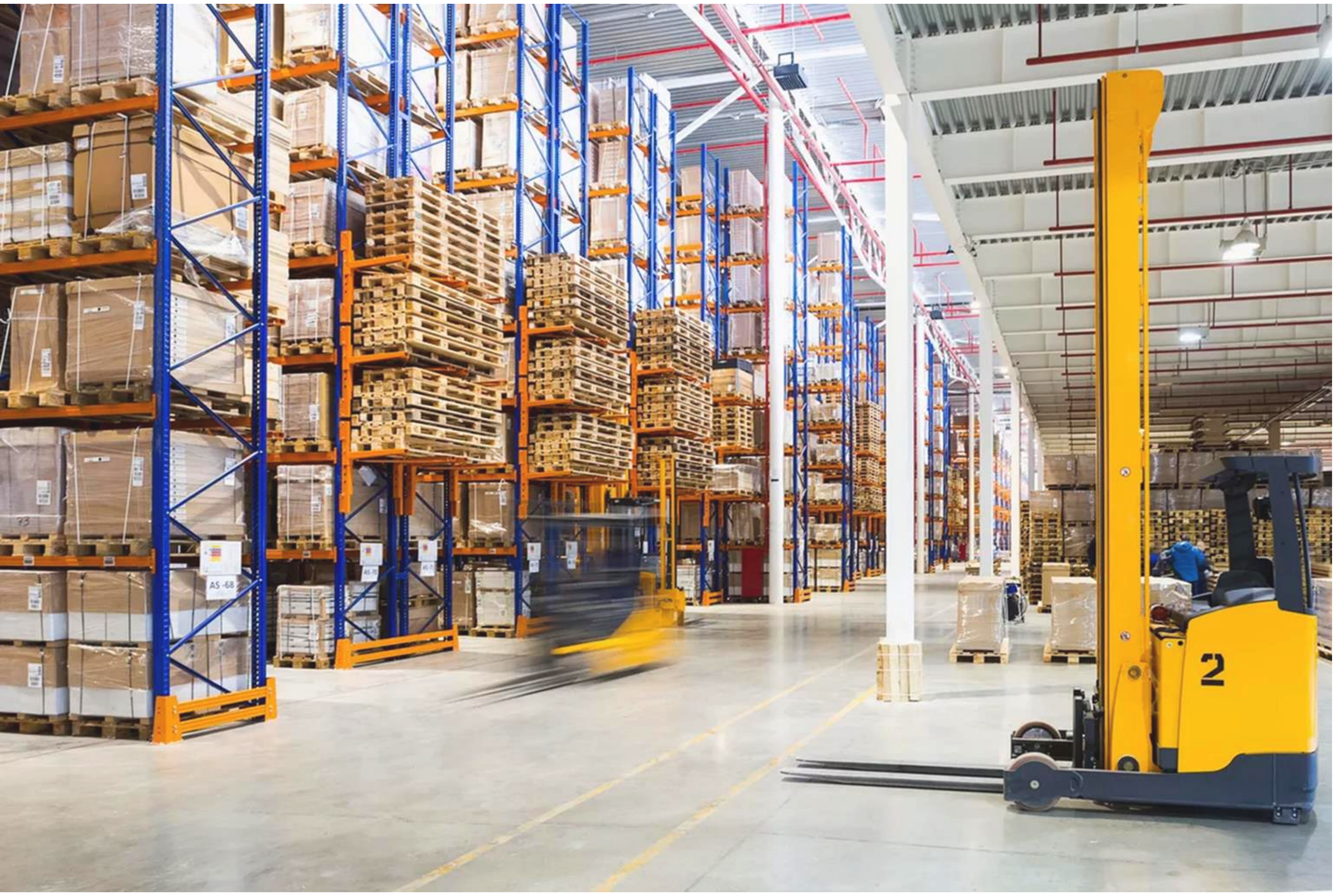
10-10-2019



IMPROVING THE EFFICIENCY OF A PICKER-TO-PARTS EXPORT WAREHOUSE

Author	Arne van Dijk
Location	Enschede
Internal Supervisor	Person X
External Supervisor	Peter Schuur
University	University of Twente

UNIVERSITY OF TWENTE.

COLOFON

	AUTHOR
Author	Arne van Dijk
Student number	1862537
University	University of Twente
Study	Industrial Engineering and Management
Date	10-10-2019
Document title	Improving the efficiency of Company X's export warehouse

	Company Supervisor
Name	Person X
Position	Logistics manager

	ACADEMIC SUPERVISOR
Name	Dr. P.C. Schuur
Faculty	Behavioural Management and Social Sciences

	SECOND SUPERVISOR
Name	Dr. I. Seyran Topan
Faculty	Behavioural Management and Social Sciences

PREFACE

My bachelor thesis is called: “improving the efficiency of Company X’s export warehouse”. This report is written as a final test for the bachelor Industrial Engineering and Management at the University of Twente.

This research is executed at the Company X. In this research, the current state of the export-warehouse of the company is analysed. After a thorough analysis, this research is aimed at creating a new strategy for allocating the products in the warehouse more efficiently.

I want to thank my internal supervisor. He was always available for questions and feedback. He would provide me with a lot of freedom in my work and he was always willing to help me. I also want to thank the rest of the staff of Company X and in particular the IT-department, who were a great help.

I also want to thank Peter Schuur and Ipek Seyran Topan, my first and second supervisor of the University of Twente. Ipek provided me with useful feedback during the preparation of this research, while Peter guided me during the execution of this research. The meetings with Peter were always very pleasant, where we critically discussed the progress of my assignment as well as the most random other topics.

Finally, I would like to thank my friends and family for their support and interest in my assignment.

I hope you will enjoy reading my bachelor thesis.

Arne van Dijk

Enschede, October 2019

MAIN CONSTRUCTS

There are several constructs in this research that are essential for a thorough understanding. This research focusses on decreasing the travel distance in a high-throughput warehouse. To provide a better understanding of this goal, an explanation of the following terms is given: warehousing, product-allocation, order-picking, SKU, I/O-point, picking lines, PGS-goods and floor-location.

Warehousing is the act of storing goods that will be sold or distributed later (Business Encyclopedia, 2019).

Product-allocation is a combination of the words product and allocation. Allocate means 'to fix the place of; locate' (Random House Unabridged Dictionary, 2019). Allocating products thus means to fix the place of products. An allocation-design in this research means a plan produced to show where the products are located in the warehouse.

