the literature review with an investigation about what is currently known in literature about SKA allocation, whereby we focus on other similar settings and the correlation to our situation. Next, we combine the results from the literature review with the results from research question 1, and look into the methodology that is most suitable for our specific case. The second and third research question is defined below.

Research Question 2: *What is currently known in literature about SKA allocation?*
a) How is the SKA allocation executed in comparable settings?
b) How can those SKA allocation methods be used in correlation to the local warehouse store in subject?

Research Question 3: *What kind of SKA allocation method is most suitable for this research?*

(iii) Model Design and Validation

After we have studied the available literature and combined it with the context analysis, we start designing the actual model based on the opportunities found. This research question is answered with the use of a combination of literature review and expert input. This ensures that we design a valid and robust model, which is implementable and provides benefits for the customers and employees of the local warehouse store. First, we need to select a design framework which we can use for structuring the model design. Afterwards, the actual model can be designed and validated. Research question four, five and six are defined below.

Research Question 4: *What methodology design framework should be used for the model design?*

Research Question 5: *How should the model be designed to support the efficiency of SKA utilization?*

Research Question 6: *How can the designed model be verified and validated?*

(iv) Implementation

The implementation of the model is, due to time limitations, out of the scope of this research. Nevertheless, it is important that correct documentation is provided to support the implementation of the model in practise. The implementation plan that can be used to implement the model in different store settings and situations. The last research question is defined below.

Research Question 7: *How can the model be implemented in practice?*
a) What steps need to be executed to be able to execute the model?
b) How can the model be adapted to a change in store settings?

1.5 Structure of the Report

The structure of this report is divided into the different sections, as explained in the previous section, namely: (i) context analysis, (ii) literature review, (iii) model design and validation and (iv) implementation plan. Within this report these sections are presented in a chronological sequence, whereby in Chapter 2 the context analysis is given and the answer to the corresponding research question. In Chapter 3 the literature study is given and in Chapter 4 the design, validation and implementation plan of the model is presented. This research is concluded in Chapter 5, with the conclusions of this research and recommendations for further research. Figure 1.9 shows a graphical representation of the structure of this report.

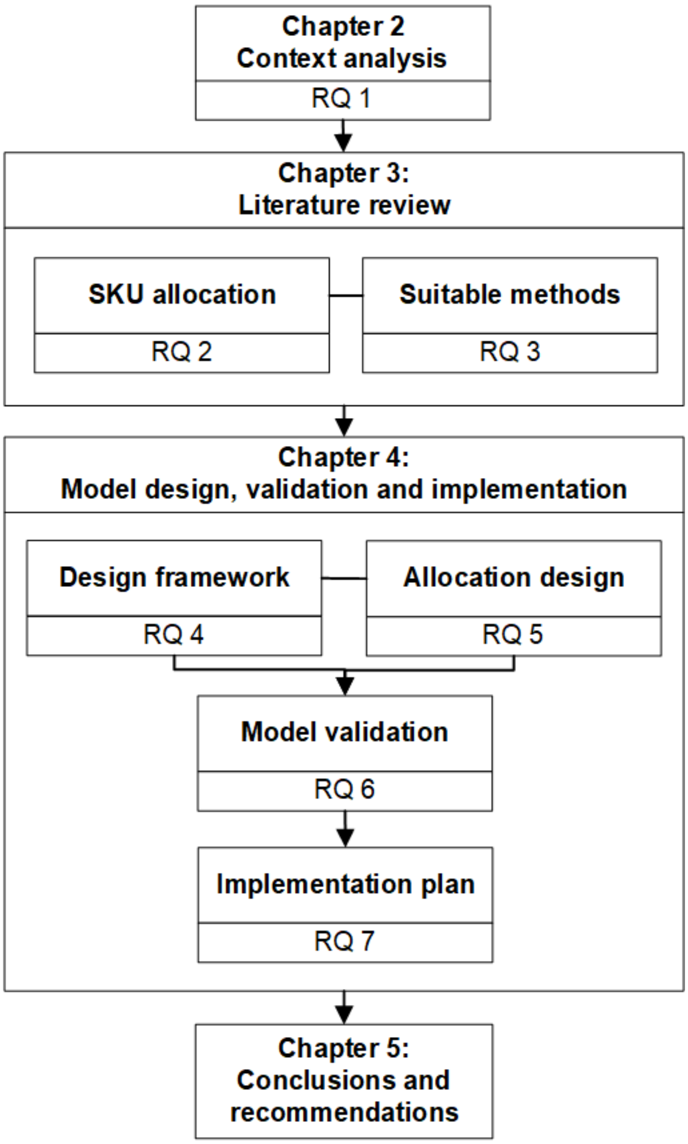


Figure 1.9: Structure of the report

Chapter 2

Context Analysis

This chapter provides the context analysis of the current situation within the local warehouse store, with regards to the scope of this research. Section 2.1 covers an overview of the logistic flow, from the production to the end customer. The in-store logistics and material handling is further outlined in Appendix A. Section 2.2 provides the characteristics of the SSFA and WH departments, in which the focus lies on the SKA allocation process. In Section 2.3 the corresponding KPIs, as apply to the departments in subject, are discussed. Section 2.4 outlines the upcoming changes of the IKEA Group, based on strategy and vision. Finally, Section 2.5 concludes this chapter and provides a concluding answer to research question 1.

2.1 The Logistic Flow

This section focuses on the logistic flows from the production to the end customer, with a focus on the logistics within the IKEA store. Section 2.1.1 starts with a global overview of the supply chain of an IKEA store, with the focus on the different distributions methods, from the production to the end customer and the flows through the local IKEA store. In Appendix A we focus more specifically within the supply chain and provide an in-depth analysis of the in-store logistics of the IKEA store, from the ordering of products to the arriving of products at the customer.

2.1.1 The Supply Chain

The supply chain of IKEA is a network of facilities that are owned and operated by IKEA or by IKEA business partners, e.g. factories, DCs and stores. The processes within the supply chain are interdependent activities performed and shared by the organizations within the supply chain, including, but not limited to, activities within:

- sales planning and forecasting
- ordering
- delivering and handling goods

The supply chain of IKEA can be seen as a multi-echelon system, since it makes use of several stock points within its flow from supplier (central location of the production) to the different warehouse stores. Consolidation points enable part loads from suppliers to merge into Full Truck Loads (FTLs). This enables benefits of scale and reduces the impact for the environment.

In the previous chapter it is discussed that IKEA has own production facilities, but also makes use of more than 1.000 suppliers within 51 countries. To manage this amount of suppliers, IKEA makes use of high-flow and low-flow DCs. The low-flow range is stored centrally for large regions, while the high-flow range is stored in centers closer to the relevant market [15]. The high-flow focuses on the 20 percent of SKUs that account for 80 percent of the volume, low-flow warehouses are more manual. The European Low Flow (ELF) is located in Dortmund (Germany). These DCs supply the customer DCs and the IKEA stores. Furthermore, the IKEA stores receive Direct Deliveries (DD) from the supplier, in which the products are not distributed though one of the DCs. An example of DD are shipments of large high-flow cabinets (The ”PAX” range), that come directly from the supplier in Poland. Consolidated flows are also considered as DD, although some storage may exists a the consolidation points. If a supplier is not available to meet the DD, one of the DCs could provide this demand if inventory is sufficient at that echelon. Large customer orders can also be directly delivered from the supplier to the customer. A simplified overview of the supply chain of IKEA is given in Figure 2.1. The different colors, and corresponding text, represent different shipping methods.

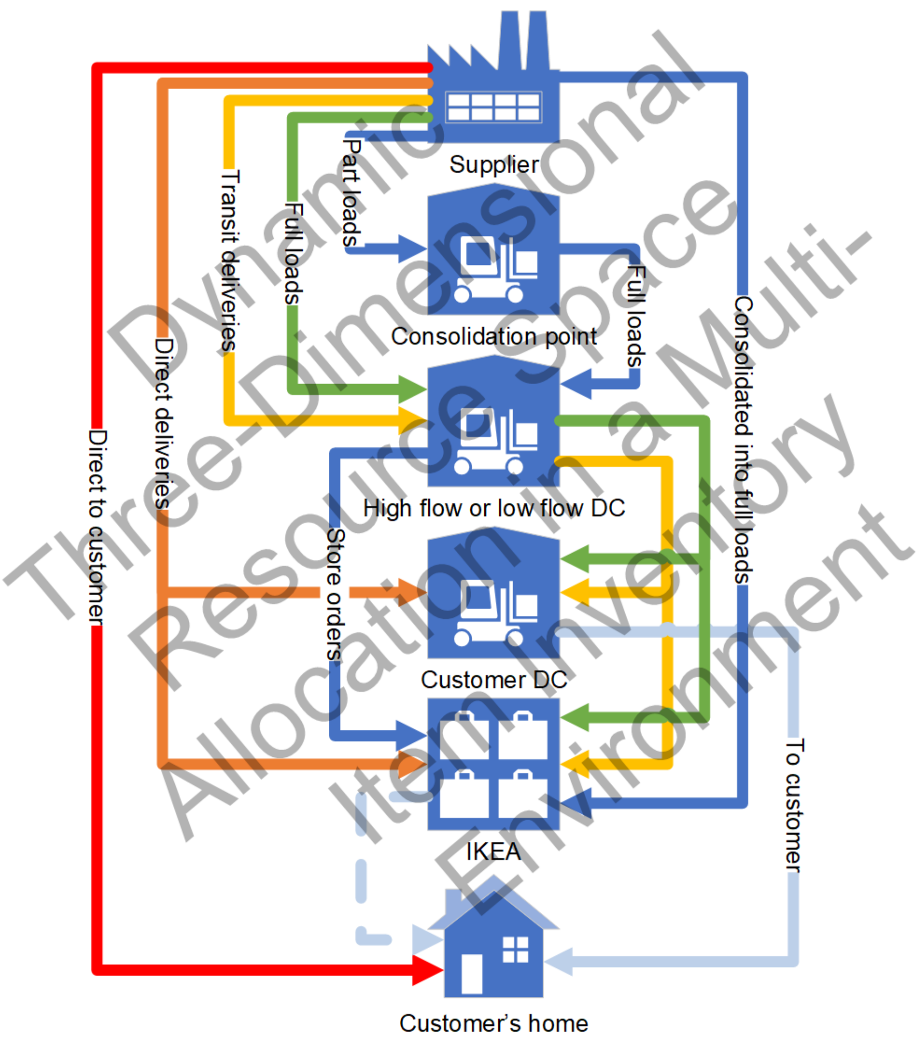


Figure 2.1: IKEA Supply Chain

2.2 SKA Allocation Within SSFA and WH Departments

SKA allocation within the SSFA and WH departments is an entire process, whereby goods can be assigned, adjusted or un-assigned to a certain SKA. The way the SKA allocation is done differs per store and depends on store specific characteristics and complexity. Within the IKEA Group an allocation process is defined based on knowledge of IKEA co-workers. This process can be divided into five different stages (Figure 2.2). Within this thesis we focus on the actual product allocation part and only briefly discuss the other parts. Product allocation within the SSFA and WH departments has multiple goals, namely:

- Enabling large sales volumes and low costs in all fields.
- Enabling customer involvement (within SSFA) to keep prices low.
- Maximizing the product availability, while minimizing the logistical costs.
- Reducing product handling and internal damages.
- Creating a balance between an efficient picking process and an easy customers' buying process.

In Section 2.2.1 we outline the first three steps of the process, namely analysis, planning and dimensioning the warehouse. Subsequently, we define the safety and ergonomic restrictions in Section 2.2.2, whereby afterwards we outline the actual allocation and maintaining process in Section 2.2.3.

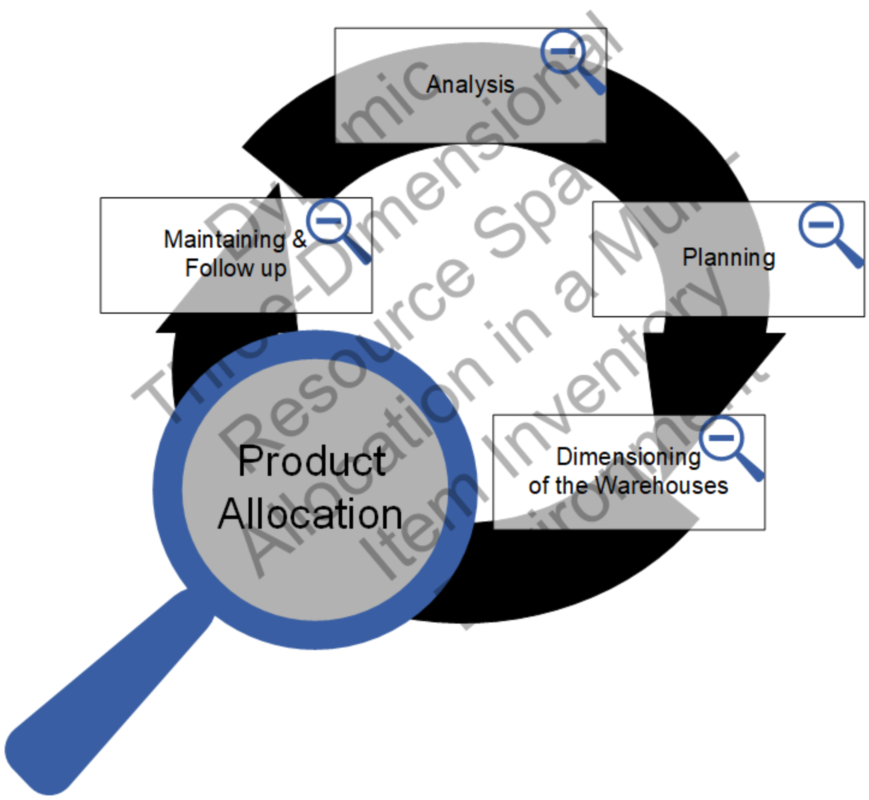


Figure 2.2: Product allocation process

2.2.1 Analysis, Planning and Dimensioning the Warehouse

The first step in the allocation process is the analysis of the current and mid to long term planning of the store. This includes research on, but not limited to, the needs of the customers in the local market, commercial agenda, seasonal activities, global and country business plans, market developing and multichannel strategies. In other words, this means analysis on what you want to sell, how much and when. For the upcoming years the IKEA Group announced strategical changes, we outline these changes Section 2.4. We do not go further into detail of the analysis part of the product allocation process, since this part is set as fixed and out of the scope of this research.

The second step in the allocation process is the planning where to place groups of products. This phase has an important effect on the customers' buying process, internal damages, picking operations, SSFA and WH division, and overall goods flow. Decisions have to be made in what sequence, and where, the ranges and products are going to be allocated.

Range Sequence

The layout of the SR and MH departments are based on HFB groups (Chapter 1). In the SSFA and WH departments the layout is not singly based on these HFB groups, because the shopping behavior is different in comparison with the SR and MH departments. In the SSFA the customers often have a picking list that help their buying process. Within the range sequences the HFB groups and commercial combinations are kept together as much as possible, in order to support the easy-buying process for the customers. This means that product combinations that are often bought together are also located close to each other, although the products are different HFB groups.

The Common Store Planning (CSP) provides general principles for the range sequence, the local warehouse store in subject follows these principles. The store and organize furniture is placed in the beginning of the SSFA, to secure a location close to the goods receiving area. This increases the efficiency of replenishment. Bulky and heavy products (e.g. system wardrobes and sofas) are located closer to the cash lines, in order to increase the easy-buying process. Smaller HFB groups (e.g. IKEA children's range) are placed to the right of the customer flow, since they do not require a lot of warehouse space. Furthermore, some products are restricted to certain racking because of their size. The CSP provides a XL-aisle for long items, e.g. the PAX-range. The allocation of a product range within the same aisle increases the picking efficiency of these products for both the customers, as for the employees. The other areas are intended to be flexible, to react on peak and off-season periods. An example of the product range sequence according to the CSP can be found in Figure 2.3.

Product Sequence

The product sequence means the sequence in which the products are going to be allocated, based on ergonomics, safety and product characteristics. Within the product sequences multiple aspects have to taken into account, i.e. similar products need to be placed apart from each other to avoid confusion, products with higher sales should be placed closer to the main aisles in order to reduce replenishment distances, products that are likely to be bought together should be completely located in either the SSFA or WH department and small items (e.g. knobs and handles) should be located in a visable spot at the end of the SSFA to support impulse and easy buying. The ergonomics and safety rules are further outlined in Section 2.2.2. Figure 2.4 shows the suggested product sequence according to the CSP.

Figure 2.3: Suggested range sequence according to CSP

Figure 2.4: Suggested product sequence according to CSP

Dimensioning the Warehouse
The layout of the IKEA stores are set by the IKEA standard layout principles. This includes the sizes of activity areas, the width of the aisles and the several racking possibilities. It is all documented in the Standard Operating Procedures (SOP). This layout is further out of the scope of this research. The SSFA stocks the best selling part of the IKEA furniture range. The general rule within the IKEA stores is that at least 75% of the furniture sales volume is allocated to the SSFA department (often this is set to at least 80%). The other items, so called slow(er)-movers, are allocated to the WH department and can be collected by the customers at the merchandise pick-up point. The article density in the WH is therefore higher, generally speaking the division between the SSFA and WH department based on article numbers is approximately 50/50. Figure 2.5 shows an example of the basis decision curve of SKA allocation. It can be seen that the fast(er) moving articles are located into the SKA of the SSFA and the slow(er) movers to the SKA of the WH, whereby approx. 80% of the total turnover in pieces is located into the SSFA, corresponding to approx. 50% of the total number of articles. The division is store specific and depends on what is most favorable for the store. The only requirement is that a majority of the IKEA stores total furniture sales in pieces are available to visitors in the SSFA, in order to keep the prices and costs low.

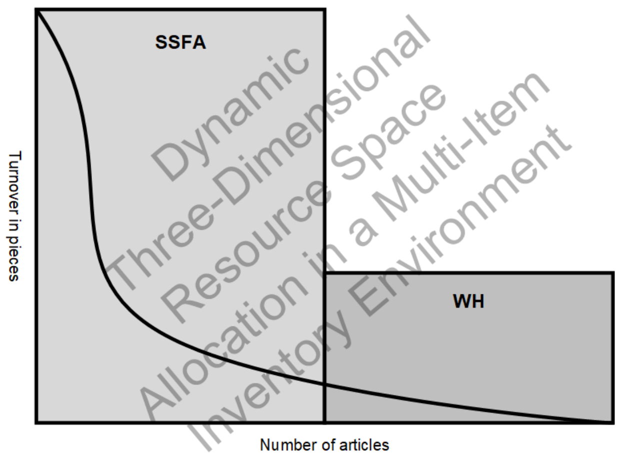


Figure 2.5: The basic division curve of articles between the SSFA and WH

2.2.2 Safety and Ergonomic Restrictions

Safety and ergonomic restrictions are key aspects within the determination of SKA allocation. The products differ in weight, size and therefore the difficulty of handling. The customers and co-workers are therefore important stakeholders within the allocation of the products. Within the CSP a maximum weight of 15 kg is set for products placed on level 10 and upwards. Furthermore, a maximum gripping height of 185 cm is set.