Order-picking is the activity of withdrawing items from inventory to fulfil an order (Business Dictionary, 2019). There are different techniques for order-picking. In Company X's warehouse, order-pickers use stackers to drive through the warehouse. A pallet is placed on the stacker. The products from the order are placed on this pallet. These products are read on a device all pickers wear on their arm and get scanned by the same device. When all products are picked and placed on the pallet, the pallet gets checked and packed. This is where the order-picking process ends.

An SKU (stock keeping unit) is a warehousing item type that is unique because of some characteristic (such as brand, size, colour, model) and must be stored and accounted for separate from other items. Every SKU is assigned a unique identification number (inventory or stock number) which is often the same as (or is tied to) the item's EAN or UPC (BusinessDictionary, 2019). In this research, SKU's are also called products.

The I/O point is the input/output point. This is the point where the order pickers start and end their tour through the warehouse during the order-picking process.

A set of **picking lines** for the same company that need to be picked on the same day together form an **order**. Each picking line contains one or more products of the same kind.

PGS-goods are goods that contain dangerous substances like chemicals. The goods are listed on a Dutch list named: 'Publicatiereeks gevaarlijke stoffen'. For PGS-goods, different legislation is applicable compared to regular goods in fields like warehousing and transport.

Floor-locations are floor-level locations of every location in the warehouse.

MANAGEMENT SUMMARY

In the management summary, an overview of this research is given. The aim of this research is explained, as well as the approach to solving the central research question, the results and the recommendations.

Problem Identification

Several observations indicated that Company X's warehouse is not running as efficient as possible. Due to the fact that the allocation of products is based on 'gut feeling' rather than quantitative models, several problems arise. First, products with a high and low pick-frequency are intertwined, they are not systematically divided over the warehouse. Secondly, products with a low pick-frequency are often located at A-locations. Furthermore, there is no specific location for cross-dock products and products that are picked by the service counter employees.

Central Research question

The goal of this research is to find an appropriate strategy to allocate Company X's products more efficiently in their existing warehouse, in a way that the average picking time per order is reduced. This leads to the following central research question:

What is an efficient allocation of products in the export warehouse and associated routing, so that the average travel distance per order is reduced?

The average travel distance per order is used as main KPI, as it is the specific variable with an impact on the average picking time per order, which can be influenced by changing the storage strategy.

Methodology

The research is structured in the following way: First, the warehousing process of Company X is analysed by personal observation and an interview with the logistics manager, to improve the understanding of the current situation. Hereafter, the bottlenecks of Company X are analysed by participating in research, to understand the nature of the problem and where possibilities for improvement exist. Then, a literature study has been carried out, to search for possible solutions to the problems that became clear in the bottleneck analysis.

Results

At first, the aim of this research was to allocate each product to a specific location. However, during the data-gathering phase, it appeared that there was no data available about the cube of different products. As the cube of the products varies significantly and the space available at different locations as well, it became clear that it was not possible to do so without the data. Therefore, a new approach is adopted. The research focusses on creating a strategy based on existing literature that could be used to allocate every product in the warehouse when the currently missing data becomes available. Two strategies are proposed, one based on the ABC-principle and one based on the Correlated Storage Method (CSM). The strategy based on the ABC-principle is proposed for the short term, while the strategy based on the CSM is proposed for the long term.

ABC-principle

The first solution that is proposed is based on the ABC-principle. This basic principle splits the SKUs in three different groups. The first group contains 20% of the SKUs with the highest picking frequency, the second group contains the next 30% of the SKUs with then the highest pick frequency. The third group contains the last 50% of the products with the lowest pick frequency. Then the warehouse is split up in three similar groups: In a group that contains the 20% locations closest to the I/O-point and so on. Within each class, the SKUs that are picked most frequently will be located the closest to the I/O-point and the products that are picked the least frequently are located further away from the

I/O-point, while taking into account the cube of the products and the available space while assigning products to specific locations.

The fact that the products are assigned to a group of locations instead of a specific location, provides the distributor with more freedom in allocating the products. This person can match the cube of products with the available space on the spot, while adhering to a clear plan.

In this research, the ABC-principle has been tailored to the requirements (see section 3.2) of Company X. Data about the distances in the warehouse has been collected through field research and the data about the pick frequencies of the different SKUs has been retrieved from the WMS-system. Combining these date with the preferences and (legal) requirements, the following allocation-design has been constructed:

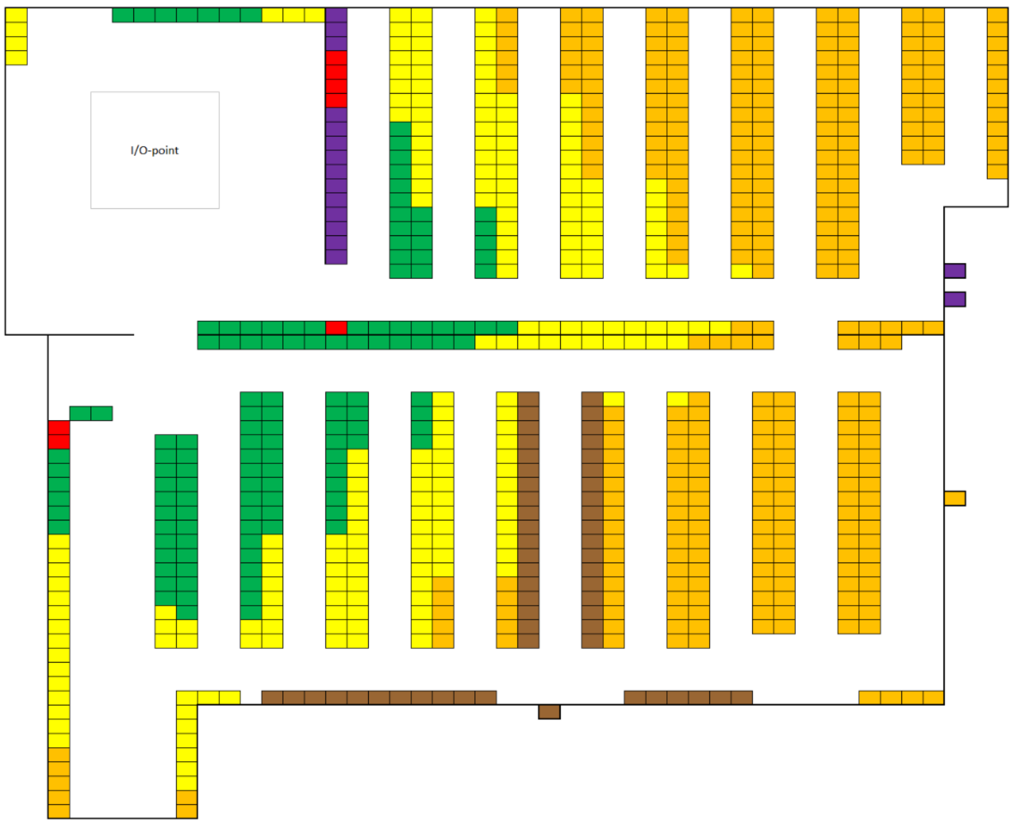


Figure M.1: Allocation-design constructed with the ABC-principle

In figure M.1, the colours of the cells have the following meaning and number:

Type of location:	Nr.	Description:	Colour in map:
A-locations	135	The first 20% fast-runners	
B-locations	210	The next 30% semi-fast-runners	
C-locations	344	The last 50% slow-runners	
PGS-locations	16	Products on the PGS-list	
W-locations	54	Products to be picked by walking pickers	
Location X	7	These locations cannot be used, because of safety regulations	
Total:	766	All locations	

Table M.1: Explanation of the colours in Figure M.1

Correlated Storage Method

The second strategy that was constructed uses more variables and if this roadmap is used for every SKU, then every SKU will be allocated to a specific location. In this strategy, the SKUs are systematically split in different groups of high correlation. Each group will receive a specific cluster in the warehouse, based on the characteristics of the group and the cluster. Furthermore, within each cluster, the SKUs are ranked on their COI, where products with the highest COI will be placed at the beginning of an aisle and products with a low COI at the end. With this strategy, SKUs are placed at a location close to the I/O-point in case they are frequently picked and are placed close to SKUs with a high correlation.

As the strategy based on the CSM takes more variables into account than the strategy based on the ABC-principle, the strategy will result in a more efficient allocation-design. Therefore, it is preferable to use this strategy over the ABC-principle. However, it is more difficult to implement and first the data about the cube and weight of the products that will have a fixed location must be collected. Therefore, this research proposes to implement the strategy based on the ABC-principle on the short term, then collect the necessary data and implement the CSM on the long term. Furthermore, to improve the overall performance of the warehouse, it would be wise to investigate which products should have a fixed location in the warehouse and which should not.

Priority	Actor	Action
1	Warehousing Department	Implement the strategy based on the ABC-principle.
2	Warehousing + Sales + Purchasing Department	Investigate which products should have a fixed location and which should not have one.
3	Warehousing + Purchasing Department	Collect the data of the cube and weight of all SKUs that will have a fixed location in the warehouse.
4	Warehousing Department	Implement the strategy based on the CSM.

Table M.2: Priority of recommendations

Recommendations

The recommendations in this research stem from the most important results. The recommendations can be split in two groups: recommendations from this study and suggestions for further research. This study recommends the following:

- Implement the strategy based on the ABC-principle for the short term.
- Collect the data of the cube and weight of all products that will be placed in the warehouse.
- Implement the strategy based on the CSM for the long term.
- Switch the direction in which the locations in the aisles are numbered.

The suggestions for further research are the following:

- Investigate which products should have a fixed location in the warehouse and which products should not.
- Investigate how much influence the cube has on the pick sequence.
- Investigate the costs of a change in direction of the racks.

MANAGEMENTSAMENVATTING

Behalve een Engelse managementsamenvatting bevat dit verslag ook een Nederlandse versie hiervan. Het onderzoek is uitgevoerd voor een Nederlands bedrijf en om het onderzoek toegankelijk te maken voor al het personeel van dit bedrijf is hier een Nederlandse samenvatting van het onderzoek.

In de managementsamenvatting wordt een overzicht van dit onderzoek gegeven. Het doel van dit onderzoek wordt uitgelegd, evenals de aanpak voor het oplossen van de centrale onderzoeksvraag, de resultaten en de aanbevelingen.

Probleemidentificatie
Verschillende waarnemingen gaven aan dat het magazijn van Bedrijf X niet zo efficiënt werkt als mogelijk is. Vanwege het feit dat de toewijzing van producten is gebaseerd op intuïtie in plaats van kwantitatieve modellen, doen zich verschillende problemen voor. Ten eerste zijn producten met een hoge en lage pick-frequentie niet systematisch over het magazijn verdeeld. Ten tweede bevinden producten met een lage pick-frequentie zich vaak op A-locaties. Daarnaast is er geen specifieke locatie voor cross-dock producten en producten die worden gepickt door de medewerkers van de servicebalie.

Centrale onderzoeksvraag
Het doel van dit onderzoek is om een geschikte strategie te vinden om de producten van Bedrijf X efficiënter in hun bestaande magazijn toe te wijzen, zodat de gemiddelde pick tijd per order wordt verkort. Dit leidt tot de volgende centrale onderzoeksvraag:

Wat is een efficiënte toewijzing van producten in het exportmagazijn en bijbehorende routing, zodat de gemiddelde reisafstand per order wordt verminderd?

De gemiddelde reisafstand per order wordt gebruikt als hoofd-KPI, aangezien het de specifieke variabele is die van invloed is op de gemiddelde picktijd per order, welke kan worden beïnvloed door de opslagstrategie te wijzigen.

Methodologie
Het onderzoek is op de volgende manier gestructureerd: Als eerste wordt het magazijnproces van Bedrijf X geanalyseerd door persoonlijke observatie en een interview met de logistieke manager. Dit wordt uitgevoerd om het inzicht in de huidige situatie te verbeteren. Hierna zijn de knelpunten van Bedrijf X geanalyseerd aan de hand van participerend onderzoek, om de aard van het probleem te begrijpen en te ontdekken waar mogelijkheden voor verbetering bestaan. Vervolgens is een literatuurstudie uitgevoerd om te zoeken naar mogelijke oplossingen voor de problemen die naar voren komen in de knelpuntenanalyse.