Next to the ergonomic restrictions, there are multiple safety restrictions within the product allocation process. Next to the width of the aisles, escape routes and other safety restrictions there are also restrictions within the racking. These restrictions are subjected to fire legislation and can be summarized into four main points, as defined below.

- The distance between the sprinkler and SKUs is at least 15 centimeters, measured from the sprinkler heading to the first package. In practice this rule is implemented with a string at the height of 15 centimeters from the sprinklers (Figure 2.6 and 2.7). This rule makes sure that the sprinkler water is distributed freely among the entire racking section.

- Around the uprights there is at least 7.5 centimeters of free space at both sides (including the upright itself) in order to create a transverse channel (Figure 2.6 and 2.7)
- At level 10 there is at least 15 centimeters of free space between the back to back sections in order to create a transverse channel (Figure 2.7). This transverse channel needs to be in one line within a racking. Note that at the floor level (level 00) back to back placing is possible.
- At both level 00 and 10 there need to be transverse channels around packages or stables of SKUs longer than 150 centimeters (which are stabled as one solid piece, straight upon each other). These transverse channels need to be placed at a maximum of 150 centimers within a racking section (Figure 2.7). Further the occasional irregular spaces, planned or unplanned, will function as flue space. Appendix E shows the sprinkler restrictions in more detail.

Figure 2.7: Transverse channels within the racking levels

2.2.3 Allocation Process and Maintaining

There are several ways of SKA allocation, but due to the complexity and multiple variables that need to be taken into account, a manual expertise is favorable. The most common method for SKA allocation is divided into 11 steps and outlined below. This method is amended from the product allocation guidelines of the IKEA Group. Nonidentical products are only allowed to be placed next to each other, so not on top or behind each other.

1. Create a list of all items that need to be allocated, except for items that have past the End Date Sales (EDS) and have a stock of zero.
2. Identify all the items that already have a fixed location.
3. Identify the SKA dimensions.
4. Identify articles that are non-DC pick. These are articles that are only sent on a Full Pallet Load (FPL), such that at least a FPL SKA is preferable.
5. Identify the ergonomic characteristics of each item (Section 2.2.2) and identify the items that are over the weight limit.
6. Identify large, oversized and other items that are subject to a higher risk of damage.
7. Determine what range allocation is best suitable to fit the large and oversized articles, in order to create an efficient picking operation and easy buying process.
8. Identify the dimensions of the pallets of the articles, if the articles need to be loaded with a pallet and how much articles are on a pallet.
9. Identify required sales space quantity per product.
10. Allocate the articles per HFB, keep families together (when possible) and allocate the best selling articles first, such that lower selling articles are more likely to be allocated on level 10 locations.
11. Allocate fast moving closer to the aisles within the SSFA department and closer to the pick-up desk in the WH department;

Every week the forecasts are updated within the Sales Location Management (SLM) tool (Appendix A). These forecasts updates correspond to a recommended sales space capacity. In order to achieve sufficient inventory on the floor, the space capacities need to be maintained. Furthermore, the commercial aspects (including activities and EDS), shopping behavior, introduction of new products and damages need to be taken into account in maintaining the product allocation.

2.3 Key Performance Indicators

The KPIs are important factors to follow up on the performance of the SKA allocation. Within the IKEA store several KPIs are used to identify and follow up on the performance of the store. We identify four KPIs that are a direct indicator on the performance of the SKA allocation.

- Internal damages: A high number of internal damages could indicate that products are being damaged during the stocking, shopping or picking process. The location of the articles could influence this number of internal damages. The goal is to keep the number of internal damages as low as possible. Figure 2.8 and 2.9 show examples of (increased risk of) damages.

Figure 2.8: Damage due to products (mattresses) located at wrong level.

Figure 2.9: Damage due to products placed to close to each other.

- CSL: The CSL is a function of different indicators. The first indicator is the order fill rate. The order fill rate is the fraction of the total customer demand that is met from stock. The stock out rate is the complement of the fill rate and is the fraction of sales lost due to stock out. The SKA per SKU should have enough space to meet the customer demand, in order to obtain a high CSL and no loss sales. An article that oversales could require a bigger sales location. Local local shortage could occur if articles are allocated to a not large enough SKA.

- Handling: High handling number could indicate that articles are not located to a correct SKA, resulting in a need to replenish these articles more frequently, resulting in higher costs. Also within the handling the direct flow rates (and therefore also backflow rates) are included. The goal for both the SSFA and WH department is a direct flow of at least 75 %.

- Fast picking: The order picking within the WH department has the goal to be picked within four minutes, plus one minute for every extra product, after accepting the order to be picked by an employee.

2.4 Upcoming Strategic Changes

IKEA stores are operating in a dynamic market. Every year new products are added to their product range and old products are removed from it. IKEA continuously renew their products to keep up with customer demand, create new demand and keep up with the latest trends. Like the product range of IKEA, also the whole home furniture market is dynamic. On the holding level transformations of the business model are announced [16], to keep up with the latest changes in the market. The Chief Executive Officer (CEO) of IKEA has promised a radical change in response to the changing shopping habits of the customers and the shift towards online shopping [16]. The upcoming three-year strategy of IKEA includes full digital solutions in all countries, including home delivery options at "an affordable price" and the move from out-of-town stores to stores within city centers [16]. Within the IKEA strategy this is announced as services that make it easier for people to bring home, care for and pass on products [17]. Next, IKEA also explores the ideas of loaning furniture to customers instead of selling it, using Virtual Reality (VR) to help customers plan their home interiors and other kind of store formats [16]. Furthermore, the strategy focuses more on sustainability and a positive impact to the society, whereby it aims, e.g., to achieve zero emission home deliveries by 2025 and becoming climate positive [17].

These changes could have an important impact in the way customers shop at IKEA. Currently only a small part of the IKEA range is home delivered. The largest part of these products are picked and delivered from the local warehouse stores. This means that the inventory first need to move from the supplier and DC to the store and then to the customer. Within the IKEA strategy they focus on home delivery options and other store formats. If the amount of home deliveries rise, it becomes favorable that the customer delivery point is shipped upwards in the supply chain, from the local warehouse store to the customer DC or DC (due to e.g. reduced logistic costs and economies of scale). This result in a decrease flow of products through the local warehouse store, which implies less inventory needed. Less inventory needed implies less space needed. Within this thesis we focus on the available space problem within the SSFA and WH departments. Although, we currently don't know what the effects would be, it could be possible that within a few years customer habits are changed and the problem is becoming less urgent. Therefore we empathize in this thesis on short term solutions, as explained in the previous chapter, such that these strategic changes do not influence our solution.

2.5 Conclusion

This chapter provided the context analysis of the local warehouse store in subject, whereby we looked at the current organization of the logistics flows, processes and information flows within the local warehouse store. With the conclusion of this chapter also research question 1 is answered. Overall we can conclude that the logistic flows, processes and information flows are organized according to the guidelines of the IKEA Group. Comparing the practise within the local warehouse store, to the documentation from the IKEA Group brings a lot of similarities. Nevertheless, every IKEA store is unique and also has unique practises. Within the guidelines of the IKEA Group these unique practises are also mentioned.

In Section 2.1 we looked at the characteristics of the distribution network and the internal material handling. We conclude that the supply chain of IKEA is a network of facilities that are owned and operated by IKEA or by IKEA business partners, e.g. factories, DCs and stores. The supply chain of IKEA is a multi-echelon system, whereby different kind of loads are moved to the local warehouse store, depending on the sending echelon, such as DD, DC and ELF. The organizations within the supply chain perform similar activities, including, but not limited to, activities within sales planning and forecasting, ordering, delivering and handling goods. Those activities are part of an entire cycling process, including plan sales (how much do we want to sell), plan demand (how much do we think we are going to sell), plan sales locations (where are we going to sell), plan need (what do we need to order and when) and replenishment (how do we make sure the products are available for the customers).

Section 2.2 covers the characteristics of the SSFA and WH departments, including the SKA allocation. The SKA allocation process is an entire process, including activities within analysis, planning, dimensioning, product allocation and maintaining. The analysis, planning and dimensioning aspect include activities within the determination of the range sequence, product sequence and product division between the SSFA and WH departments. These are all input parameters for the product allocation. Within the product allocation it is only allowed to store identical products on top and behind each other in the same racking section. Next, also the safety aspects are important for the allocation process. Within the racking sections multiple fire restrictions are set to create transverse channels for sprinklers.

The KPIs to focus on are determined in Section 2.3. We identified four KPIs, namely number of internal damages, CSL, handling rate and order picking speed. Next to these identified KPIs, more KPIs are used within the IKEA store to determine the performance of the different departments, but we assume these KPIs are not directly operational for determining the performance of the SKA allocation.

Finally, in Section 2.4 we investigated the upcoming strategical changes within the supply chain of IKEA. Within the IKEA strategy it is announced that they are going to focus on services that make it easier for people to bring home, care for and pass on products. Furthermore, the upcoming three-year strategy of IKEA includes full digital solutions in all countries, including home delivery options at an affordable price and the move from out-of-town stores to stores within city centers. Although, we currently dont know what the effects would be, it could be possible that within a few years customer habits are changed and the IKEA supply chain will look completely different in comparison to the supply chain today. This emphasizes the need for short-term solutions, within the current means.

Chapter 3

Literature Review

Inventory management is seen as one of the major focus areas in supply chain management. The importance of inventory management is already discussed and recognized for a long time. Exsäter [18] recognizes that the total investment in inventory is enormous and that the strategic importance of inventory management is fully recognized by top management [18]. This statement is emphasized by recent figures of a survey by the American Productivity & Quality Center (APQC). In this survey 71 % of the respondents identify inventory management as one of the areas of focus for 2018 [19]. This is the third most mentioned aspect, after supply chain planning (80%) and supplier relationship management (73%). The statement is further illustrated by the manufacturing and trade inventories and sales report of the U.S. Census Bureau (2018), which identifies a total business inventory of $1,967.5 billion in September 2018 [20]. That corresponds to approximately 10 % of the Gross Domestic Product (GDP) of $ 20,659.0 billion in quartile 3 of 2018 [21]. Inventory levels in the Netherlands show even a relatively higher number. In the Netherlands an inventory level of 43.4 billion was recorded in the end of 2017 [22], which is approximately 17 % of the GDP of 737.1 billion (2017) [23].

Of this $1,967.5 billion in business inventories only a small part, $27,903 million (approximately 1.4%), is applicable to home furniture businesses and comparable stores [20]. The reason why inventory is hold differs per industry. Exsäter [18] discusses two main reasons why inventory is hold, namely economies of scale and uncertainties. Economies of scale imply batch ordering [18]. Uncertainties imply the uncertain behaviour of supply, demand and transportation (i.e. lead times), which create the need for Safety Stock (SS) [18] (see Appendix C for SS calculations).

In this research we focus on the storage of this inventory within the SKA of the SSFA and WH departments of the local warehouse store. Borin et al. [24] discuss that retail selling space is a fixed resource and that managing it means making frequent decisions which items to stock and how much space to allocate to those products. Furthermore, Zufryden [25] identifies that the best way of the allocation of this finite and scare space among alternative products is a critical operational decision that is faced by all retailers. This space allocation influences the perceptibility, and hence the demand and sales revenue from certain products [25]. It also influences various costs, including transportation, ordering, holding, replenishment and out-of-stock costs [25]. This is emphasized by the results from the context analysis (Chapter 2). In this chapter we execute a literature review to identify the best way to allocate this finite and scare retail space among alternative products, whereby we specifically look at possibilities to include the strategy of IKEA to optimize customer service and include ways to define the performance of the warehouse, in order to fulfill the overall goal of this thesis.

Before we start with the literature study, we first define the key terminology of this thesis, namely the terms dynamic, three-dimensional, resource, allocation and multi-item environment. The key terminology is subtracted from the characteristics of allocation process, as discussed in Chapter 2. The literature in this review is selected based on the suitability with the described allocation process. The further literature selection process is discussed in Chapter 1. Figure 3.1 shows a visualization of most of the defined terminology. Further terminology is defined in the corresponding sections when applicable.

Dynamic: *The term dynamic in this thesis refers to the process of allocating resources, characterized by constant change, whereby the allocation of one resource influences the allocation of other resources. The constant change refers also to the dynamic character of the SKU dimensions, which can change according to the way the packages are stacked.*

Three-dimensional: *In the context of this thesis, we define three-dimensional as the length, width and height corresponding to both the SKUs, as the resources to be assigned to the SKUs.*

Resources: *In the context of this thesis, we define resources as the SKA, with three-dimensional characteristics, within the floor picking and rack picking sections of the SSFA and WH departments.*

Allocation: *In the context of this thesis, we define allocation as the assignment of resources (SKA) to SKUs and the other way around.*

Multi-item environment: *In the context of this thesis, we define multi-item environment as an environment, whereby the resources (SKA) need to be allocate to multiple items (SKUs).*

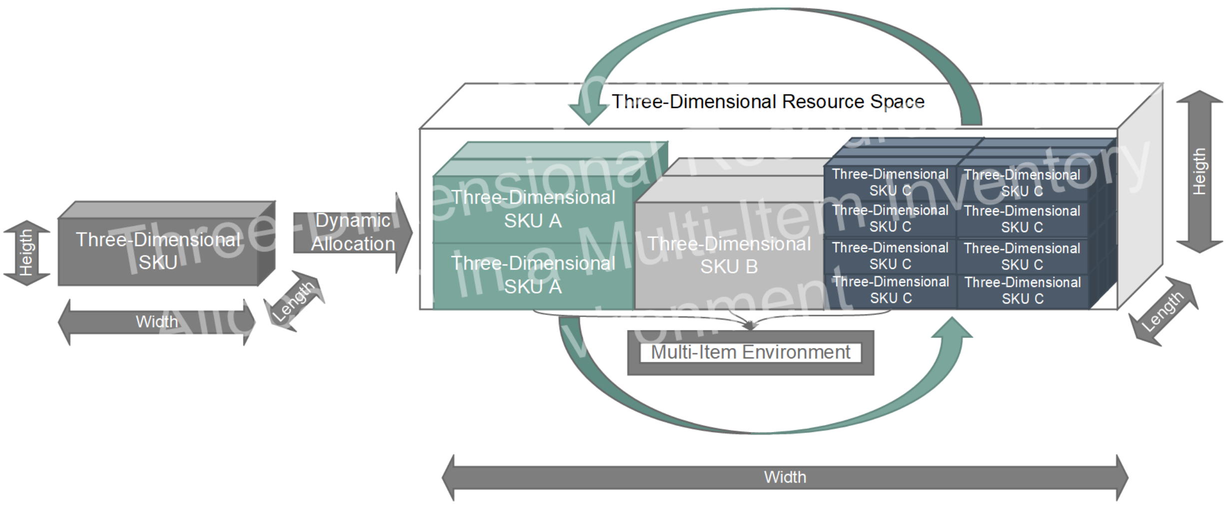


Figure 3.1: Visualization of literature study terminology

We structure this chapter in the following way. In Section 3.1 we go into the literature of inventory storage policies, with a focus on storage within warehouses. Since the warehouse design itself is out of the scope of this research, we set the warehouse design as fixed and do not focus on the related literature. In Section 3.2 we focus on the best way to allocate the resources, whereby we focus on packing problems. We conclude this chapter in Section 3.3 with a global overview of the reviewed literature and the answering of research question 2 and 3.

3.1 Inventory Storage in Warehouses

Inventory management is seen as one of the main focus areas within supply chain management, as mentioned in the introduction of this chapter. These inventories need to be stored, in this case we look at the storage of inventory within a warehouse setting with a retail perspective. Heragu et al. [26] discuss the two primary functions of a warehouse. The first function is identified as the temporary storage and protection of goods, the second function as providing value added services, such as the fulfillment of individual customer orders, packaging of goods, after sales services, repairs, testing, inspection and assembly [26]. The two functions are in line with the context of the departments in subject, as outlined in Chapter 2. In this section we first look at where to store inventory in warehouses (Section 3.1.1). Afterwards, we look into the optimization of the inventory storage in Section 3.1.2. We focus on the warehouse perspective and do not include (retail) shelf models.

3.1.1 Storage Process Policies

Rouwenhorst et al. [27] identify three different angles from which a warehouse can be viewed, namely processes, resources and organization. Processes refer to several distinct phases in which the item flow through the warehouse store. These processes can be divided into four main aspects, namely receiving, storage, order picking and shipping [27]. The resources refer to all means (i.e. equipment and personnel) necessary to operate a warehouse [27]. Resources within a warehouse are identified as storage units (e.g. boxes, pallets), storage systems (floor locations, racking), pick equipment (e.g. reach trucks), orderpick auxiliaries (e.g. barcode scanners), computer systems, palletizers and personnel [27]. Lastly, organization refer to all planning and control procedures performed to run the warehouse system, including, but not limited to, the receiving process (e.g. what dock to assign to what truck), the storage process and the order picking process [27].

Rouwenhorst et al. [27] define the storage process as the process whereby items are transported to the storage system and are allocated to storage locations. For the storage allocation multiple storage policies exist. Rouwenhorst et al. [27] identify multiple policies, such as the dedicated storage policy, random storage policy, class based storage policy and allocation based on correlated demand or family grouping.

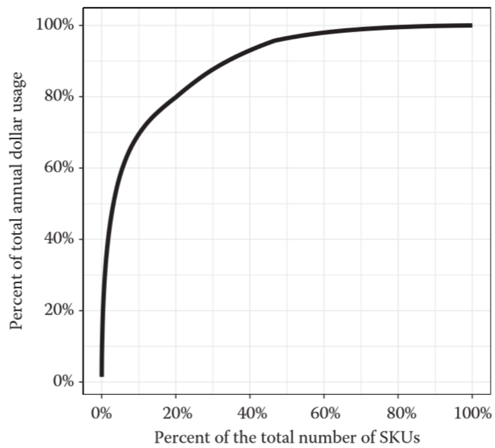


Figure 3.2: Typical value distribution of SKUs [2]

Dedicated grouping prescribes a particular location for the storage of each product, a random policy leaves the decision to the operator [27]. Class based storage policies are based on certain product characteristics, such as ABC zoning [27]. Close examination of large multi-SKU inventory systems revealed a statistical regularity in the usage rates of the items. It revealed that in de order of 20% of the SKUs account for 80% of the total annual dollar usage [2]. Figure 3.2 shows the typical distribution by value curve of SKUs. This model suggest that not all the inventory SKUs should be controlled in the same extent [2]. The model can help identify SKUs that are more important, and hence should be assigned a higher priority [2]. The priorities are based on three levels, namely A (most important, mostly 5 to 10% of the SKUs account for approximately 50% of the total annual dollar movement), B (intermediate in importance, usually more than 50% of the SKUs account for most of the remaining 50% annual dollar movement) and C (least important, remaining SKUs account for only a small part of the annual dollar movement) [2]. The actual division and usage of this strategy is case dependent [2]. Furthermore, Krupp [28] argues for an extra classification, based on the number of customer transactions. Flores and Whybark [29] argues also for an extra classification, but based on criticality. The last mentioned strategy of Rouwenhorst et al. [27] is based on the correlation of demand or family grouping. This strategy includes that products are stored together that are often required simultaneously [27].