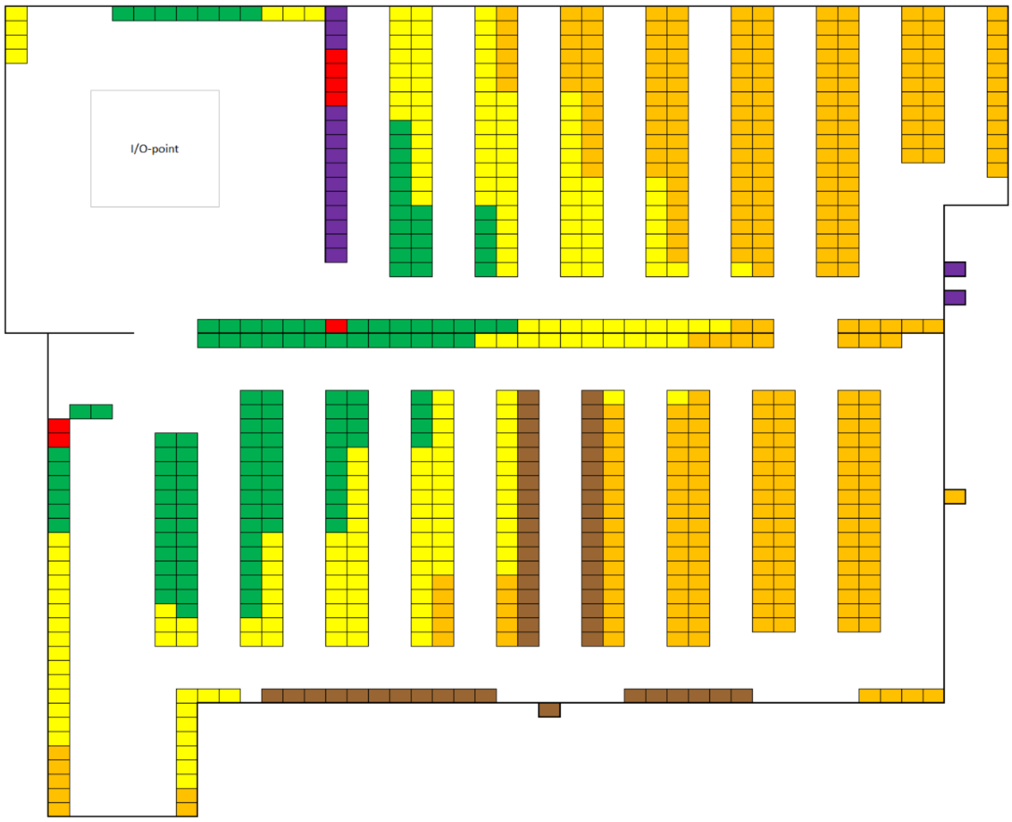
Resultaten
Aanvankelijk was het onderzoeksdoel om elk product toe te wijzen aan een specifieke locatie. Tijdens de fase van gegevensverzameling bleek echter dat er geen gegevens beschikbaar waren over de omvang van verschillende producten. Omdat de omvang van de producten aanzienlijk varieert evenals de beschikbare ruimte op verschillende locaties, werd het duidelijk dat het toewijzen van producten aan specifieke locaties niet mogelijk was zonder deze gegevens. Daarom wordt een nieuwe aanpak gekozen. Het onderzoek richt zich op het creëren van een strategie op basis van bestaande literatuur die kan worden gebruikt om elk product in het magazijn toe te wijzen wanneer de momenteel ontbrekende gegevens beschikbaar worden. Er worden twee strategieën voorgesteld, één gebaseerd op het ABC-principe en één gebaseerd op de Correlated Storage Method (CSM). De

strategie gebaseerd op het ABC-principe wordt geadviseerd voor de korte termijn, terwijl de strategie gebaseerd op de CSM wordt geadviseerd voor de lange termijn.

ABC-principe
De eerste oplossing die wordt voorgesteld, is gebaseerd op het ABC-principe. Dit basisprincipe splitst de SKU's in drie verschillende groepen. De eerste groep bevat 20% van de SKU's met de hoogste pickfrequentie, de tweede groep bevat de volgende 30% van de SKU's met vervolgens de hoogste pickfrequentie. De derde groep bevat de laatste 50% van de producten met de laagste pickfrequentie. Vervolgens wordt het magazijn opgesplitst in drie vergelijkbare groepen: in een groep met de 20% locaties die zich het dichtst bij het I / O-punt bevinden, enzovoort. Binnen elke klasse zullen de meest gepickte SKU's zich het dichtst bij het I / O-punt bevinden en de producten die het minst vaak worden gepickt, zich verder van het I / O-punt bevinden, rekening houdend met de omvang van de producten en de beschikbare ruimte tijdens het toewijzen van producten aan specifieke locaties.

Het feit dat de producten worden toegewezen aan een groep locaties in plaats van een specifieke locatie, biedt de distributeur meer vrijheid bij het toewijzen van de producten. Deze persoon kan de omvang van producten matchen met de beschikbare ruimte ter plaatse, terwijl hij zich houdt aan een duidelijk plan.

In dit onderzoek is het ABC-principe afgestemd op de eisen (zie paragraaf 3.2) van Bedrijf X. Gegevens over de afstanden in het magazijn zijn verzameld door veldonderzoek en de gegevens over de pickfrequenties van de verschillende SKU's zijn opgehaald uit het WMS-systeem. Door deze data te combineren met de voorkeuren en (wettelijke) vereisten, is het volgende allocatie-ontwerp geconstrueerd:



Figuur M.1: Magazijnindeling gebaseerd op het ABC-principe

In figuur 1 hebben de kleuren van de cellen de volgende betekenis en het volgende nummer:

Type locatie	Aant.	Omschrijving	Kleur
A-locaties	135	De eerste 20% snellopers	
B-locaties	210	De volgende 30% snellopers	
C-locaties	344	De laatste 50% traaglopers	
PGS-locaties	16	Producten op de PGS-lijst	
W-locaties	54	Producten die gepickt worden door baliemedewerkers	
Locaties X	7	Niet gebruikte locaties	
Totaal:	766	Alle locaties	

Tabel M.1: Legenda van figuur M.1

Correlated Storage Method

De tweede strategie die is opgesteld, maakt gebruik van meer variabelen en als deze strategie voor elke SKU wordt gebruikt, wordt elke SKU toegewezen aan een specifieke locatie. In deze strategie worden de SKU's systematisch verdeeld in verschillende groepen met een hoge correlatie binnen de groep. Elke groep ontvangt een specifiek cluster in het magazijn, op basis van de kenmerken van de groep en het cluster. Bovendien worden de SKU's binnen elk cluster gerangschikt op basis van hun COI, waarbij producten met de hoogste COI aan het begin van een gangpad worden geplaatst en producten met een lage COI aan het einde. Met deze strategie worden SKU's op een locatie dicht bij het I/O-punt geplaatst in het geval ze vaak worden gepickt en staan daarnaast dicht bij SKU's met een hoge correlatie.