3.1.2 Optimization Methods

In the previous section multiple slotting techniques are discussed. The goal of slotting is to determine the best place to store each SKU within a warehouse, according to a variety of factors [30]. The most common motivations for companies to focus on warehouse slotting is the need to place more SKUs into an already overflowing warehouse and the goal to reduce the overall handling costs and effort [31]. The slotting has an influence on various costs, including transportation, ordering, holding, replenishment and out-of-stock costs [25], as mentioned in the introduction of this chapter. Order-picking activities is the most labor-intensive activity within a warehouse [31]. Of the total time the order-picking takes, around 55% is subjected to travelling [32]. Efficient slotting could help to reduce this travel time. Furthermore, also factors such as the replenishment time (and corresponding costs) and ergonomics are influenced by the slotting. To find the most optimal setting of the slotting, with regards to certain factors, optimization techniques can be used. We define optimization as the usage of existing (or developed suitable) algorithms to solve a problem optimally, or to a satisfactory solution. The literature describes a broad range of optimization methods, that can globally be divided into explicit methods, or exact algorithms, and approximation methods, or heuristics. The exact algorithms determines an optimal solution, that often requires much computation time. Heuristics provides a feasible solution, that is as good as possible, in as little time as possible. Real world problems can be very complex and hard to solve. In this research we focus on approximation methods, or heuristics, in order to be able to provide a feasible solution, within a reasonable amount of time. In this section we briefly outline the local search technique.

Local Search

The basics of local search is iterative improvement. The starting point of iterative improvement is an initial solution, from this initial solution neighbourhood solutions are searched with lower costs. If a neighbourhood solution is found with lower costs, it replaces the current solution and the search continues. Otherwise, the solution returns to its current solution [33]. Aarts et al. [33] discuss the details of the local search algorithm in more detail.

There is a broad range of local search algorithms discussed in literature, such as tabu search and simulated annealing. Glover [34] discuss the details and applications of tabu search in more detail. Simulated annealing is a method proposed by Kirkpatrick, Gelett and Vecchi [35] and Cerny [36]. The method has the goal of finding the global minimum of a cost function, that may posses several local minima [37]. The process is based on the emulating process, whereby a solid is slowly cooled [37]. It can include a finite-time with the use of a cooling schema. Within simulated annealing the neighbourhood solution can also be accepted when it is not better than the current solution. This accepting is done according to a certain probability and reduces the effects of local minima.

3.2 Packing Problems

The problem, as described in Chapter 1, can be seen as a special case of a Three-dimensional Bin Packing Problem (3D-BPP). Lodi et al. [38] define the environment of the 3D-BPP as a given set of n three-dimensional rectangular items, each characterized by width w_j, height h_j and depth d_j ($j \in J = \{1, ..., n\}$), and an unlimited number of identical three-dimensional rectangular containers (bins) having width W, height L and depth D. It defines 3D-BPP as the orthogonally packing, without overlapping, of all the items into a minimum number of bins. The packing of items (i.e. cartons) into bins is an important material handling activity in the manufacturing and distribution industries [39]. Bin packing problems have a broad range of practical applications (although it a simplified version of real world problems) [38]. Applications of (industrial) practical applications are e.g. cutting of foam rubber and metal, container and pallet loading and packaging design [38]. I.e. container loading is seen as a special case of 3D-BPP [3] [39]. Within a container loading problem all the items (as defined above) need to be packed into a single bin, with an infinite height. The overall goal is to minimize the height of the filled bin [3]. Bin packing problems are already extensively studied starting from the early seventies and is seen as the corner stone of approximation algorithms [40].

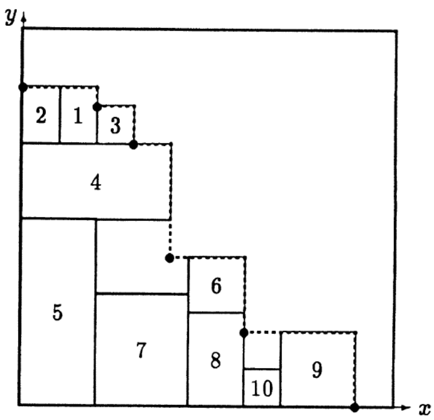


Figure 3.3: Two-dimensional single bin filling [3]

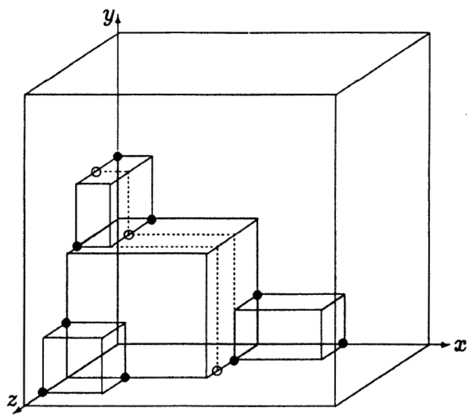


Figure 3.4: Three-dimensional single bin filling [3]

3D-BPP is a special case of the Two-Dimensional Bin Packing Problem (2D-BPP) and the One-Dimensional Bin Packing Problem (1D-BPP) and is seen as strongly NP-Hard [3] [38]. The 2D-BPP can be seen as the determination of the minimum number of identical rectangular bins of width W and height H needed to orthogonally, without overlap, pack a given set of n rectangular having width w_j and height h_j ($j \in J$) [3] [38]. The 1D-BPP is a problem in which a set of n positive values w_j have to been partitioned into a minimum number of subsets, such that the total value of each subset does not exceed a given bin capacity W [3] [38]. Figure 3.3 shows an example of two-dimensional single bin filling [3] and Figure 3.4 an example of three-dimensional single bin filling [3].

A broad range of exact and heuristic approaches are developed in order to solve bin packing problems. Martello et al. [3] presented exact and heuristic approaches to three-dimensional bin packing problems, based on a branch and bound algorithm. Chen et al. [39] provides an analytical model for the container loading problem and Wu et al. [41] provides a model for three-dimensional bin packing problem with variable bin height. Further research is conducted by Dawanda et al. [42], that presented approximation schemes for a class constrained version of the bin packing problem, with variable sized bins and color constrains. Shachnai et al. [43] presented polynomial time approximation schemes for class-constrained packing problem. Xavier et al. [44] provides an approximation schema for a Class Constrained Shelf Bin Packing Problem (CCSBP). The CCSBP is a generalization of the bin packing problem, and therefore also NP-hard. Within a CCSBP the items must be packed into the minimum number of bins, and the items within a bin must be partitioned into compartments [44]. The restriction is set that the items in the same compartment must have the same class and a maximum total size [44]. Subsequent compartments are separated by non-null shelf divisors [44]. Xavier et al. [44] define the problem formally as an instance $I = (L, s, c, d, \Delta, B)$, with a list of items L, s_e as the item size and c_e as the item class $(e \in L)$, d as the size of the shelf divisors, Δ as the maximum size of a shelf and B the size of the bins [44]. The goal of the CCSBP is to find a shelf packing of the items in L into the minimum number of bins (or shelfs) [44].

Martello et al. [45] defined approximate approaches for the bin packing problem, such as the Next-Fit (NF), First-Fit (FF), Best-Fit (BF), Next-Fit Decreasing (NFD), First-Fit Decreasing (FFD) and Best-Fit Decreasing (BFD) approaches. The NF is the simplest approximate approach. In this approach the items are sorted by increasing indices. The first item is assigned to bin 1. Items $2, ..., n$ are then assigned to the current bin if it fits, else to a new bin, that then comes the current one [45]. The FF approach is a better algorithm [45]. It considers the items in increasing indices and assigns each item to the lowest indexed initialized bin into which it fits [45]. The BF is similar to the FF approach, except the items are assigned to a feasible bin having the smallest residual capacity [45]. The other approaches are similar, except sort the items based on decreasing indices. The time complexity differs per approach, the NF has time complexity $O(n)$ and the other approaches of $O(nlogn)$.

3.3 Conclusion

In this chapter the literature study is conducted in line with research questions 2 and 3. These research questions focus on the current literature about SKA allocation in comparable settings and the correlation to the context, as described in Chapter 2. This context shows similar characteristics to the two primary functions of a warehouse, as defined by Heragu et al. [26], namely the temporary storage and protection of goods and the providing of value adding services. Rouwenhorst et al. [27] describe a range of SKA allocation methods that are applicable to warehouse settings. They define the storage process as a process whereby items are transported to the storage system and allocated to storage locations. For the allocation process they describe multiple storage, or slotting, policies, such as dedicated slotting, random slotting and class based slotting policies. The dedicated and class based slotting policies are in line with the slotting policies, as described in the context analysis.

The goal of slotting is to determine the best place to store each SKU, according to a variety of factors. In the previous chapter these factors are explained, namely the three-dimensional characteristics of both the SKUs, as of the resources, and the specific characteristics per SKU, such as demand and HFB group. Furthermore, in the previous chapter the characteristics of the allocation process are outlined. The choice for the most suitable methodology is based on the suitability of the methods in comparison with the characteristics of the allocation process. The key characteristics of the allocation process can be summarized as:

- The allocation process is dynamic, it includes changes in range, racking and demand.
- The allocation process supports the efficiency of the KPIs, as defined in Chapter 2. Namely, fast-picking, internal damages, CSL and handling rate.
- The allocation process includes the safety restrictions, as defined in Chapter 2.

- The allocation process includes different sizes of racking and dynamic sizes of products.

The allocation process, as summarized above and explained in Chapter 2, can be seen as a special case of a bin packing problem, whereby every racking can be seen as a bin, there are a finite number of bins and every bin can have different dimensions. Furthermore, the safety restrictions can be implemented by reducing the available dimensions of the bin. Due to the dynamic character of the products, the dimensions to allocate can differ according to the demand (i.e. number of products to allocate) and available racking. Within the bin packing problem methodology this dynamic character can be implemented by changing the available racking, based on the dynamic created product dimensions. The methodology behind the bin packing problem can be amended to fit the characteristics of the allocation process, as iterated on the previous page and is therefore a suitable methodology for the allocation model.

The bin packing methodology creates a solution, in contrast to the local search methods, that make use of an initial (random) solution to find a better solution. Due to the dynamic character of the product dimensions, the local search methods are not preferable. These methods can be used in further research on further optimization based on the solution created by the amended bin packing methodology.

With the use of the restriction that it is only allowed to store identical SKUs on top and behind each other, the three-dimensional problem can be reduced to a one-dimensional problem. The height and length of the SKUs can be set as a criteria for the resource selection and therefore only the width can be used for solving the actual problem (since only this dimension is shared with other SKUs). This simplifies the problem and therefore reduces the time it takes to find a solution. Figure 3.5 shows an example of the differences between the different bin packing problems, amended to our situation. In this situation the number of bins is finite and therefore the goal is to allocate as much items as possible in the available finite number of bins, whereby the bins can have nonidentical dimensions. This is a different objective in comparison with the actual 3D-BPP, that incorporates an unlimited number of identical three-dimensional rectangular bins [38].

For solving the 1D-BPP the approximate approaches, as described by Martello et al. [45], can be used to determine the best results, based on the width dimension of the SKUs and the resources. The other characteristics of the SKUs can be taken into account with the use of the different slotting strategies, such as dedicated and class-based slotting, by adding extra selection characteristics to the resources.

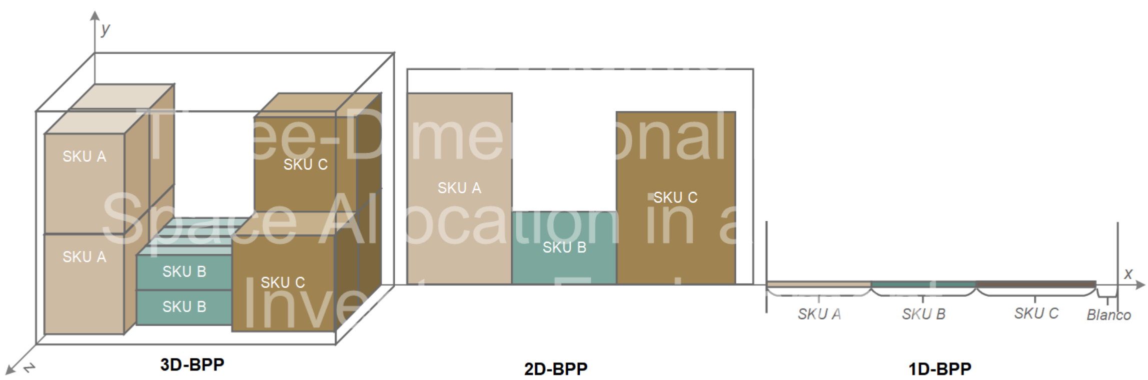


Figure 3.5: The 3D-BPP, 2D-BPP and 1D-BPP

Chapter 4

Model Design

This chapter describes the design of the resource allocation model. We start this chapter with the outline of the development methodology. In Section 4.1 we first give a brief overview of possible development methodologies, whereby afterwards we outline and discuss the choice for the waterfall method in more details. The sections that follow are structures according to the waterfall methodology. In Section 4.2 we go into the requirements and analysis phase of the model. In Section 4.3 we go to the next phase and outline the design of the model. Section 4.4 describes the actual coding of the model, Section 4.5 the testing and Section 4.6 the integration phase. We conclude this chapter in Section 4.7.

4.1 Development Methodology

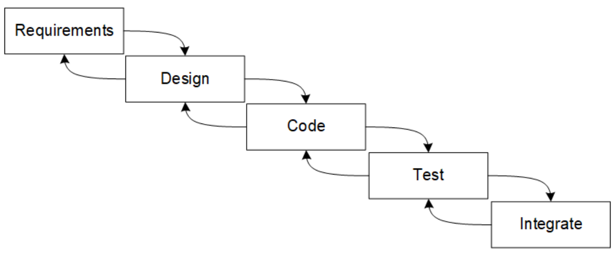


Figure 4.1: The waterfall method, phases according to Thayer et al. [4]

To structure our model development, we define a development methodology. For this methodology we look at available software development methodologies. Over the past decades a broad range of (hybrid) software development methodologies are developed, such as the waterfall method and agile methods. Multiple authors, such as Boehm [46], Thayer et al. [4] and more recently Awad [47] give a overview and discussion about a broad selection of these methods, their history and application. We use the waterfall methodology for our model development. Royce [48] introduced the waterfall method in the 1970s. This approach emphasizes a structured progression between the different phases [47]. The approach can be structured down into five main phases. Awad [47] explain the different phases as follows. The first phase is the requirement phase and determines what the model should be able to do. The second phase is the designing phase. In this phase it is determined how the model is designed. The third phase is the coding phase, in this phase the actual coding is done. In the fourth phase the testing of the system is done and in the fifth phase the actual implementation (i.e. documentation and training) is done. Figure 4.1 shows a visual example of the waterfall sequence, according to Thayer et al. [4]. We choice the waterfall method because it gives a clear overview of the different stages, it is widely used for small (and large) software projects and also have been reported successfully in many projects [47]. The interpretation of the phases is amended to our specific case.

4.2 Requirements

The first step of the waterfall method is the determination of the requirements of the model. The overall goal of the model is in line with the fulfillment of the overall goal of this thesis, namely to develop an efficient, adaptive and generic approach of SKA allocation, within the SSFA and WH departments. In this case a clear stakeholder is identified, namely the IKEA Group and more specific the co-workers responsible for the goods allocation process within the local warehouse store in subject. Furthermore, the goods allocation has an effect on a broader range of stakeholders within the employees, as explained in Chapter 2. The requirements of the model need to be in line with the overall goal of this thesis and the requirements retrieved from the stakeholders and the process, as discussed in Chapter 2. We divided the requirements between functional requirements, technical requirements and other requirements. The requirements focus on what the program should do, not on how the program should do it. Table 4.1 shows the program of requirements.

Table 4.1: Program of requirements

Functional requirements	**Explanation**
Adaptive	The model needs to be adaptive, such that it can include the changes in range, racking and demand.
Generic	The model needs to be generic, such that it is applicable to all similar store setting.
User friendly	The model needs to be user friendly, such that it can be operated without any expert help.
KPIs	The model needs to be designed such that it support the efficiency of the KPIs, as defined in Chapter 2. Namely, fast-picking, internal damages, CSL and handling rate.
Safety restrictions	The model needs to be able to support and include the safety restrictions, as defined in chapter 2.
Slotting	The model needs to be able to allocate the resources based on, at least, the dedicated and class based slotting strategies.
Output	The model needs to provide the racking number, section and level allocated. to a SKU.
Output	The model needs to provide insight into the performance of the racking and KPIs.
Output	A visual example of the racking needs to be given.
Performance	The model needs to provide a solution in a reasonable amount of time.
Performance	The model needs to be antifragile, such that errors make the system better.
Process	The model needs to be able to execute the same allocation process, as discussed in Chapter 2.
Technical requirements	
Platform	The model needs to be able to run on Windows 10.
Executable	The model needs to be executable and stand alone.
Integration	The model needs to be able to integrate with basic Excel spreadsheets.
Other requirements	
Maintenance	The coding of the model needs to be documented clearly, such that further maintenance can be done efficiently.

4.3 Designing

The second phase of the waterfall method is the designing phase. In this phase the model is designed. In this designing we implement both the business logic, that needs to be designed, as the Graphical User Interface (GUI). In Section 4.3.1 the logic behind the program is explained, including the logic behind the slotting methods and the dynamic dimensions. In Section 4.3.2 the GUI is designed and discussed.

4.3.1 Business Logic

In Chapter 2 the context analysis of the problem is given and the corresponding goods allocation process. In this process multiple steps and restrictions are identified. The restrictions of the model are outlined in Section 4.2. In Chapter 3 a literature study is conducted, with the focus on the best way of SKA allocation in the described context. From this literature study is concluded that the bin packing methodology is the best suitable methodology that can be amended to our specific case. To be able to execute this method, first the dynamic dimensions of the SKUs need to be determined.

Dynamic SKU Dimensions

The width is the only dimension that is shared with other items, the other dimensions are therefore only relevant for the selection of the correct racking. In Appendix A it is discussed that items are loaded with and without a pallet or only with a number of customerpacks. In every situation different dimensions occur, that need to be taken into account for the selection of the correct racking. Since the depth and height within a facing may not be shared with multiple SKUs, the goal is to optimize these dimensions with the most items of the same kind as possible and therefore reduce the amount of width a SKU needs.

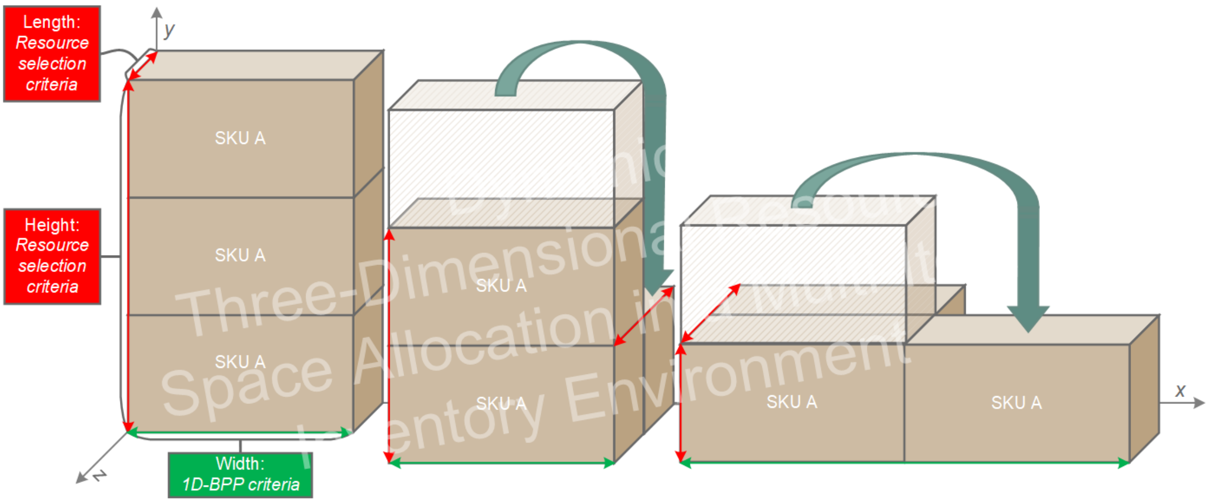


Figure 4.2: Dimensions finding principle

Figure 4.2 shows a visual representation of this stacking principle. It shows an example of three customerpacks that need to be allocated. These customerpacks can be placed upon each other (extra height), behind each other (extra length) and next to each other (extra width). Since we want to minimize the width, it is logic that first the items are placed upon each other to maximize the height or behind each other to maximize the depth. It is more preferable to first maximize the height fully, since this result in full facings for the customers. So, when three boxes need to be allocated, first these three boxes are placed on top of each other. This result in certain dimensions for length, width and height. Afterwards it is checked if these dimensions can be fit within a particular racking. If so, the items are allocated there, if not, the next step is to place one box behind the stable. The height of the stable is therefore reduced, but the length increased. Next, the racking is checked again. If it is still not possible, or the depth or height is extreme (bigger than the maximum depth or height of a racking), the boxes can be placed next to each other. The same principle is used for the placing of full pallets. After a racking is found that fits the criteria, the stable can be placed there according to the 1D-BPP approximate approaches, as discussed in Chapter 3. This principle is further discussed in Section 4.4. The corresponding dimensions that need to be allocated differ per SKU packaging type.

Package Dimensions

The SKUs that need to be allocated differ in packaging type and therefore also in packaging dimensions. The principle for finding the correct dimensions to allocate per SKU is based on the initial dimensions of one customerpack, multibox or pallet, depending on the delivery type and how the SKU needs to be allocated. Figure 4.3 shows a graphical representation of the allocated dimensions of different packaging types. The figure represents two racking sections, one racking section on level 00 (floor level) and one racking section on level 10 (shelf level). It shows that the products allocated on the floor level, are allocated on a pallet. So for these products the pallet dimensions need to be used for the procedure of finding the dimensions to allocate. On the shelf level only customerpacks are allocated. The corresponding dimensions are need to be used for finding the correct dimensions to allocate. For mattresses on ground level the pallet dimensions needs to be taken, for mattresses on shelf level the customerpack dimensions. The dimensions per packaging type are further explained on the next pages.

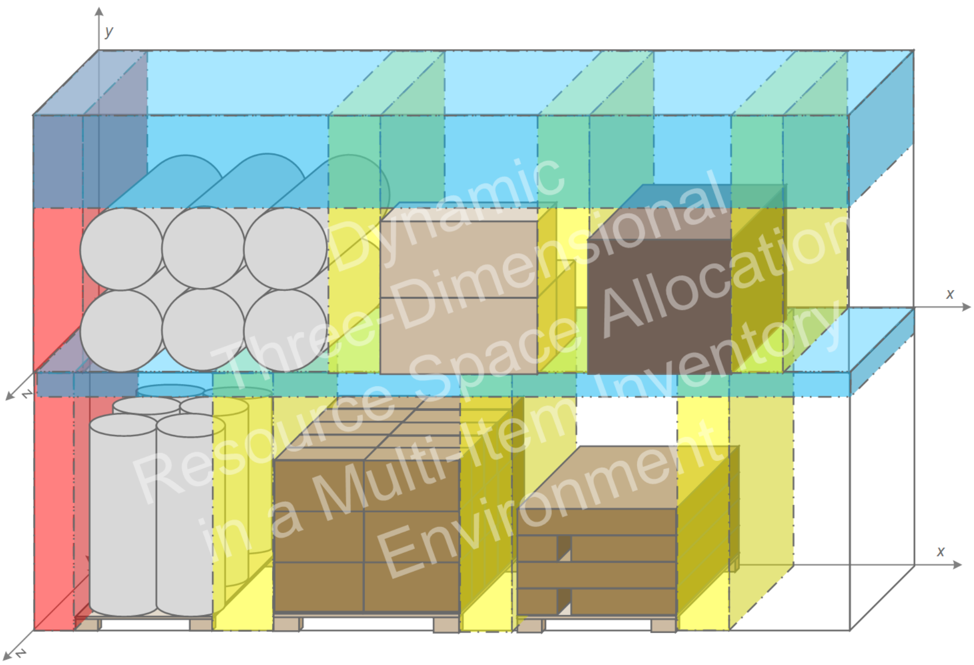


Figure 4.3: Allocated SKU dimensions in racking

Customer- and Multipack Dimensions

A multipack consist of multiple customerpacks. It is not allowed to allocate a fracture of a multipack, so the allocation of a multipack is identical to the allocation of a number of customerpacks. Within the determination of the sales space quantity this is taken into account, such that always an integer value of multipacks need to be allocated (if applicable). Figure 4.4 shows the dimensions to be allocated of a customerpack. It can be seen that the dimensions to allocate are an integer multiple of the dimensions of the customer pack, depending on the number of boxes to allocate. Figure 4.5 shows the same principle for the multipacks, that is identical to the allocation process of a customerpack. Nevertheless, the dimensions of the multipacks can differ from the integer multiple dimensions of the customerpacks, so in the business logic it is necessary to identify SKUs that are delivered with a multibox or customerpack, to find the correct dimensions to allocate. Furthermore, it can occur that a SKU is heavier than 15 kg, but not delivered on a pallet. The DT is therefore 0 (customerpack), but the SKU is not allowed to be allocated on level 10 locations, due to the weight restriction. In this case an extra height of 15 cm (simulation of an Euro Pallet (EP)) is added and the product is allowed to be allocated on level 00 (Figure 4.6).

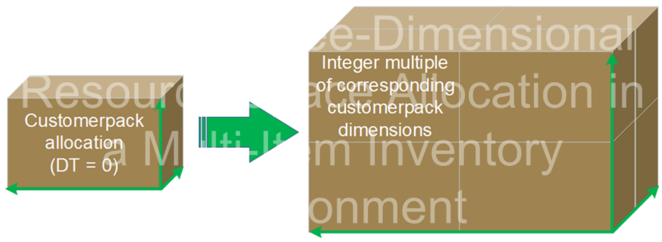


Figure 4.4: Customerpack dimensions to allocate

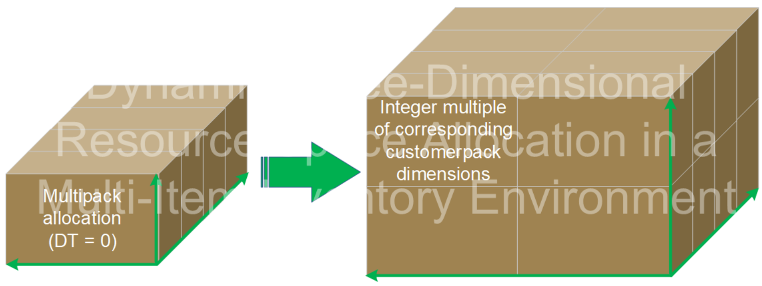


Figure 4.5: Multipack dimensions to allocate

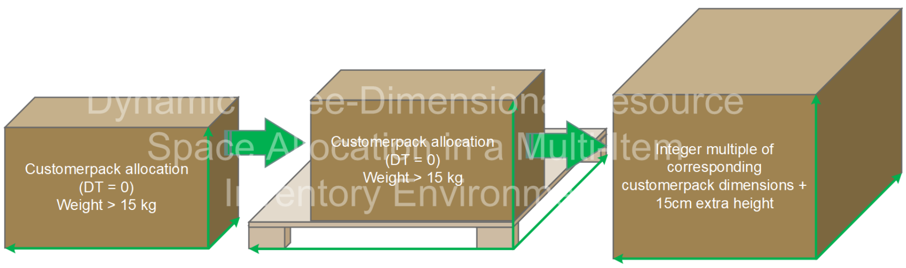


Figure 4.6: Heavy customerpack dimensions to allocate

Pallet Dimensions

If a SKU needs to be allocated with a pallet, the corresponding pallet dimensions are used. If the sales space quantity is equal to the number of products on an integer number of pallets, the stacking principle is the same as the allocation of a customerpack (Figure 4.4). This increases the stocking speed. Figure 4.7 shows the principle of finding the correct dimensions to allocate of a pallet.

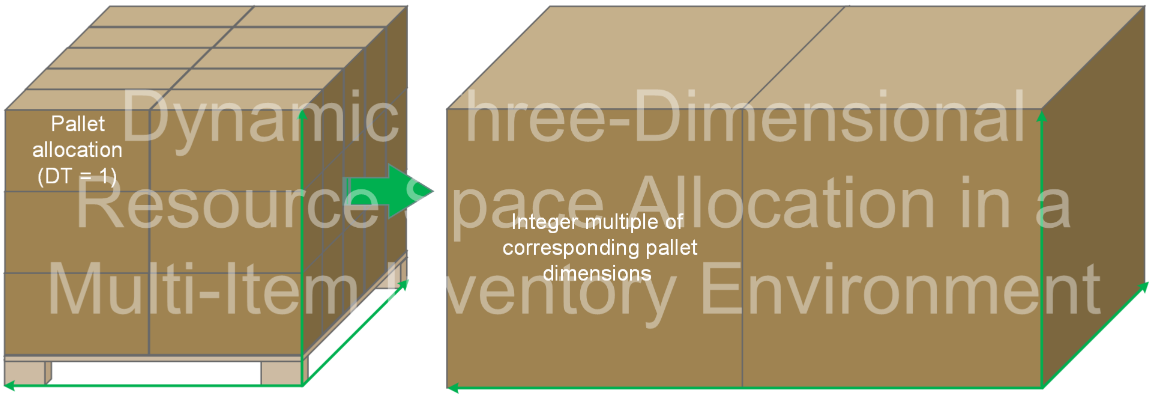
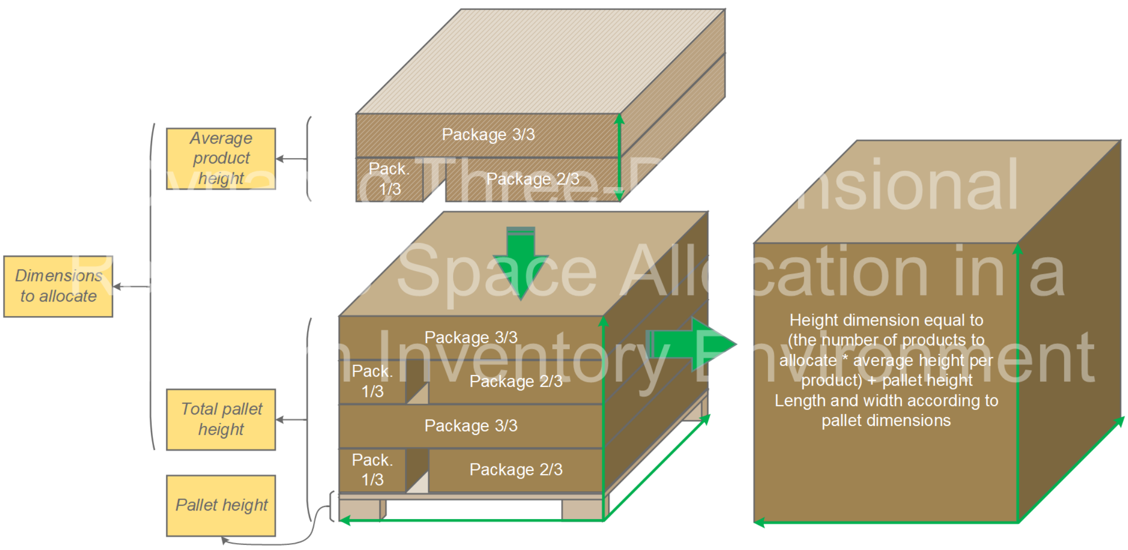


Figure 4.7: Pallet dimensions to allocate

It can be possible that a single product consists of multiple boxes. If the number of products on one single pallet is more or less than the sales space quantity, the pallet dimensions needs to be adjusted. This is done according to an estimation of the dimensions of one single product. Figure 4.8 shows this principle. The average height of a product is calculated by dividing the total height of a pallet (minus the pallet height itself) by the number of products on a pallet. This value is added or withdrawn from the total pallet height. The length and width stay identical to the pallet dimensions. These adaptive dimensions are approximations of the actual dimensions, therefore the expert opinion has to be taken into account when allocation those products.



Dynamic Three-Dimensional Resource Space Allocation in a Multi-Item Inventory Environment

Figure 4.8: Pallet dimensions (with extra height) to allocate

Mattress Dimensions

Mattress dimensions are a special case of pallet and customerpack dimensions. If the sales space quantity of a mattress is identical to an integer multiplication of the number of mattresses per pallet, the dimensions are measured according to the same pallet principle (Figure 4.7), as shown in Figure 4.9.

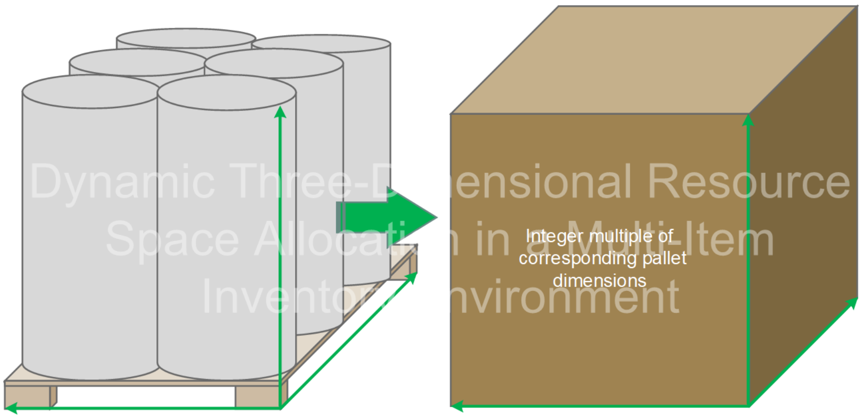


Figure 4.9: Mattress pallet dimensions to allocate

If the sales space quantity of a mattress is more than the number of mattresses per pallet, but not an integer multiplication, these extra mattresses can either be stores before the pallet (extra length), on top of the pallet (extra height) or as a customerpack on a shelf (without a pallet). If the mattresses need to be allocated on a shelf, the allocation type is set as a customerpack instead of a pallet. Figure 4.10 shows the pallet dimensions with extra length, Figure 4.11 the pallet dimensions with extra height and Figure 4.12 the customerpack dimensions of the mattresses. These adaptive dimensions are approximations of the actual dimensions, therefore the expert opinion has to be taken into account when allocation those products.

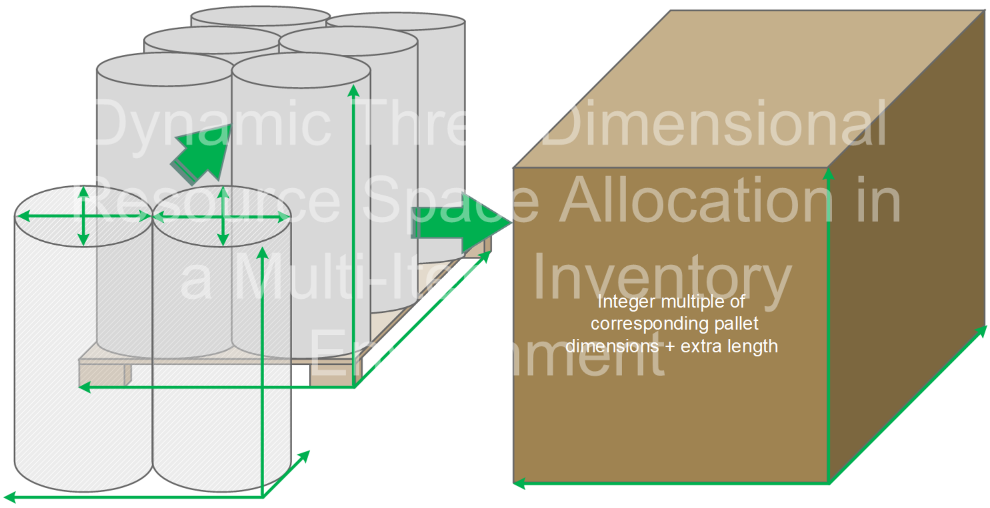


Figure 4.10: Mattress pallet dimensions (with extra customerpack length) to allocate

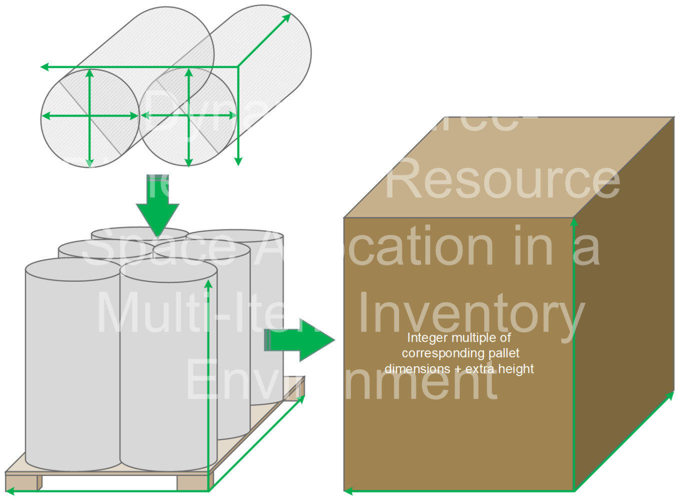


Figure 4.11: Mattress pallet dimensions (with extra customerpack height) to allocate

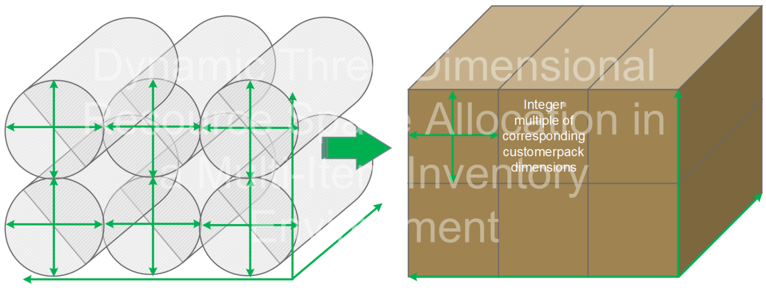


Figure 4.12: Mattress customerpack dimensions to allocate

The One-Dimensional Bin Packing Problem (1D-BPP)

In the previous chapter multiple strategies for the 1D-BPP are defined. These different kind of strategies can be used to determine the best results. Figure 4.13 shows a visual example of the 1D-BPP, amended to this special case. In the previous step the dimensions of the SKU are determined. In every step of the dynamic determination of the dimensions, it is checked if the dimensions fit into a racking. If it fits into at least one racking, the SKU can be placed. This placing can be done according to different strategies. It is possible that the SKU fits into multiple racking. Then the 1D-BPP principles, as discussed in the previous chapter, can be used to determine the best allocation results. Figure 4.13 shows a SKU that needs to be allocated. Two different racking show sufficient space (Subset D). According to the first-fit strategy, the SKU is allocated into the first racking that fits. According to the best-fit strategy, the SKU is allocated to the racking that will leave the fewest blanco space.