Omdat de strategie op basis van de CSM meer variabelen in aanmerking neemt dan de strategie op basis van het ABC-principe, zal de strategie resulteren in een efficiëntere indeling. Daarom verdient het de voorkeur om deze strategie te gebruiken boven het ABC-principe. Het is echter moeilijker te implementeren en eerst moeten de gegevens over de omvang en het gewicht van de producten met een vaste locatie worden verzameld. Daarom stelt dit onderzoek voor om de strategie op basis van het ABC-principe op korte termijn te implementeren, vervolgens de nodige gegevens te verzamelen en de CSM op lange termijn te implementeren. Om de algehele prestaties van het magazijn te verbeteren, is het bovendien verstandig om te onderzoeken welke producten een vaste locatie in het magazijn moeten hebben en welke niet.

Priority	Actor	Action
1	Magazijnbeheer	Implementeer de strategie gebaseerd op het ABC-principe.
2	Magazijnbeheer + Verkoop + Inkoop	Onderzoek welke producten een vaste locatie moeten hebben en welke niet.
3	Magazijnbeheer + Inkoop	Verzamel de gegevens over de omvang en het gewicht van alle producten die een vaste locatie in het magazijn zullen krijgen.
4	Magazijnbeheer	Implementeer de strategie gebaseerd op de CSM

Tabel M.2: Prioriteit van de aanbevelingen

Aanbevelingen
De aanbevelingen in dit onderzoek vloeien voort uit de belangrijkste resultaten. De aanbevelingen kunnen in twee groepen worden verdeeld: aanbevelingen uit dit onderzoek en suggesties voor verder onderzoek. Deze studie beveelt het volgende aan:

- Implementeer de strategie op basis van het ABC-principe voor de korte termijn.
- Verzamel de gegevens van de omvang en het gewicht van alle producten die in het magazijn worden geplaatst.
- Implementeer de strategie op basis van de CSM voor de lange termijn.
- Keer de richting waarin de locaties in de gangpaden genummerd zijn om.

De suggesties voor verder onderzoek zijn de volgende:

- Onderzoek welke producten een vaste locatie in het magazijn moeten hebben en welke producten niet.
- Onderzoek hoeveel invloed de omvang heeft op de pickvolgorde.
- Onderzoek de kosten van een verandering van richting waarin de stellingen geplaatst zijn.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

In the framework of completing my bachelor studies Industrial Engineering and Management at the University of Twente, I performed research in the field of efficient product allocation at the export-warehouse of Company X B.V. In this chapter, the background of Company X is explained, as well as the research motivation, the problem identification, a broad explanation of how the problem is approached, the scope of this research, the research design and the validity and reliability of this research. At the end, a short summary of the chapter is provided.

1.1 Background Company X

This parts has been left out due to confidentiality reasons.

1.2 Research Motivation

The company has experienced strong growth in recent years and more products are moving out every year. To cope with the growing demand, it is necessary to organize the export warehouse more efficiently, so that more orders can be picked with the same resources in the same time frame. Currently, Company X's warehouse contains enough space and has a high throughput time. Therefore, the focus is on picking efficiently rather than the highest utilization of space.

1.3 Problem Identification

For fast-moving warehouses like Company X's, the order-picking process comprises on average around 60% of the total process from receiving to shipping (Drury, 1988). It is a costly process that takes time and labour, so it is important that this process runs as efficiently as possible. At the moment this research starts, the process is not running as efficiently as Company X wants. The current allocation-design of products to picking locations is based on logical thinking and 'gut feeling' without quantitative support of product data and models. The lack of quantitative support causes a couple of problems in the warehouse. products with a low throughput (slow-runners) and products with a high throughput (fast-runners) are not systematically distributed through the warehouse; they seem to be randomly distributed over the warehouse. Complementarity between different products has also not been taken into account in the allocation-design. Furthermore, there is no clear system for cross dock products and no system for allocating newly introduced products. The lack of use of product information causes the order pickers to drive longer routes on average than necessary.

The earlier mentioned problems cause that the warehousing process is not running as efficiently as Company X wants. This is the action-problem of this research. Over the first 5 months of 2019, Company X processed on average 15426 picking-lines per month (Magazijngegevens KPI's, 2019). An average month has around 22 working days, so 15426/22 ≈ 701 picking-lines per day. The company is

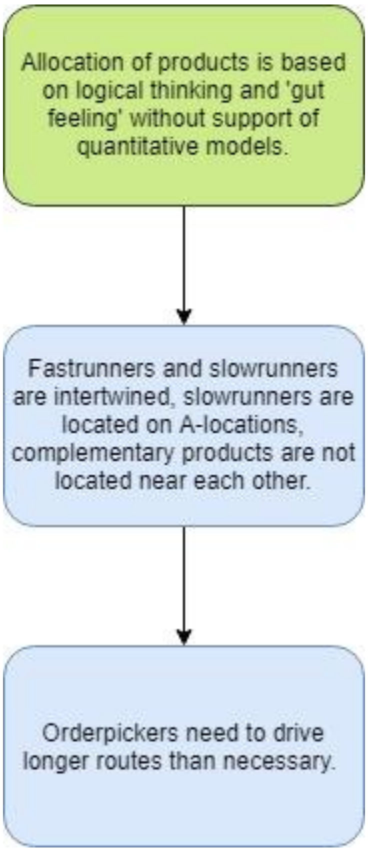


Figure 1.1: Problem Cluster

convinced that this number could be higher with the current resources. For that reason, Company X wants a new allocation-design for the export warehouse; to increase the efficiency of the order-picking process. The main KPI in this process is the average travel distance per order. Other KPIs are: the average time per picking line processed and the utilisation grade. The average travel distance per order is chosen as main KPI, as it is a good indicator of the efficiency of the order-picking process and it is possible to decrease the value of this KPI with a different storage strategy. The core purpose of this research is to decrease the average travel distance per order.

In conclusion, the core problem is that the allocation of products to picking locations is based on logical thinking and 'gut feeling', without support of quantitative models. This causes many products to be located on illogical locations, which causes the order-pickers to drive longer routes through the warehouse than necessary. This problem is crucial to the company, because order picking is a costly process. This problem is not caused by any other problem, it is certain that this is an actual problem and it can be influenced.

1.4 Problem Solving Approach

To solve the core problem of this study, a clear problem solving approach is made to determine exactly how the research will proceed. This approach starts with the research question. Hereafter, a number of sub-questions are stated, which are necessary to answer the research question. The main stakeholders in this problem are the logistics manager, the order-pickers and the replenishers.

1.4.1 Research Question

What is an efficient allocation of products in the export warehouse and associated routing, so that the average travel distance per order is reduced?

1.4.2 Sub-questions

The sub-questions of this research are written in bold. Every sub-question is on its turn divided in several questions that indicate what information is needed to solve the corresponding sub-question.