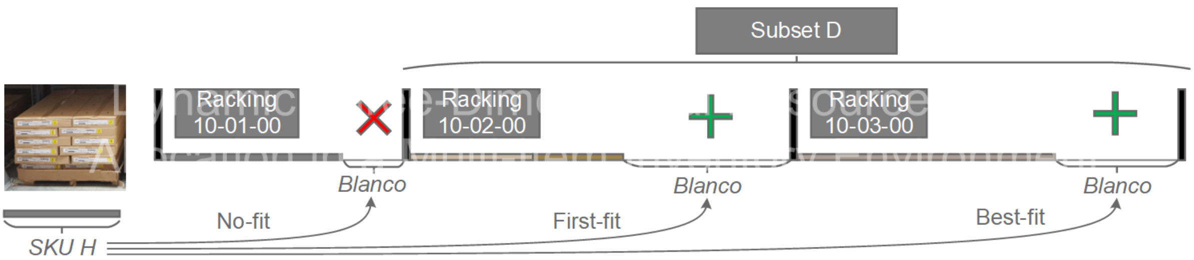


Figure 4.13: The 1D-BPP principle

KPI Logic

In Chapter 2 the KPIs are discussed and operationalised. In the previous section the requirements of the program are outlined, including the implementation of the defined KPIs. The KPIs involved are the internal damages, CSL, handling rate and fastpicking operations. To be able to implement the KPIs to its fullest potential, first the business logic behind the KPIs have to be declared.

The causes of internal damages are discussed with the involved employees and logistic experts. As also outlined in Chapter 2 the main reasons for internal damages within the racking are not suitable dimensions for the SKUs (i.e. allocated dimensions too small) and not enough slack space between different SKUs. To implement the identified causes of the damages, we include multiple slack variables, that are adaptive per racking. These slack variables include slack between SKUs and slack between SKUs and the uprights. The latest is further explained during the safety restrictions business logic. The slack variables are adaptive per racking, such that each racking can have different slack settings, depending on necessary safety restrictions and design of the racking (Figure 4.15).

The logic behind the CSL and the handling rate is part of the initial solution, whereby with the use of the 1D-BPP methodology and optimization it is tried to allocate as much as items as possible within the SKA. To create this initial solution the characteristics of the SKUs and racking are important, such as the length, width, height, delivery type and demand. These characteristics can be used to sort the SKUs and racking to obtain different solutions, with different performance. The logic behind the fast picking operation is that every racking is allocated to a certain fastpicking area, based on meters to the output and the time it takes to pick an item (Figure 4.14). Within the SSFA the same principle can be applied. The SKUs can be sorted according to demand rate and the racking sorted according to fastmovers area, such that the fast moving SKUs are most likely to be allocated close to the output.

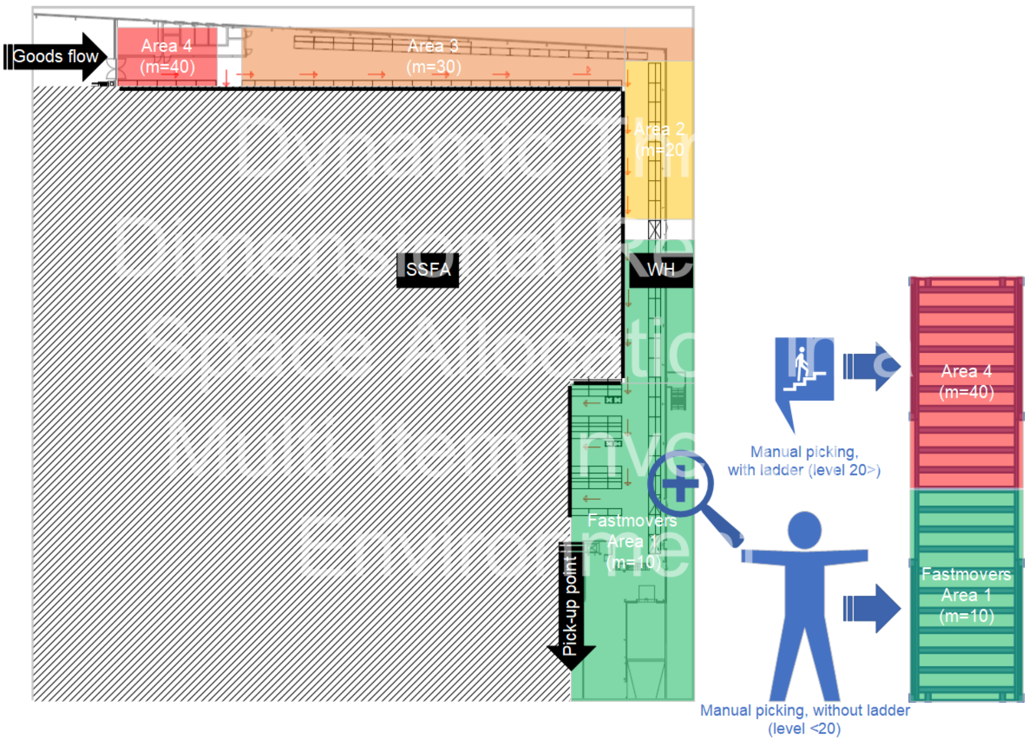


Figure 4.14: The defined racking areas within the WH

Safety Restrictions Logic

Within the program of requirements also the safety restrictions are outlined, as discussed in Chapter 2. Four different kind of safety restrictions are mentioned, namely the slack between the uprights and SKUs, the slack between sprinklers and the SKUs, the slack between SKUs if an SKU is longer than 150 cm and transverse channels at the back at level 10 and higher.

The transverse channels at the back of level 10 and higher can be implemented by reducing the length (depth) of a racking when applicable. The other restrictions are implemented with the use of slack variables, that reduce the dimensions available to store the SKUs within a racking. Figure 4.15 gives a visual representation of the different slack settings. The slack settings are adaptive, such that every racking can have individual settings. The slack between the uprights and the SKUs can also be used to reduce the internal damages, as mentioned on the previous page.

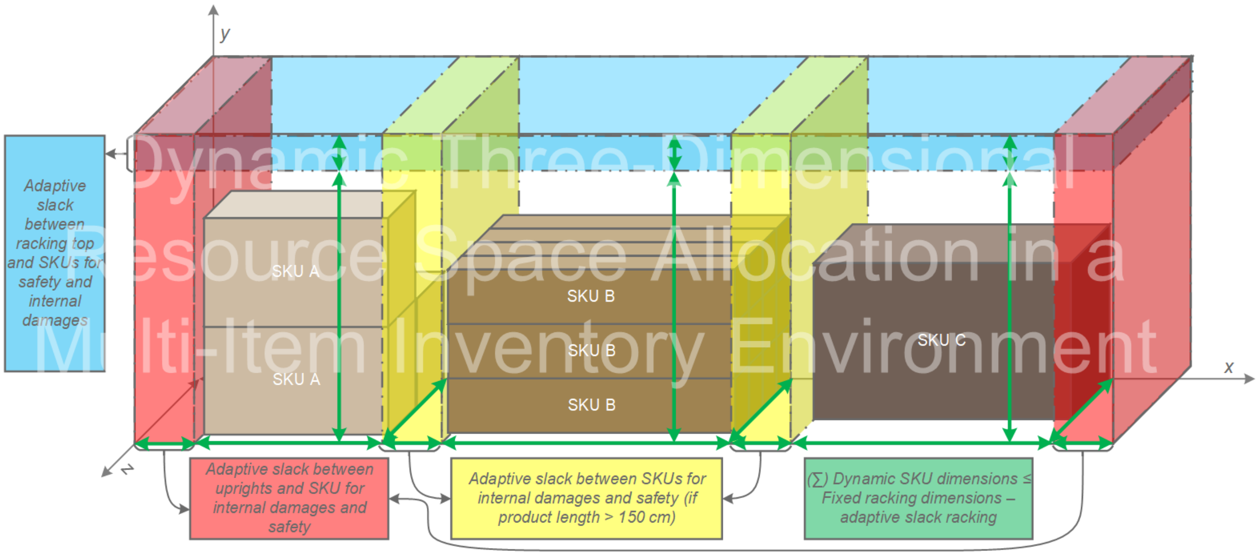


Figure 4.15: Safety restrictions and internal damages

Slotting Logic

The slotting logic is based on dedicated storage (i.e. SKUs with a fixed location) and dynamic storage, depending on the racking available. The logic behind the slotting is that the SKUs and the racking are sorted, based on a set of priorities. For the SKUs we defined the length, width, height, demand, weight and product area as sorting priorities. For the racking the length, width, height and fastmoving area. The sorting of both the racking and the SKUs cause that certain products are allocated first and therefore have the broadest available section of racking. The consequence is that these products have more SKA available (i.e. less SKUs are allocated yet) and therefore have a higher probability that there is enough space to allocate them. The products that have a dedicated location are sorted on top of the list, such that they are allocated first. The sorting of the racking have the consequence that the racking on top of the list (i.e. with the highest priority) is allocated first (if the dimensions of the SKU can fit into the dimensions of the racking). The sorting of the products is done from high to low values and the sorting of the racking from low to high values, such that the available space is allocated as efficient as possible. Else, it can cause that small products are allocated into large racking sections, with the consequence that large products can not be allocated, due to the fixed resource environment.

4.3.2 Graphical User Interface

The GUI is an important aspect within the program development, since this increases the user friendliness of the program. From the program of requirements we extracted four different areas, namely:

- Input area: To include the adaptive and generic requirement, an input area is included. This area includes the possibility to upload an excel file with the product characteristics and racking characteristics.
- Information area: To increase the user-friendliness of the program, an information area is included. In this area information can be retrieved with regards to the design of the program, the methodology, the way of working and the possibility to obtain further information.
- Control area: To include the antifragility of the program, a control area is included that enables the user to control and check the input on errors and easily adjust them (make the system better). The data involved is uploaded in the input section and can be divided into product and racking characteristics.
- Settings area: To include the different safety restrictions, KPIs and allocation settings, a settings area in included. In this area the different restrictions and settings can be adjusted and turned on/off.
- Output area: To include the requirements of file output and visual representation, an output area is included. In this area product and racking files can be downloaded, as also a visual representation of a selected racking.

Figure 4.16 shows a visual representation of the designed GUI, based on the above defined areas. Appendix F shows the further layout of the program.

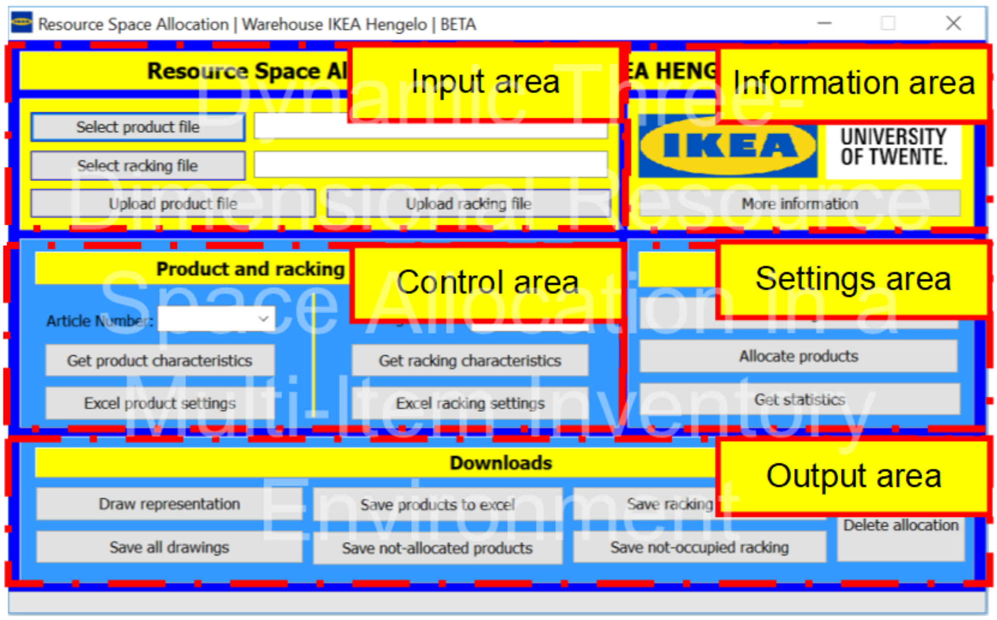


Figure 4.16: The designed GUI

4.3.3 Input Data

To implement the defined business logic into programming language, a set of input data is required. This input data can be divided into product and racking data. Appendix G shows the product characteristics input data and the racking characteristics input data. This data is available through the databases of the warehouse store in subject. Before the data can be used, the data has to be merged, transformed and checked for errors and accuracy. Due to the limited size of the data set and the requirement that no external programs are needed to be able execute the program (except for excel), this is done manually with excel scripts and no data transformation program is used.

4.4 Coding

The next step in the waterfall methodology is the coding part. In this part the actual coding is done. This coding is done in a structured way. First the program is divided into multiple subprograms. These subprograms can be divided into several coding clusters, that are stand-alone coding scrips and therefore can be programmed and tested individually. Before the actual coding is done, flowcharts and pseudo coding is made. Pseudo coding is a readable description what the coding must do. In Section 4.4.1 the different subprograms are identified. First the flow charts are made, afterwards these flowcharts are translated into pseudo coding and finally transformed into actual coding, that can be implemented and tested. The programming and program design is done in Embarcadero Delphi, in the object orientated programming language Pascal.

4.4.1 Subprograms

The program can be divided into several subprograms. These subprograms can be subtracted from the created GUI, namely input programs, information programs, control programs, settings (and executing) programs and output programs. Every program can further be divided into several subfunctionalities, that together form the functionality for that particular area. The flow charts can be found in Appendix H.

Input Programs
The input programs have the goal to upload the product and racking characteristics into the memory of the program. This is done by transforming the excel data into multi-dimensional string arrays. By uploading the file into the program memory, the connection to the excel files have to be made ones and therefore increases the speed of the program significantly. The coding in this part includes one coding functionality that can be used to connect to a selected excel file and upload it into a given three-dimensional array, depending on if the product or racking file is selected. Appendix H shows the flowcharts for this functionality.

Information Programs
The information programs have to goal to provide the user with information about the program, the methodology and how to operate the program. This is done by a push-up window. The flowcharts for this functionality can be found in Appendix H. This functionality is a complement to, but not a replacement of, the user manual (Section 4.6).

Control Programs

The control programs have the goal to open and show the data from the uploaded excel files to the user. The user select a certain product or racking ID, whereby afterwards a push-up window appears with the corresponding characteristics, amended to each specific case.

Settings and Executing Programs

The settings and executing programs have the goal to execute the allocation method. This allocation coding can be divided into several sub parts, namely the product sorting, the racking sorting, the search for the dimensions to allocate and the actual allocation of resources.

The bubble sorting algorithm is used for the sorting of both the products and the racking. Within this algorithm nested sorting criteria are implemented, based on the selected priorities. This means that if the selected numbers can be swapped based on priority 1, all the other priorities are irrelevant. Else, priority 2 is checked and so on. Figure 4.17 shows the flow diagram of this sorting procedure, amended to the sorting of the product array.

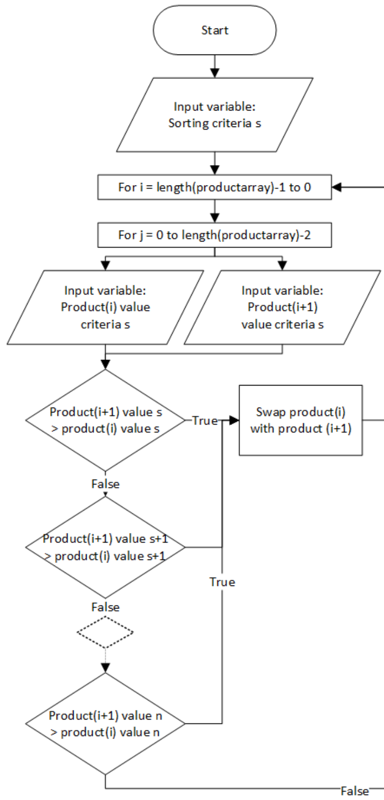


Figure 4.17: Nested sorting flow chart

An own algorithm is designed to find the correct dimensions to allocate of the SKUs. Figure 4.18 shows a visual representation of this approach. The first step in the heuristic is allocating all items that need to be allocated on top of each other, such that the x and z-dimensions are equal to the customerpack or pallet dimension and the y-dimension equal to the multiplication of the y-dimension with the number of products or pallets to allocate. Afterwards the dimensions are changed, according to the racking available. These available racking are divided between different subsets, namely SubsetA (Set of all racking (Equation 4.1)), SubsetB (subset of all racking with sufficient height, including the slack values (Equation 4.2)), SubsetC (subset of all racking with sufficient height and length (Equation 4.3)) and SubsetD (subset of all racking with sufficient height, length and width, including the slack values (Equation 4.4)). The heuristic is further explained on the next pages. The corresponding flowcharts can be found in Appendix H.

$$SubsetA \ni AllRacking \tag{4.1}$$

$$SubsetB \subseteq SubsetA | (Y_{racking} - YSlack_{racking}) \geq Y_{SKU} \tag{4.2}$$

$$SubsetC \subseteq SubsetB | Z_{racking} \geq Z_{SKU} \tag{4.3}$$

$$SubsetD \subseteq SubsetC | XLeft_{racking} \geq (X_{SKU} + XSlack_{SKU}) \tag{4.4}$$

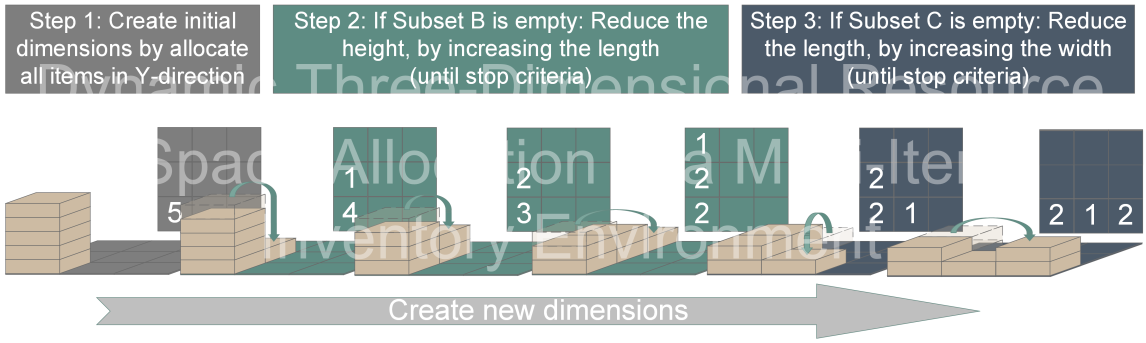


Figure 4.18: New dimensions heuristic

After dimensions are found, it is checked if they fit into at least one racking. Figure 4.19 shows a visual explanation of the actual allocation heuristic. The overall goal of the heuristic is to allocate as much items as possible (Equation 4.5). A SKU can only be assigned to one racking (Equation 4.6), but a racking can be assigned to multiple SKUs (Equation 4.7). If a SKU is allocated to a racking, the SKU is allocated and can not be allocated to other racking (Equation 4.8). A SKU can either be allocated or not and a racking can either include this SKU or not (Equation 4.9). The value i ($i \in N$) indicates the SKU number and the value j indicates the racking number ($j \in M$). The heuristic is based on the 1D-BPP methodology, but amended to our specific case.

$$Max \sum_{i=1}^{n} P_i \tag{4.5}$$

$$\sum_{j=1}^{m} \sum_{i=1}^{n} P_i A_{ij} \leq 1 \tag{4.6}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} \geq 0 \tag{4.7}$$

$$A_{ij} \leq P_i \tag{4.8}$$

$$P_i, A_{ij} = \{0, 1\} \tag{4.9}$$

The first step in the heuristic is checking if there exist racking that can fit the height (including the defined slack), to create SubsetB (Equation 4.2). In other words, if the SKU wants to be allocated in that racking, the height of the racking has to be sufficient to allocate the SKU (Equation 4.10). The height of the SKU and racking have to be greater than zero (Equation 4.11) and the slack at least zero (Equation 4.12).

$$A_{ij} Y_i \leq Y_j - YSlack_j \tag{4.10}$$

$$Y_i, Y_j > 0 \tag{4.11}$$

$$YSlack_j \geq 0 \tag{4.12}$$

If SubsetB is empty, it means that there is no racking that has sufficient height, so new dimensions have to be found. This indicates reducing the height, by increasing the depth and checking SubsetA again (Figure 4.18). If the height cannot be reduced, the SKU cannot be allocated (Figure 4.19).

If SubsetB is not empty, SubsubC is created, that exists of all racking of SubsetB that also have sufficient length (depth) (Equation 4.3). In other words, if the SKU wants to be allocated in the racking, the height and the length of the racking have to be sufficient (Equation 4.13). If the length of the SKU is longer than 150 cm, than the extra width slack is implemented (Equation 4.14 and 4.15), whereby S_j indicates if the slack is added or not (Equation 4.16) and M is a big number. The length of both the SKUs, as the racking, have to be greater than zero (Equation 4.17).

$$A_{ij}Z_i \leq Z_j \tag{4.13}$$

$$A_{ij}Z_i \geq 1500 + 1 - M(1 - S_j) \tag{4.14}$$

$$1500 \geq A_{ij}Z_i + 1 - MS_j \tag{4.15}$$

$$S_j = \{0, 1\} \tag{4.16}$$

$$Z_i, Z_j > 0 \tag{4.17}$$

If SubsetC is empty, new dimensions have to be found. Since increasing the height and depth provide no feasible racking, only the width can be increased (Figure 4.18). If SubsetC is not empty (so at least one racking is found with sufficient height and depth), then SubsetD is created. SubsetD exists of all racking of SubsetC, that also have sufficient width (including the defined slack) (Equation 4.4). In other words, if the SKU want to be allocated to the racking, the height, length and width of the racking have to be sufficient (Equation 4.18). The width of both the SKUs, as the racking, have to be greater than zero (Equation 4.19). The width of the slack values can also be zero (Equation 4.20).

$$A_{ij}X_i \leq X_j - XSlackSKU_j - \sum_{i=1}^{n} A_{ij}X_i - S_jXSlack150_j \tag{4.18}$$

$$X_i, X_j > 0 \tag{4.19}$$

$$XSlackSKU_j, XSlack150_j \geq 0 \tag{4.20}$$

If SubsetD is empty, it is first checked if the y-dimension can be further reduced (Figure 4.19). If this is the situation, then the y-dimension is reduced according to Figure 4.18 and the allocation heuristic is ran again. It could be possible that there exist racking with less height, but with more width and/or length. If the y-dimension cannot be reduced, the product cannot be allocated. This information can be subtracted from the program, with the use of the output programs.

If SubsetD is not empty, the 1D-BPP Knapsack problem is executed. In this problem the 'knapsack' is the racking in SubsetD. The 3D problem is reduced to an 1D problem, whereby only the width of the racking in SubsetD is relevant, since the height and length are racking selection criteria. The knapsack algorithm is executed on SubsetD and also includes the defined slack variables for the width. The first step in this algorithm is the sorting of SubsetD based on the width left. For this problem approximate approaches are used, as defined in the previous chapter. The sorting of SubsetD is done according to the bubble sorting algorithm. The corresponding flowcharts can be found in Appendix H.

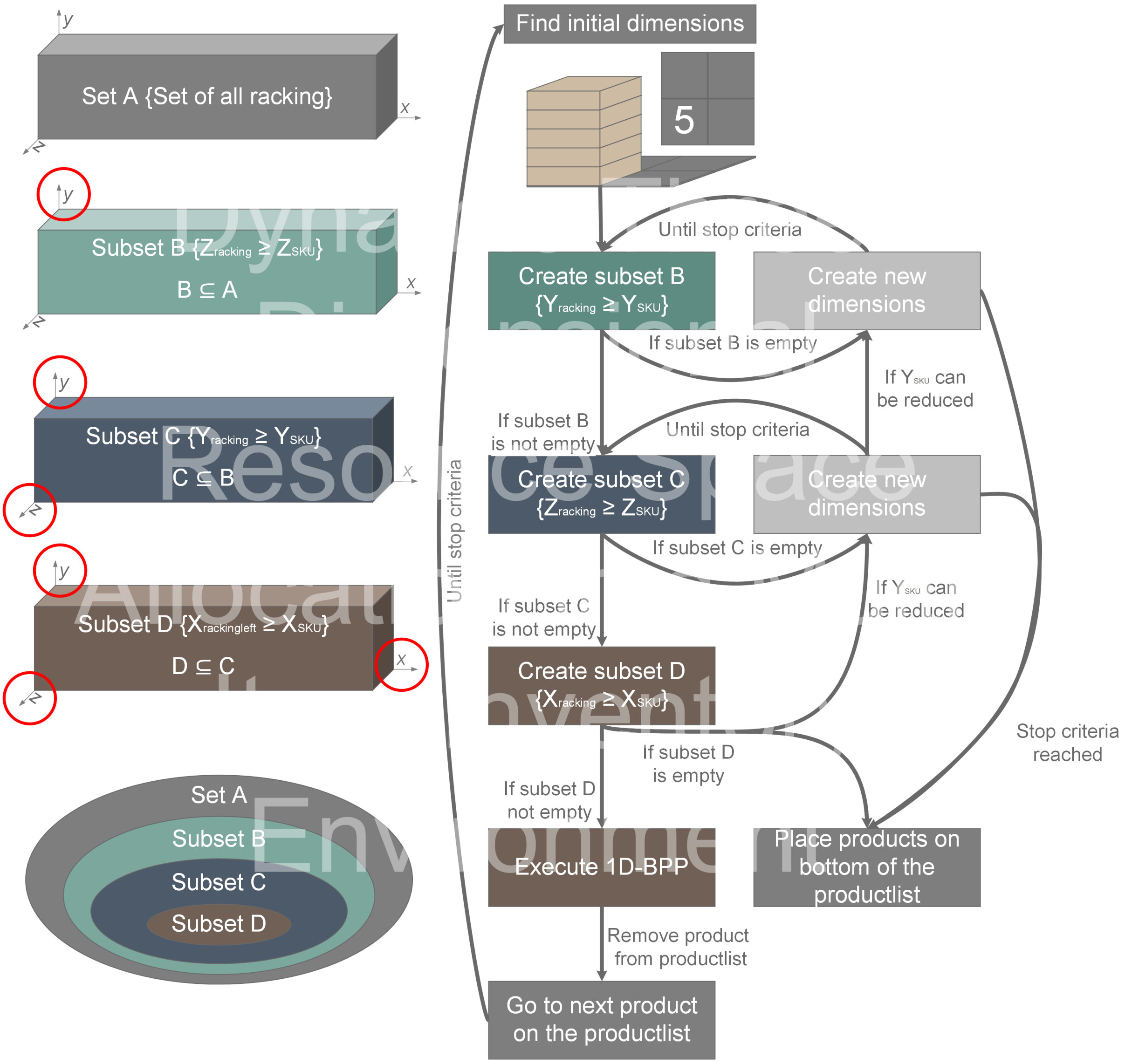


Figure 4.19: Resource selecting heuristic

Output Programs

The output programs have the goal to transform the input data back to excel and the racking characteristics to an image file. The output to excel is based on the same principle as the input programs, except it is reversed. In the creation of each racking image, the productlist is checked for products that are allocated to the selected racking. Then the dimensions are selected and drawn on the dimensions of the racking itself. The corresponding flowcharts can be found in Appendix H.

4.5 Testing

The next step in the waterfall method is the testing of the program. The testing is done with a combination of quantitatively testing, based on excel output, and visually testing, based on image outputs. The visually and quantitatively checking support each other, visual representations can be checked by quantitative data and the other way around. First the program is tested on functionalities (Section 4.5.1), whereby afterwards the program is verified with real-world situations (Section 4.5.2).

4.5.1 Testing of Functionalities

In Section 4.1 the program of requirements is discussed. The program of requirements has the goal to outline all the requirements that the program needs to fulfill. In the design of the business logic these requirements are implemented, as also in the actual coding part. The testing of these functionalities is important to verify that the program meets all the required functionalities and therefore fulfill its overall goal. The program meets its technical requirements, it is a stand alone executable 32bit .exe program, that is tested on Windows 10. It also provides a correct integration with Microsoft Excel and no other programs are required to execute it. The maintenance of the program is included in the program manual. The testing of the functional requirements is done in cooperation with the identified stakeholders. Multiple scenarios are ran, to verify the functionalities. Table 4.2 shows the summary of the testing of the requirements.

Table 4.2: Testing of requirements

Functional requirements	Explanation
Adaptive	The model makes use of excel inputs, that can be changed according to range, racking and demand
Generic	The model makes use of excel inputs, that can be adjusted to every store setting
User friendly	The program is tested by scenario testing
KPIs	The discussed KPIs are included
Safety restrictions	The safety restrictions are included
Slotting	Dedicated, class based and dynamic slotting strategies are implemented
Output	The output excel files include all the required information
Output	The output includes all the required information
Performance	A data set of 1.374 items and 359 racking is uploaded and executed within 5 minutes
Performance	The data can be controlled within the program
Output	A visual example of every racking can be downloaded
Process	The model executes the same allocation process

4.5.2 Program Verification

The program is validated in two different ways. The first way is the validation of current racking settings with the model. This racking validation is split down into four different sections, namely validation of allocation of customer packs on level 10 and higher, validation of pallets on level 00, validation of customer packs on level 00 (heavy products) and validation of customer packs in racking with sprinkler installations. The second way of validation is the validation of the entire warehouse. In this validation a benchmark is set of the current allocation of the SKUs, whereby afterwards the model output is compared with the benchmark and suggestions for improvement can be extracted.

Figure 4.20 shows the model visualization output of racking number 69-05-04 (corresponding to racking number 690412 in the model). The corresponding characteristics of the SKUs are loaded into the model and the characteristics of the single racking. The dimensions of the racking and SKUs in the visual output are scaled according to their actual dimensions. It can be seen that the model successfully allocated the customer packs and adaptive racking slack. The yellow arrows indicate the location of the actual SKUs in comparison with the visualized SKUs. Figure 4.22 shows the visual representation output of the model of racking 47-19/20/21-00, that corresponds with location 470700 in the model. It can be seen that the model successfully allocated the pallets on level 00 and the adaptive racking slack. Figure 4.21 shows the successful allocation of heavy customer packs on level 00 and Figure 4.23 the successful allocation of customer packs in a racking with extra slack for the sprinkler installation.

Figure 4.20: Model visualization output of racking 69-05-04

Figure 4.21: Model visualization output of racking 49-24/25/26-00

Figure 4.22: Model visualization output of racking 47-19/20/21-00

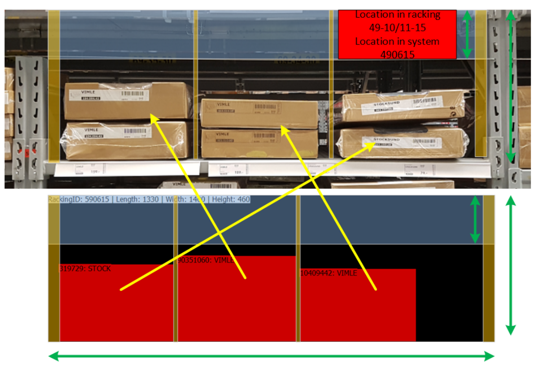


Figure 4.23: Model visualization output of racking 49-10/11-15

4.5.3 Data Analysis

This section is not available in this version.

4.5.4 Model Performance

The model performance is based on the data sets analyzed in Section 4.5.3. These data sets consist of 359 racking sections and 1,374 SKUs allocated to the WH, excluded the SKUs allocated to the buffer locations. On average this means that one single racking section needs to be allocated to 3.83 SKUs.

The average width of a pallet (if a SKU is delivered with a pallet (DT=1)) is equal to 789,1 mm. The total number of products with DT=1 is 262. This means that at least 206,744.2 mm of racking width on level 00 needs to be present to be able to store all the pallets. Without taking the slack values and the number of packages to allocate into account. Table 4.3 shows the available racking width, based on average values. It can be seen that the total width available on level 00 locations is 196,315 mm. This is lower than the total number necessary to store the pallets. In practise this problem is reduced by indirect flows. This means that from a pallet a number of Customerpacks (CPs) are allocated on shelf level and the leftovers are placed in a buffer location. Figure 4.24 shows the division between direct and indirect flows of pallet deliveries. Of the total number of 262 pallet deliveries, 106 deliveries are indirect, of which 49 have a weight lower than 15 kg. This reduces the average width needed on level 00 by 44,979 mm to 161,765 mm, based on average values. In the model performance we include these indirect flows, to simulate the existing goods allocation.

Table 4.3: Racking available width

Location type	Number of racking	Average width (mm)	Total width (mm)
Level 00 (AT = 0)	71	2,765	196,315
Level 10 (AT = 1)	237	2,086	494,382
Level 20 (AT = 2)	51	2,812	143,412
Total	359		834,109

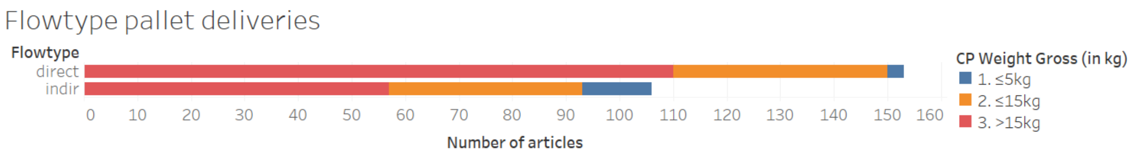


Figure 4.24: Flowtype pallet deliveries

Table 4.4 shows the average width and the total width necessary of SKUs that are delivered by CP. The total width necessary for products less than 15 kg is 360,766 mm. This is less than the available width on level 10 and level 20. This width is without slack and without including the number of packages to allocate. Based on these average width values, there is sufficient width on level 10 and level 20 shelves. The CPs heavier than 15 kg need to be allocate on the floor level. The result in a total width necessary on level 00 is 255,621 mm. This is more than the available racking width on level 00. This indicates that the model output will show a lack of space of level 00.

Table 4.4: SKU necessary width

CP weight	Number packages (DT = 0)	Average width (mm)	Total width (mm)
$\leq$ 5kg	656	316,1	207,361
$>$ 5kg, $\leq$ 15kg	328	467,7	153,405
$>$ 15kg	160	586,6	93,856
Total	1,144		454,622

The Model Output

The priorities of the sorting are set as defined in the previous section. The first priority is set as the height, the second priority the length and the third priority the width. The other priorities have less influence, due to the nested sorting procedure. Table 4.5 shows the output of the model, divided between the different allocation types (AT = 0 (CP), AT = 1 (Pallet) and AT = 2 (Multipack (MP))) and weight segments. It can be seen that there is a clear division between the allocation percentages. The SKUs that need to be allocated on shelf levels (either level 10 or level 20) are fully allocated. SKUs that need to be allocated on level 00 (pallet deliveries and packages heavier than 15 kg) are not fully allocated. This result in a total SKU allocation of 92.7 %. This correlates to the racking occupation. The racking on level 00 are fully occupied, in contrast to the racking on level 10 and level 20. Overall this results in a racking allocation of 81.1 %. These results are in line with the results from the data analysis, that indicated that the model will show a lack of space on level 00.

Table 4.5: Model output bechmark test

	Allocated	**Not allocated**	**Percentage allocated**
SKUs ($\leq$ 5kg) (AT = 0)	470	0	100%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 0)	353	0	100%
SKUs ($>$ 15kg) (AT = 0)	160	57	73.7%
SKUs (Total) (AT = 0)	983	57	94.5%
SKUs ($\leq$ 5kg) (AT = 1)	1	2	33.3%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 1)	17	11	60.7%
SKUs ($>$ 15kg) (AT = 1)	75	30	71.4%
SKUs (Total) (AT = 1)	92	43	68.1%
SKUs ($\leq$ 5kg) (AT = 2)	198	0	100%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 2)	0	0	100%
SKUs ($>$ 15kg) (AT = 2)	0	0	100%
SKUs (Total) (AT = 2)	198	0	100%
SKUs (Total) (All AT)	**1,274**	**100**	**92.7%**
Racking (level 00)	71	0	100 %
Racking (level 10)	186	51	78,5 %
Racking (level 20)	34	17	66,7 %
Racking (total)	**291**	**68**	**81.1 %**

Figure 4.25 shows the product allocation per allocation type. It can be seen that the majority of SKUs are allocated (Allocated = 1). The not allocated SKUs are divided between allocation type of 0 (CP) and 1 (pallet). The CP allocation results from CPs with a weight heavier than 15 kg (Table 4.5).

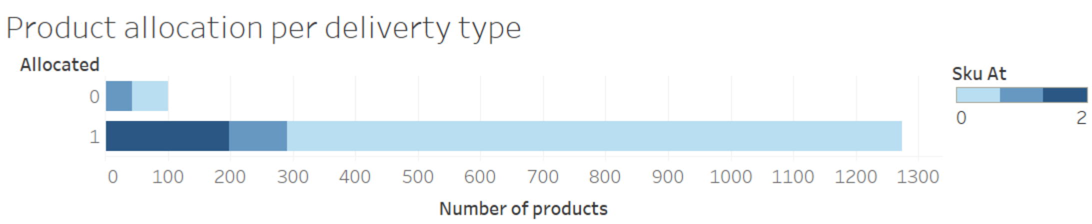


Figure 4.25: Product allocation per allocation type

Figure 4.26 shows the division of the not allocated SKUs among the different weight segments. The figure shows only the allocation types 0 (CP) and 1 (pallet), since all MPs (AT = 2) are allocated (Table 4.5). Furthermore, the figure shows clearly that the CPs, that can not be allocated, are all assigned to the highest weight class.