1. **What does the current warehousing process look like?**
   -How does the warehousing-process run?
   -How does the order structure look like?
   -How is the warehouse structured?
   -What product information is available?
   -What are the current KPIs?
   -How does the current design score on the KPIs?

The first step in solving the core problem is to analyse the current situation. To improve the current situation, one needs to understand why certain decisions in the present design are made. A thorough analysis of this allocation-design provides information that needs to be considered when a new design is developed. Furthermore, it gives a deeper insight in the current problems and how these problems can be solved. To gain this information, an interview with the logistics manager is held. More information about this interview is provided in the chapter research design and the interview is transcribed in appendix A1. Besides this interview, the researcher has worked one day in the warehouse to get a deeper understanding of the details of the warehousing process. Furthermore, historical data is analysed to calculate scores on the current KPI's.

2. **In which field could the warehousing process of Company X be improved?**
   -What are the main bottlenecks?
   -What are the requirements from Company X?
   -In which field can the company improve the most?

The 'current system analysis' is used as a base to analyse in which area the company could improve the most. The requirements of the company are explained. Taking the bottlenecks and the requirements in mind, the most interesting possibilities for improvement are investigated.

3. **Which knowledge does already exist in literature about allocating products in a warehouse with a high throughput time?**
   -Which heuristics and quantitative methods are suggested in literature about allocating products in an efficient way?
   -What are the preconditions, assumptions and restrictions of those heuristics and methods?
   -Which methods and strategies fit the situation of Company X best?

After analysing the current situation, it is important to know how this information has to be processed. The first step for designing a new-allocation design, is to find out what common knowledge there is about allocating products in a warehouse with a high throughput time. This information is obtained by a systematic literature review. This literature study focussed specifically on storage strategies. A theoretical framework was designed that fits the situation of Company X. To assure that the models, methods and heuristics from the literature study fit the situation of Company X, the preconditions, assumptions and restrictions of these models were studied next to the preferences and restrictions of Company X.

4. **Which strategies be constructed for Company X, using the available product information and quantitative models from the literature, while taking restrictions and preferences from the bottleneck-analysis into account?**
   -Which systems and logics are used to construct the different designs?

In this phase of the research, all knowledge is combined to create storage strategies based on the gathered information. The different designs that are constructed are explained and analysed.

5. **Which strategy fits the situation for Company X the best?**
   -What are the advantages and disadvantages of the different designs?
   -Which allocation-design is advised for Company X?
   -Other recommendations for Company X
   -Suggestions for further research

After designing several allocation-designs, the different designs are analysed on their advantages and disadvantages. In conclusion, a decision is made for which allocation-design is advised for Company X. Besides, recommendations and suggestions for further research are made.

1.5 Scope

The research focusses on designing an appropriate storage strategy that can be used to allocate products on the picking-locations in the export-warehouse of Company X. The current design of the warehouse is fixed, hence the warehouse design is outside the scope of this project. However, the beams on the lower locations are not fixed, so the allocation of the beams is taken into account in this project in an uncomplicated way. To keep the project manageable, this research is not focussed on the allocation of products to the replenishment locations. The receiving and shipping process are not part of the scope of this project.

1.6 Deliverables

This research results in the following deliverables:

- A qualitative and quantitative analysis of the current allocation of products in the warehouse, associated routing and warehousing process.
- An analysis of different storage strategies with an elaborate explanation of differences between the strategies and how they would fit in Company X's situations.
- A recommendation of one or more storage strategies and how these strategies should be implemented.

1.7 Knowledge Questions

Based on the problem solving approach, several knowledge questions are formulated. These knowledge problems are the core of the different chapters. The problems are explained more elaborately in the problem solving approach. For the clarity of this research, the main knowledge problems are stated here:

- What does the current warehousing process look like?
- In which field could the warehousing process of Company X be improved?
- Which knowledge does already exist in literature about allocating products in a warehouse with a high throughput time?
- Which strategies be constructed for Company X, using the available product information and quantitative models from the literature, while taking restrictions and preferences from the bottleneck-analysis into account?
- Which strategy fits the situation for Company X the best?

1.8 Research Design

In the section 'Knowledge Questions' above, the main knowledge problems in this research are stated. These problems are solved in different ways. First, the current allocation-design is analysed. To find out the scores of the current warehouse on the KPIs, measurements are done. For a batch of orders, the average travel distance is measured, using a map of the warehouse and assuming that the order is picked in such a way the average travel distance is minimized with fixed locations.

Subsequently, a literature study is conducted in search for existing knowledge about allocating products in a warehouse with a high throughput time. This research makes clear which variables are important in allocating products and what information needs to be considered when creating an allocation-design. However, every warehouse differs in many ways and especially in the product-range. The differences and aspects of products are crucial in deciding which storage strategy will be implemented. It is important that all significant details are considered when the products will be allocated and to know which details are significant. To discover all these details, an explanatory research is conducted by means of semi-open interviews with one or more warehouse employees of Company X.

1.8.1 Type of Research

The type of research in this situation is explanatory. The goal is to explain relations between different variables. For example, how the cube and the weight of a product determine the order in which different products need to be placed on a pallet and with that the average travel distance

1.8.2 Research Population

The research population in this research is warehouse employees (order-pickers, team leader and the logistics manager) of Company X.

1.8.3 Subjects

The subjects in this research are the warehouse employees of Company X. They work daily in the research environment and are therefore a valuable source of knowledge in this research.

1.8.4 Research Strategy

The strategy of this research is as follows. To find clues about what information is important for allocating the products in the warehouse of Company X, the researcher conducts an interview with the logistics manager. Furthermore, the researcher participates in research by working a day in the warehouse.

1.8.5 Methods of Data Gathering

During this research, three different methods of data-gathering are used. To obtain data about the KPIs in the current system, observation is used. To gather knowledge about existing heuristics and quantitative models about allocating products, literature study is used. Then, to acquire knowledge about factors and variables that need to be considered specifically in Company X's situation for deciding on an appropriate storage strategy, the communication approach is used (interviews). The literature study and the interviews are qualitative research, as the results are open for interpretation. The observation is quantitative research, as the numbers that result from this research are facts and thus not open for interpretation.

1.8.6 Data Analysis Method

The outcome of the interview is analysed by a comparison between the results and a comparison with the literature. If some factors that need to be considered in the construction of an allocation-design for Company X's warehouse, appear in the interview, then this factor is investigated.

The data of the observation are first analysed on the validity. Extreme numbers in the dataset are investigated and possibly left out of the calculation. The data that is left is used to calculate the average travel distance per order for a certain sample.