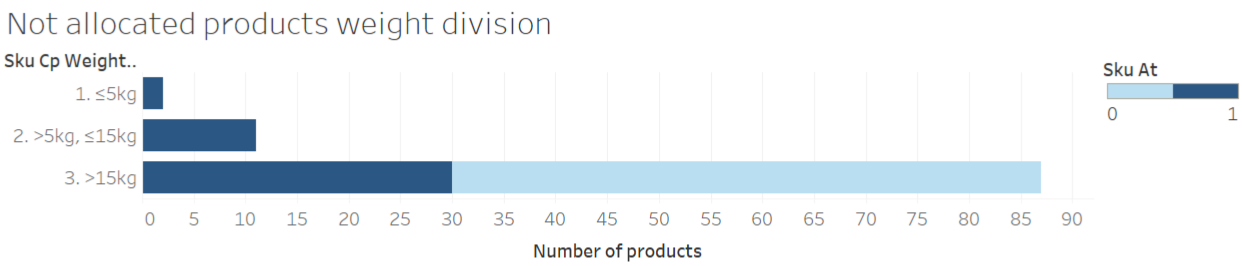


Figure 4.26: Not allocated products weight division

Figure 4.27 shows the CP width, CP height and CP length box plots of the not allocated products, with an allocation type of 0 (CP). Figure 4.27 shows the pallet width, pallet height and pallet length box plots of the not allocated products, with an allocation type of 1 (pallet). The box plots show the distribution of the width, height and length (measured in mm).

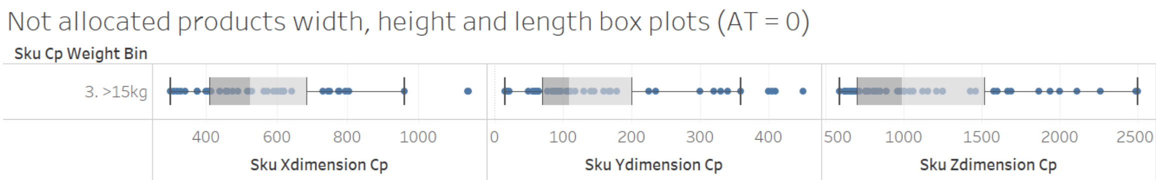


Figure 4.27: Not allocated products width, height and length box plots (AT = 0)

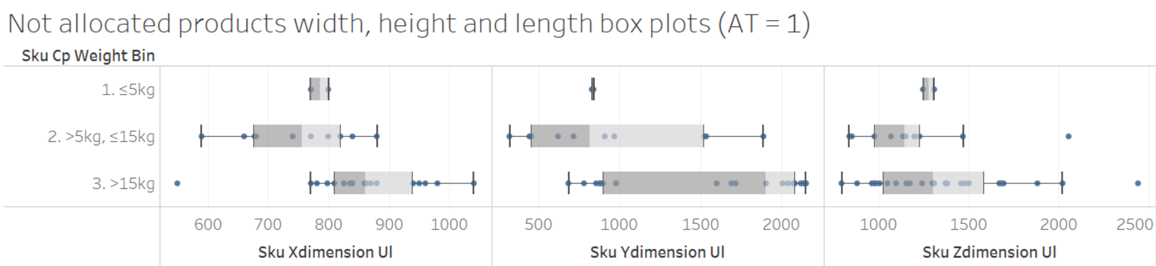


Figure 4.28: Not allocated products width, height and length box plots (AT = 1)

Figure 4.29 shows the racking occupation, divided between location types, whereby location type 0 is level 00, type 1 is level 10 and type 2 is level 20. This figure shows the visualization of the figures of Table 4.5. It can be seen that only level 10 and level 20 racking are still empty. Figure 4.30 shows the width, height and length box plots of the not occupied racking, divided between location type (measured in mm). It can be seen that the majority of the empty racking has a height lower than 500 mm. Furthermore, the length division of empty racking on level 10 shows a broad distribution.

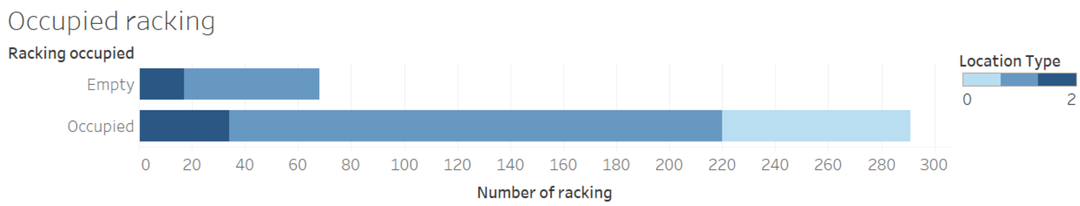


Figure 4.29: Racking occupation

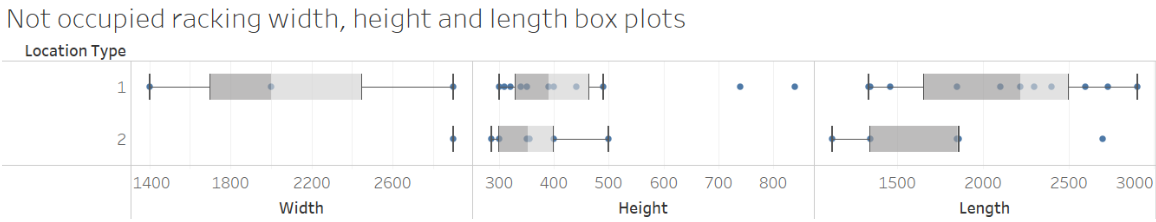


Figure 4.30: Not occupied racking width, height and length box plots

Table 4.6 shows performance of other allocation settings, in comparison with the original output (as discussed above). When no slack is applied, the allocation increases to 94.3% and the racking occupation decreases to 78.3%. This is a logical consequence of that no space is needed within racking for safety restrictions and therefore more products can be allocated within less racking. If the products are sorted based on fast movers, the allocation decreases by one single product to an allocation percentage of 92.6% and a higher racking occupation of 82.7%. The weight restriction of level 10 shows the largest difference between the original model output. The SKU allocation percentage increases to 98.0%, with a racking occupation of 89.4%.

Table 4.6: Performance of other settings

	Original	**No slack**	**Fast movers**	**Weight till 20kg**
SKUs allocated	1,274 (92.7%)	1,296 (94.3%)	1,273 (92.6%)	1,346 (98%)
Racking allocated	291 (81.1%)	281 (78.3%)	297 (82.7%)	321 (89.4%)

4.6 Integration

The integration is the final phase within the waterfall method. In this phase the roll out and actual implementation of the model is done. Due to time limitations, the actual implementation is out of the scope of this research. Therefore, we focus on the implementation plan in this phase. This plan includes how the model can be implemented in practise, what steps need to be executed in order to be able to execute the model and how the model can include the adaptive character of the racking and products. The program is developed to be executed stand alone, such that no integration with information systems is necessary. The goal of the implementation plan is twofold. The first goal is to provide a summary of the methodology, performance and benefits of the program, to increase the support for the implementation. The second goal is to provide an user manual, with the focus on how the program can be executed, adapted to different settings and the learning aspect for the user. The implementation plan can be found in Appendix I.

4.7 Conclusion

In this chapter the actual model is designed and created, with the focus on research questions 4 till 7. For the model design it is chosen to use the waterfall methodology. Within this methodology six stages are separated, namely the restriction, design, code, test and integrate phase. The model is designed according to these six different stages. The restrictions are defined and discussed in line with context analysis of Chapter 2 and the needs of the stakeholders. These restrictions are transformed into business logic in the design phase. In this phase the input of the literature study is combined with the restrictions phase, to define the logic behind the coding. The business logic is based on the 3D-BPP methodology and amended to our specific case. With this design the efficiency of the SKA utilization is proposed to be increased. The coding is based on this business logic.

The verification and validation of the model is based on the SKA allocation of the WH department. The validation is based on comparison between the current allocation of SKUs and the output of the model. The model provides an allocation of 92.7% of the SKUs currently allocated to the sales locations within the WH and a racking occupation of 81.1%. In the current situation the allocation and occupation is 100%. The difference between the model output and reality is caused due to the flexibility of the manual allocation. This flexibility results in that certain items are allocated at locations that they are not allowed to, according to the model. If the weight restriction of level 10 locations is withdrawn, the allocation percentage increases to 98.0%. The other 2% is discussed with experts and is proposed to be the result of flexible manual allocation and difficult to allocate products. Figure 4.31 shows an example of a product that is difficult to allocate by the model, due to irregular shape. Resulting in non-allocated products or too much allocated space.

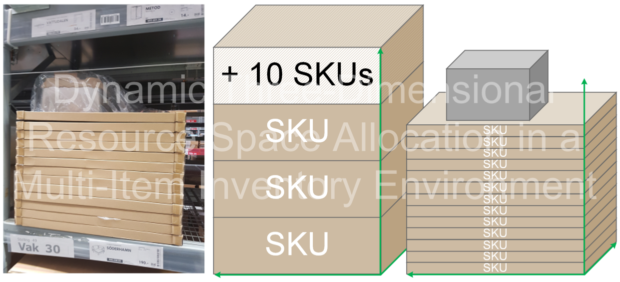


Figure 4.31: Difficult to allocate SKU

The model output provides insight into the performance of the model and the performance of the racking layout. The recommendations for the racking layout are further discussed in Chapter 5. Next to the benefits of the model, the model shows also some downsides. The model performance is as good as the quality of the data input. Within the data analysis a number of SKUs are not taken into account in the allocation, since no correct dimensions are available of them. This reduces the accurateness of the model output. Furthermore, the model doesn't allocate identical product into different racking (i.e. two or more sales locations). This needs to be manually set by adding an extra item with the same characteristics.

The last phase of the waterfall methodology is the integration phase. Due to time limitations, the actual integration is out of the scope of this research. To implement this phase, an implementation plan is created. In this implementation plan the benefits and business logic of the model are outlined, and an user manual is presented.

Chapter 5

Conclusions and Recommendations

This chapter includes the conclusions and recommendations of this thesis. In Chapter 1 the research questions are discussed. In the previous chapters all the different research questions are answered. In this chapter the main research question is answered. In 5.1 the conclusions of this thesis are outlined and the main research question is answered. In Section 5.2 the recommendations for this research and for further research are stated and discussed.

5.1 Conclusions

The resource allocation within the WH and SSFA departments is not identical to the allocation within most other warehouse settings. It is a multi-dimensional problem, whereby the finite resource space, nonidentical dimensions, desired co-storage and safety and ergonomic limitations are important restrictions within the allocation. The overall goal of this research is to developed an efficient, adapative and generic approach of SKA allocation, within the racking sections of the SSFA and WH departments. To fulfill this overall goal, the main research question is formulated as follows:

How should an adaptive and generic SKA allocation approach be designed, such that it provides an efficient SKA usage within the racking sections of the SSFA and WH departments?

To provide an efficient allocation, the nonidentical dimensions of the SKUs and racking are taken into account. An allocation heuristic is developed to dynamic allocate the SKUs into a dynamic set of racking. The heuristic provides new dimensions of the SKU every time no suitable racking can be found, based on the initial dimensions of the customerpack, multipack or pallet and the number of packages to allocate. Within the heuristic the height and length dimension are used to select racking that can fit the dimensions, whereby afterwards the knapsack principle is used to allocate the SKUs, based on the width dimension. The three-dimensional problem is in this way reduced to a one-dimensional problem. The approach requires SKU and racking data input. This data input can be changed, according to store characteristics and products to be allocated. This results in a generic and adaptive method, that can allocate resources to SKUs.

The model is programmed in a stand-alone executable program. The method is verified to a selection of racking sections within the WH and benchmarked against the current allocation within the WH. It provides an allocation percentage of 92.7% and an occupation of 81.1% of the racking.

5.2 Recommendations

During this research a significant amount of time has been spent working with logistic employees within the warehouse. This practical work experience, in combination with the expertise and known-how of the logistic workers, is an important factor to get a broad understanding of the problem and to create a suitable model that fits the problem. Nevertheless, not all the problems can be operationalised and fixed with the use of scientific and computer models. The expertise and know-how of the first-line workers is an important input factor for further recommendations. These recommendations are based on input of the logistic workers, on-hand experience, the output of the model and the scope of this research. The recommendations include both practical, as theoretical recommendations for further research. First , in Section 5.2.1, the recommendations from the model output are outlined. The other recommendations, both practical, as theoretical, are outlined in Section 5.2.2.

5.2.1 Change of Racking Layout

The analysis of the model output shows a lack of level 00 locations and a surplus of level 10 and level 20 locations. This indicates a mismatch between the available racking and the products to allocate. Within the current racking layout extra level 00 locations can be created by reducing a number of level 10 locations. Figure 5.1 shows an example of a racking level 10 location that can be cannibalized to obtain an extra level 00 location. In total there are 18 possibilities to increase the level 00 locations. The length and width of the proposed racking are fixed dimensions, the height is flexible, due to the flexible allocation of shelves. Table 5.1 shows the corresponding racking identification numbers and dimensions.

Figure 5.1: Level 10 cannibalization

Table 5.1: Level 10 locations that can be cannibalized to level 00

RackingID	Racking section	Width (mm)	Height (mm)	Length (mm)
49-02-XX	3 and 4	1,400	2,300 max.	1,050
49-03-XX	4 and 5	1,400	2,300 max.	1,050
49-05-XX	9 and 10	1,400	2,300 max.	1,330
49-06-XX	10 and 11	1,400	2,300 max.	1,330
68-01-XX	1 and 2	1,400	2,300 max.	1,040
68-02-XX	2 and 3	1,400	2,300 max.	1,040
68-03-XX	4 and 5	1,400	2,300 max.	1,040
68-04-XX	5 and 6	1,400	2,300 max.	1,040
69-01-XX	1 and 2	1,400	2,300 max.	1,340
69-02-XX	2 and 3	1,400	2,300 max.	1,340
69-03-XX	4 and 5	1,400	2,300 max.	1,340
69-04-XX	5 and 6	1,400	2,300 max.	1,340
70-01-XX	1 and 2	1,400	2,300 max.	1,300
70-02-XX	2 and 3	1,400	2,300 max.	1,300
70-03-XX	4 and 5	1,400	2,300 max.	1,120
70-04-XX	5 and 6	1,400	2,300 max.	1,120
70-05-XX	6 and 7	1,400	2,300 max.	1,120
70-06-XX	7 and 8	1,400	2,300 max.	1,120
Total		25,200		

Figure 5.2 shows the width, height and length box plots of the not allocated products with an AT of 0 (CP), Figure 5.3 the corresponding box plots of the products with an AT of 1 (pallet). This information can be used to determine how high the level 00 locations should become, to store a certain product. It is not feasible to store all the necessary products on level 00. The new height of the racking depends on the expert choice what kind of items to allocate in these new sections.

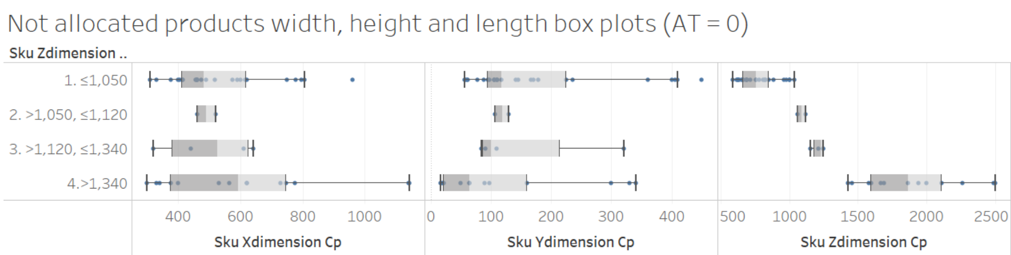


Figure 5.2: Not allocated products box plots per length segment (AT=0)

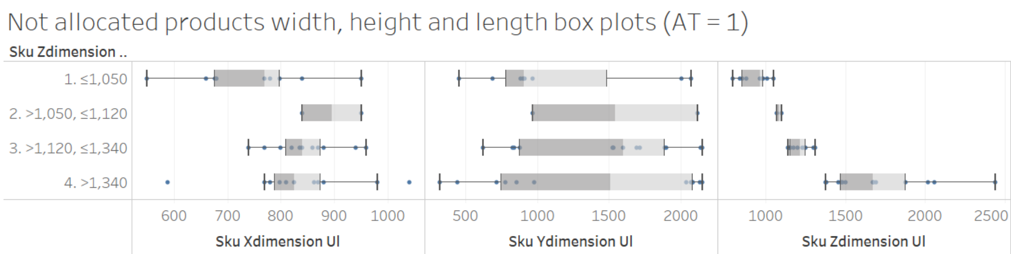


Figure 5.3: Not allocated products box plots per length segment (AT=1)

This recommendation is emphasized with the results of a modified racking set. The racking in Table 5.1 are changes, such that per extra 00 location two level 10 locations are cannibalized. In total the number of 10 locations is reduced with 36 racking sections and the number of level 00 locations is increased by 18 locations. These 18 locations represent 25,2 m extra width (Table 5.1) and the level 10 locations 50,4 m reduced width. The height of the new level 00 locations differs between 700 and 750 mm, due to the withdrawal of two shelves. In practise the height could be increased or decreased, based on the preferences of the co-workers.

Table 5.2 shows the results of the modified racking set, in comparison with the original test of Chapter 4. The total product allocation rate is increased by 2,4%, from 92,7% to 95,1%. This represents an allocation of 1.306 out of the 1.374 articles. Furthermore, the racking occupation is increased by 6,6% to 87,7%. This means that in total 87,7% of the racking allocates at least one product. In total the number of available racking decreased by 18 racking, to 341 available racking.

The main contributor to the increased allocation rate are the products with an allocation type of 0 (customer pack) and a weight of more than 15 kg. These products show an allocation increase of 14,3%, to 88,0%. This represent an increase of 31 extra articles than can be allocated. If we look further to the products with an allocation type of 1 (pallet delivery), we see that the allocation percentage only increased by 0,7%. The products heavier than 15kg show a decrease of 2,9% allocation rate, in contrast to the products below 15kg, that show an increase of 10,7%. This new racking set also allocates different articles, so not the same articles are allocated as in the model output from the previous chapter. These results emphasize the recommendation that extra level 00 locations will benefit the allocation performance.

Table 5.2: Model output modified racking set

	Allocated	**Not allocated**	**Percentage allocated**	**Difference**
SKUs ($\leq$ 5kg) (AT = 0)	470	0	100%	0.0%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 0)	353	0	100%	0.0%
SKUs ($>$ 15kg) (AT = 0)	191 (160)	26 (57)	88.0% (73.7%)	14.3%
SKUs (Total) (AT = 0)	1,014 (983)	26 (57)	97.5% (94.5%)	3.0%
SKUs ($\leq$ 5kg) (AT = 1)	1	2	33.3%	0.0%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 1)	20 (17)	8 (11)	71.4% (60.7%)	10.7%
SKUs ($>$ 15kg) (AT = 1)	73 (75)	32 (30)	68.5% (71.4%)	-2.9%
SKUs (Total) (AT = 1)	94 (93)	42 (43)	69.1% (68.4%)	0.7%
SKUs ($\leq$ 5kg) (AT = 2)	198	0	100%	0.0%
SKUs ($>$ 5kg, $\leq$ 15kg) (AT = 2)	0	0	100%	0.0%
SKUs ($>$ 15kg) (AT = 2)	0	0	100%	0.0%
SKUs (Total) (AT = 2)	198	0	100%	0.0%
SKUs (Total) (All AT)	**1,306 (1,274)**	**68 (100)**	**95.1% (92.7%)**	**2.4%**
Racking (level 00)	89 (71)	0 (0)	100 %	0.0%
Racking (level 10)	175 (186)	26 (51)	87.1% (78.5%)	8.6%
Racking (level 20)	35 (34)	16 (17)	68.6% (66.7%)	2.1%
Racking (total)	**299 (291)**	**42 (68)**	**87.7% (81.1%)**	**6.6%**

The empty racking on level 10 and level 20 can be used to store products that are currently allocated to the buffer. Due to the character of these locations (i.e. shelf locations), the maximum weight restriction is 15 kg and no pallets are allowed to be stored on these locations. Figure 5.4 shows the weight histogram of the products allocated to the buffer locations within the warehouse. It can be seen that the majority of the products have a delivery type of 1 (pallet delivery) and are therefore also stored as a pallet. Since there is no space for these products on level 00 locations, these products cannot be moved from the buffer to the floor.