The sources that are analysed in the literature study, are analysed on the type of warehouse they apply to and on the type of storage strategy that is used in the study to optimise the allocation-design. Using this information, the storage strategies that fit the situation of Company X best are picked for further research.

1.9 Summary

In this chapter the reader is introduced to the company and to the approach of this research. In this research, the warehouse of Company X, a wholesaler in primarily cleaning and safety products, is investigated, to find out how the efficiency of the order-picking process in the export-warehouse could be improved. To effectively research the problem, an analysis of the current situation is done. The bottlenecks are analysed hereafter. After these analyses, a literature study is performed to search for literature that offers solutions to the earlier mentioned bottlenecks. Then, several solutions are designed and explained. In the final chapter, the solutions are analysed and recommendations are given.

CHAPTER 2: CURRENT SYSTEM ANALYSIS

In this chapter, the current warehousing process of Company X is analysed. The warehouse-design is reviewed and the current storage policy is explained and analysed. Furthermore, information about the product-range of Company X is provided. At the end of this chapter, the KPIs that are currently in place are discussed. The analysis about the KPIs is descriptive as well as explanatory.

2.1 Warehousing process

In this part, the warehousing process of Company X is analysed. When new goods arrive at the docks, these goods are processed by the receiving employees of the warehouse. They are divided over three different parts of the warehouse: the export-warehouse, the bulk-warehouse and the PGS-warehouse (see figure 2.1).The PGS-warehouse contains products with dangerous substances (see main constructs). All goods are received on pallets (EPAL or block), Arboxes, or in individual boxes. If there is enough space in the warehouse, the Euro-pallets are sent directly to the export-warehouse. Otherwise, the pallets are sent to the bulk-warehouse.

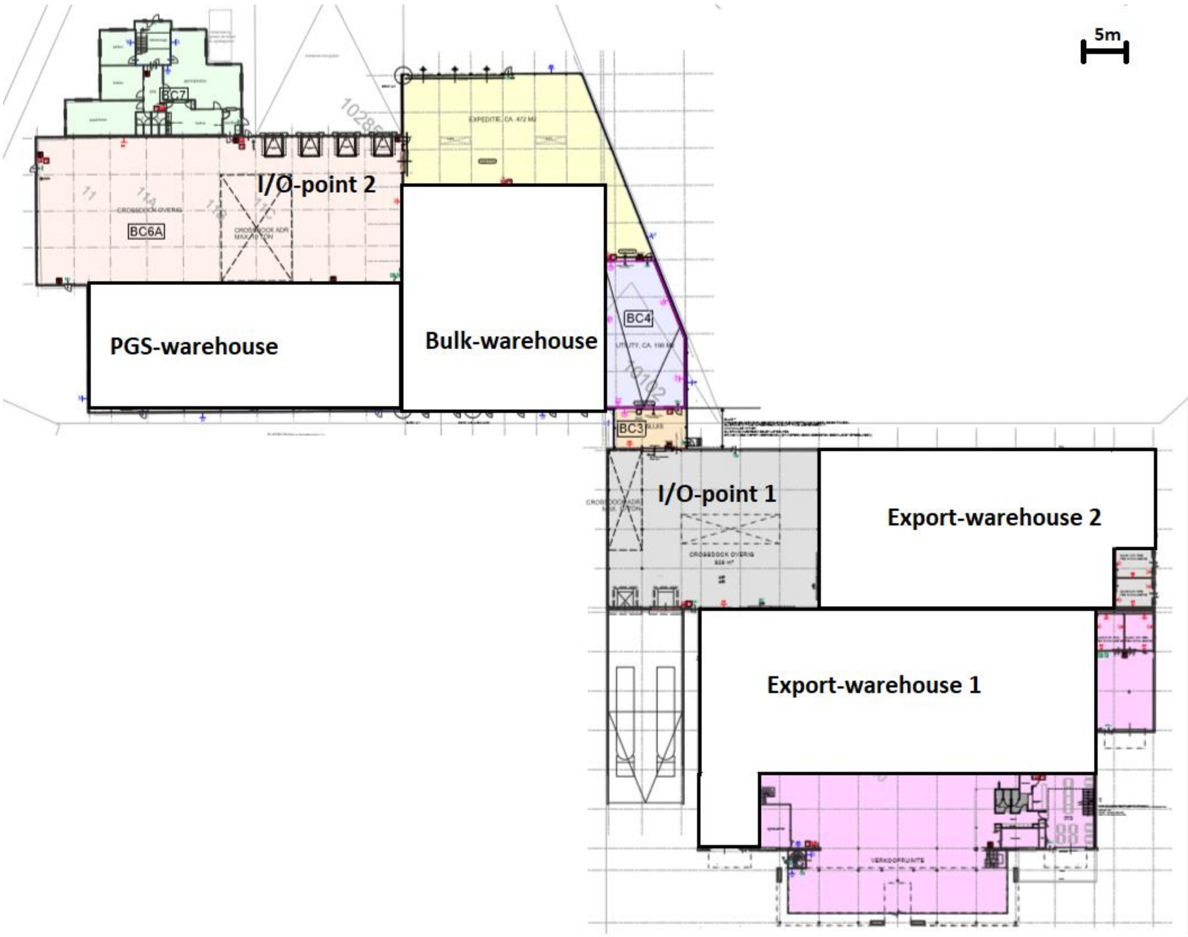


Figure 2.1: map of Company X B.V.

In the bulk-warehouse, products are picked with a small-aisles forklift. This process is relatively slow, yet it ensures a very high utilisation grade, as many picking-locations can be placed on a small area. In the most common situation, goods are sent directly to the export-warehouse. Normally, only products with a long delivery time are ordered in large quantities. These quantities do not fit in the export-warehouse and are therefore stored in the bulk warehouse. This group comprises around 20% of the different products.

When products are ordered at the sales department, an order is placed in the system. Depending on the company, the order will be picked the same day, or on a fixed day. Many of Company X's clients have a fixed delivery day. This way, Company X saves money, time and fuel by doing a delivery run in a certain area of the country only one time per week. Clients without a fixed delivery day, receive the products they order on the next day. For some of the bigger clients, different products are added up until the day before the delivery day and are then combined to an order.

The orders are saved in the system and assigned to a day that they will be picked. The orders are picked on priority. Orders are not assigned to pickers. Pickers simply receive the next order in line, when they have finished their last order. Company X works with a picker-to-goods system. This person picks the different products from the pick-locations and places them on the pallet on his stacker.