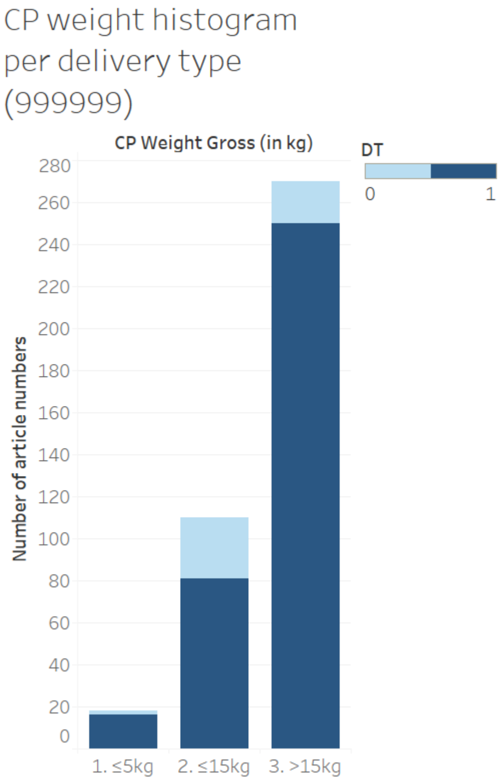


Figure 5.4: Weight histogram products allocated to buffer

The products with a delivery type of 0 (customerpack/multipack) and a weight below the 15 kg can be stored within the empty racking of level 10 and level 20. In total 31 articles have a delivery type of 0 and a weight below the 15 kg. Since currently no space is assigned to these products, the door-to-floor-points inventory levels are taken, instead of the assigned sales space quantity.

The total number of products to allocate increases by 31 articles to 1405 articles in total. Of these 1405 articles, 1338 articles are allocated. This corresponds to an allocation percentage of 95.2%. Without the extra articles, 1,306 articles were allocated (Table 5.2). So with the same resources, an extra 32 articles can be allocated.

Of the total 341 available racking, 305 racking occupy at least one product. This corresponds to an occupation rate of 89.4%. In this case still 36 racking are empty (Figure 5.5). Further research can be conducted into the optimal layout of the racking, i.e. with a dynamic racking design, based on the dynamic dimensions of the products. Including both the dynamic possibilities of the racking height and the dynamic character of the products to allocate, could result in a more efficient warehouse layout.

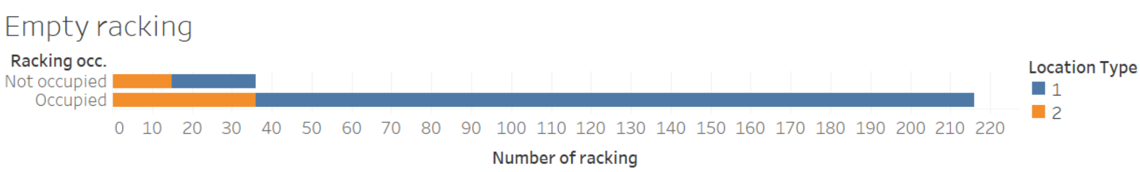


Figure 5.5: Racking occupation of modified racking set test

5.2.2 Other Recommendations

In the previous section the recommendations for a change in racking layout is outlined. This is not the only recommendation that is subtracted from this research. In this section the other recommendations are outlined, that are both practical, as theoretical based. First the further recommendations for the model implementation and usage are outlined, whereby afterwards the further practical recommendations are discussed.

Frequent usage of the model

The product range is very dynamic and has an annually change of approximately 2.500 article numbers (see Chapter 1). A part of these 2.500 article numbers is subjected to the SSFA and/or WH department. This change in range corresponds with outgoing products (so slots that becoming empty) and incoming products that need to be fitted into the warehouse racking. Due to product specific characteristics, it could be beneficial to verify the whole or a big part of the slotting when a range change occurs.

Verify the model in other departments and store settings

The model is made to be adaptive and generic for all different kind of store settings. The model is currently only verified within one store setting and in one department. Although the model is built upon the store and department specific situation and needs, the model could also be beneficial for other stores and could increase their warehouse performance. Furthermore, the model is a beta version, that still can include several errors. Further research can be executed to implement the designed methodology within the available information systems.

Simulation study on warehouse performance

The actual effects on slotting strategies on the operational operations within the warehouse can be simulated with the use of simulation software. In this research, suggestions are mentioned and discussed to improve the slotting strategy within the warehouse. The actual effects of these slotting strategies can be further investigated by a throughout simulation study. Simulation programs like Siemens Plant Simulation can simulate the warehouse progresses by digital models, that allowing you to run experiments without disturbing the existing warehouse processes. Figure 5.6 shows a visual example of a simulation study of business processes in Siemens Plan Simulation, as developed by Bemthuis [5]. Further (student) research can be conducted on the effects of a simulation study and the corresponding slotting strategy on the warehouse performance.

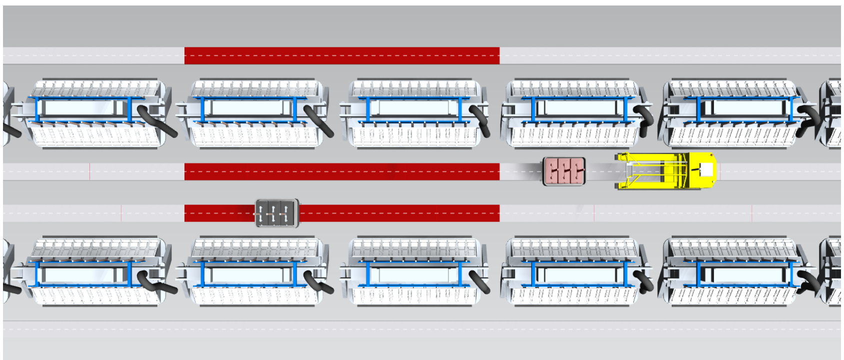


Figure 5.6: A simulation of business processes in Siemens Plant Simulation, retrieved from Bemthuis [5]

Extra protection within racking to reduce damages

One of the KPIs implemented in the model is the number of internal damages. These damages occur due to several reasons. Within the model we implemented one of the main reasons of internal damage, namely the lack of space between SKUs and other object (i.e. racking). Nevertheless, this lack of space is not the only reason why damages occur. Another identified reason is damage due to the combination of products and racking. Figure 5.7 shows an example of a product allocated at level 10. This product is wrapped in transparent foil. Furthermore, the figure shows an example of damaged transparent foil, due to the framework within the racking. This damage can be reduced by adding mats of any kind (i.e. carton, plastic or rubber) to the framework. Another possibility is to allocate fragile products only to level 00 locations, such that the framework within the racking is not relevant. This reduces the number of options where those products can be allocated and make the allocation process more difficult. This is not a likeable option, therefore the mats are more preferable.

Figure 5.7: Product damage due to racking framework

Push back protection

The length of a racking is limited. The back parts of a racking can either be located to a wall or to another racking. The gap between the framework in the racking and the end of the racking make it possible that products fall of the racking and extra damage and handling needs to be done. Figure 5.8 shows an example of multiple products that dropped of the racking framework. This increases the possibility of damages and internal handling. This problem can be fixed by adding back protection to every racking if necessary. This protection can be made of metal or by adding strings (i.e. elastic) at the back of every racking (if necessary) to prevent products from falling down.


Dynamic Three-Dimensional Resource Space Allocation in a Multi-Item Inventory Environment

Figure 5.8: Product damage due to lack of barrier

Gravity system for small products in long aisles

The range of racking that can fit products differ per product type and corresponding dimensions. In the most preferable option every product can be allocated in every racking, such that the number of restrictions are as low as possible. Every restriction makes the problem more difficult to solve and therefore reduces the possibility to find a feasible or good solution. Currently, it is not preferable that small items are allocated in long racking, since it wouldn't be possible to pick an item that is located to much backwards. This problem can be reduced by adding a gravity system for small products, when allocated in long aisles.

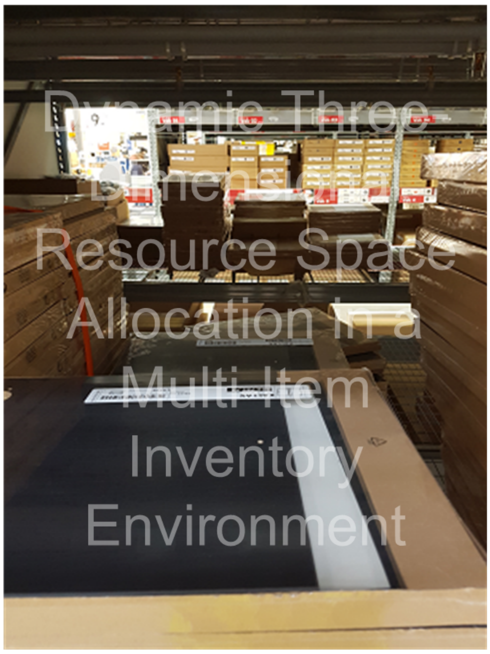


Figure 5.9: Small products in a long aisle

Investigate the possibilities of passive sensors

In the current situation a significant amount of time is spent on manual checking the inventory levels of the items, as explained in Appendix A. This is done to increase the accurateness of the stock availability. Further research into passive sensors can be executed, to increase the accuracy of the inventory levels and reduce the time it takes to check the inventories.

Bibliography

[1] Ingka Holding B.V. and its controlled entities, *Yearly summary FY17*. Ingka Holding B.V., 2017.

[2] E. Silver, D. Pyke, and D. Thomas, *Inventory and Production Management in Supply Chain*, 4th ed. Boca Raton, FL, USA: Taylor Francis Group, 2017.

[3] S. Martello, D. Pisinger, and D. Vigo, "The three-dimensional bin packing problem," *Operations Research*, vol. 48, no. 2, pp. 256–267, 2000.

[4] R. Thayer, S. Bailin, and M. Dorfman, *Software requirements engineerings*, 2nd ed. IEEE Computer Society Press, 2000.

[5] R. Bemthuis, "Development of a planning and control strategy for agvs in the primary aluminium industry," December 2017.

[6] Inter IKEA systems, "1940s-1950s - ikea," November 2018. [Online]. Available: https://www.ikea.com/ms/en_AU/about_ikea/the_ikea_way/history/1940_1950.html

[7] ——, "Ownership and structure - ikea," November 2018. [Online]. Available: https://www.ikea.com/gb/en/this-is-ikea/about-the-ikea-group/ownership-structure/

[8] ——, "Over de ikea group - ikea," November 2018. [Online]. Available: https://www.ikea.com/ms/nl_NL/this-is-ikea/about-the-ikea-group/index.html

[9] ——, "Key figures - ikea," November 2018. [Online]. Available: https://www.ikea.com/gb/en/this-is-ikea/about-the-ikea-group/key-figures/

[10] Inter IKEA systems B.V., *Financial summary FY17*. Inter IKEA systems, 2017.

[11] Inter IKEA Group, "Ikea industry - inter ikea group," Online, November 2018. [Online]. Available: http://inter.ikea.com/inter-ikea-group/ikea-industry/

[12] ——, "Range and supply - inter ikea group," November 2018. [Online]. Available: http://inter.ikea.com/en/inter-ikea-group/ikea-range-and-supply/

[13] Inter IKEA systems, "Uitbreiding ikea hengelo officieel van start - ikea," April 2012. [Online]. Available: https://www.ikea.com/nl/nl/about_ikea/newsitem/persbericht_startuitbreidingHengelo

[14] H. Heerkens and A. van Winden, *Solving managerial problems systematically*. Noordhoff, 2017.

[15] Inter IKEA Group, "Ikea distribution/warehouse - inter ikea group," Online, November 2018. [Online]. Available: https://www.ikea.com/ms/en_US/jobs/business_types/distribution_logistics/

[16] R. Milne, "Ikea vows transformation as it reshapes business model," Online, April 2018. [Online]. Available: https://www.ft.com/content/1a66c838-3cc1-11e8-b7e0-52972418fec4

[17] Inter IKEA Group, “Ikea launches new people and planet positive strategy - inter ikea group,” Online, June 2018. [Online]. Available: https://www.ikea.com/gb/en/this-is-ikea/newsroom/press-release/ikea-launches-new-people-planet-positive-strategy/

[18] S. Axsater, *Inventory Control*, 2nd ed. New York, USA: Springer, 2006.

[19] APQC, *2018 supply chain management priortities and challanges - survey summary report*. Springer, Februari 2018.

[20] The U.S. Census Bureau, “Manufacturing and trade inventories and sales, september 2018,” Online, November 2018. [Online]. Available: https://www.census.gov/mtis/www/data/pdf/mtis_current.pdf

[21] The U.S. Bureau of Economic Analysis, “Gross domestic product, 3rd quarter 2018 (advance estimate),” Online, November 2018. [Online]. Available: https://www.bea.gov/data/gdp/gross-domestic-product#gdp

[22] Centraal Bureau voor de Statistiek, “Voorraden,” Online, June 2018. [Online]. Available: https://www.cbs.nl/nl-nl/achtergrond/2018/23/voorraden

[23] Statista, “Gross domestic product (gdp) of the netherlands from 2007 to 2017 (in billion euros),” Online, October 2018. [Online]. Available: https://www.statista.com/statistics/529063/the-netherlands-gdp/

[24] N. Borin, P. W. Farris, and J. R. Freeland, “A model for determining retail product category assortment and shelf space allocation,” *Decision sciences*, vol. 25, no. 3, pp. 359–384, May 1994.

[25] F. Zufryden, “A dynamic programming approach for product selection and supermarket shelf-space allocation,” *The Journal of the Operational Research Society*, vol. 37, no. 4, pp. 413–422, April 1986.

[26] S. Heragu, L. Du, R. Mantel, and P. Schuur, “Mathematical model for warehouse design and product allocation,” *International Journal of Production Research*, vol. 43, no. 2, pp. 327–338, 2005.

[27] B. Rouwenhorst, B. Reuter, V. Stockrahm, G. van Houtum, R. Mantel, and W. Zijm, “Warehouse design and control: Framework and literature review,” *European Journal of Operational Research*, vol. 122, no. 3, pp. 515–533, 2000.

[28] J. Krupp, “Are abc codes an obsolete technology?” *APICS-The Performance Advantageg*, pp. 34–35, 1994.

[29] B. E. Flores and D. C. Whybark, “Implementing multiple criteria abc analysis,” *Journal of Operations Management*, vol. 7, no. 1-2, pp. 79–85, 1987.

[30] M. Kofler, A. Beham, S. Wagner, M. Affenzeller, and W. Achleitner, “Re-warehousing vs. healing: Strategies for warehouse storage location assignment. in logistics and industrial informatics (lindi),” in *IEEE International Symposium*, vol. Third. IEEE, 2011, pp. 77–82.

[31] J. Bartholdi and S. Hackman, *Warehouse and distribution science*. www.warehouse-science.com, 2010.

[32] E. Frazelle, *World-class Warehousing*. Atlanta, GA, USA: Logistics resources international. Inc., 1996.

[33] E. Aarts, E. H. Aarts, and J. K. Lenstra, *Local search in combinatorial optimization*. Princeton University Press., 2003.

[34] F. Glover, “Tabu searchpart i,” *ORSA Journal on computing*, vol. 1, no. 3, pp. 190–206, 1989.

[35] S. Kirkpatrick, C. D. Gelatt, and M. P. Vecchi, “Optimization by simulated annealing.” *Science*, vol. 220 4598, pp. 671–80, 1983.

[36] V. Černỳ, “Thermodynamical approach to the traveling salesman problem: An efficient simulation algorithm,” *Journal of optimization theory and applications*, vol. 45, no. 1, pp. 41–51, 1985.

[37] D. Bertsimas, J. Tsitsiklis *et al.*, “Simulated annealing,” *Statistical science*, vol. 8, no. 1, pp. 10–15, 1993.

[38] A. Lodi, S. Martello, and D. Vigo, “Heuristic algorithms for the three-dimensional bin packing problem,” *Journal of Operational Research*, vol. 141, no. 2, pp. 410–420, 2002.

[39] C. S. Chen, S. M. Lee, and Q. S. Shen, “An analytical model for the container loading problem,” *European Journal of Operational Research*, vol. 80, no. 1, pp. 68–76, 1995.

[40] H. I. Christensen, A. Khan, S. Pokutta, and P. Tetali, “Approximation and online algorithms for multidimensional bin packing: A survey,” *Computer Science Review*, vol. 24, pp. 63–79, 2017.

[41] Y. Wu, W. Li, M. Goh, and R. de Souza, “Three-dimensional bin packing problem with variable bin height,” *European journal of operational research*, vol. 202, no. 2, pp. 347–355, 2010.

[42] M. Dawande, J. Kalagnanam, and J. Sethuraman, “Variable sized bin packing with color constraints,” *Electronic Notes in Discrete Mathematic*, vol. 7, pp. 154–157, 2001.

[43] H. Shachnai and T. Tamir, “Polynomial time approximation schemes for classconstrained packing problem,” *Journal of Scheduling*, vol. 4, no. 6, pp. 313–338, 2001.

[44] E. C. Xavier and F. K. Miyazawa, “A one-dimensional bin packing problem with shelf divisions,” *Discrete Applied Mathematics*, vol. 156, no. 7, pp. 1083–1096, 2008.

[45] S. Martello and P. Toth, *Knapsack problems: algorithms and computer implementations*. Chichester, UK: John Wiley and sons, 1990.

[46] B. W. Boehm, “A spiral model of software development and enhancement,” *Computer*, vol. 21, no. 5, pp. 61–72, 1988.

[47] M. Awad, “A comparison between agile and traditional software development methodologies,” *University of Western Australia*, 2005.

[48] W. W. Royce, “Managing the development of large software systems: concepts and techniques,” in *Proceedings of the 9th international conference on Software Engineering*. IEEE Computer Society Press, 1987, pp. 328–338.

Appendix A

In-store Logistics

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Appendix B

Forecasting Methodology

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Appendix C

Safety Stock Calculations

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Appendix D

Racking Types

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Appendix E

Sprinkler Zones

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Appendix F

Program Layout

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Appendix G

Input Data

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Appendix H

Flowcharts

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Appendix I

Implementation Plan (Dutch)

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