In the export-warehouse, all locations on the floor are picking locations. Furthermore, most racks have one or several layers whereof products can be picked conveniently (see figure 2.2). The products that are stocked on these intermediate layers are products that with a small cube and are not stocked on pallets. Furthermore, the first layer (above the intermediate layer(s)) is used partly as picking location and partly as storage location. Currently, around 20% of the locations on the first layer are used as picking locations (Wevers, 2019). However, these picking locations are not as convenient to use as the picking locations on the floor. At present, orders are picked with stackers that can reach the first layer, but where the picker stays on the floor. This makes it possible to pick from pallets from the first layer. Yet, these pallets need to be taken down to the floor first, then the needed products can be picked from the pallet and at last the pallets need to be moved back to its place on the first layer. All these steps take a lot of time, which makes it inconvenient to pick from the first layer. However, Company X is in the process of purchasing new stackers. Three of these new stackers will be put into use in 2019. On these stackers, the picker goes up as the forks go up. This will make it more convenient to pick from the first layer as well. The second and the third layer are meant for stocking full pallets. The locations on these layers are called replenishment locations.

When a picking location becomes empty, this location is filled with a new pallet from one of the replenishment locations. When these replenishment locations become empty, they will be filled by a replenisher with pallets from the bulk warehouse. The goal is that the order picking locations are never empty, so that the order-picking process can proceed continuously.

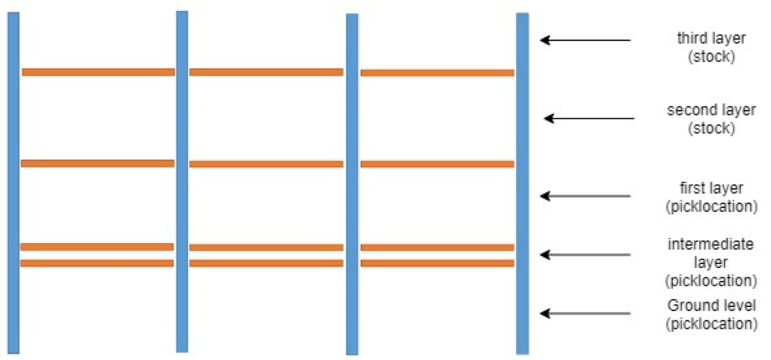


Figure 2.2: structure of a rack

2.2 Structure of an Order

The structure of an order differs for every company. The orders of Company X contained on average 4,2 picking lines in 2018. The lines in the order are arranged based on the location of the product. All the picking locations have a number and on an order, these numbers determine the sequence of picking lines, by ranking the numbers from low to high. This way, the picker directly has an acceptable route through the warehouse. Yet, this strategy does not take any other variable into account. However, pickers keep the cube of the product and the way it is packed in mind, when they determine the sequence in which they pick the products. They prefer to pick products that are packed in large boxes first and small products in unregular shapes last. Therefore pickers often deviate from the sequence that is presented on the scanner. In figure 2.3, a typical run through the export-warehouse is shown. In this case, six different products are picked, by one regular picker. The run starts and ends at the I/O-point. For a more elaborate explanation of the warehouse, see section 2.3 'Structure of the Warehouse'.

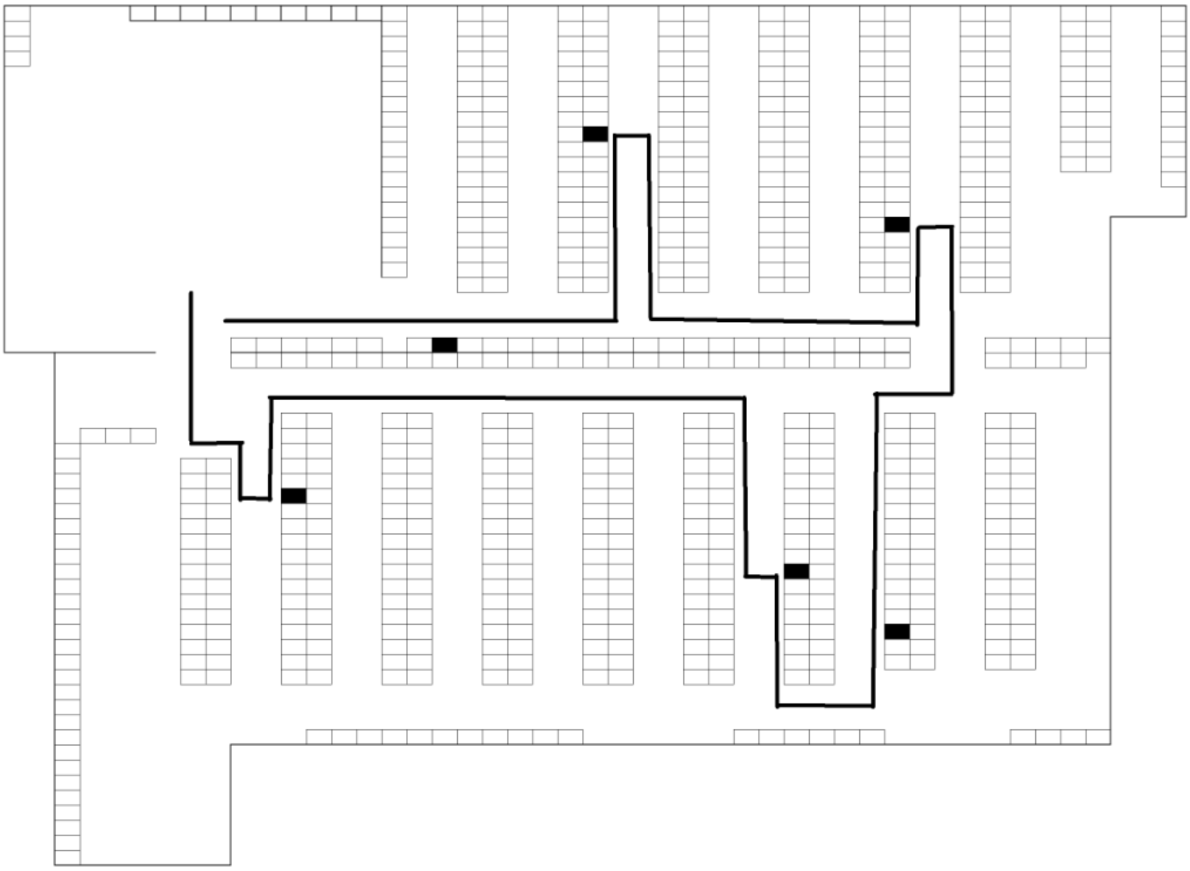


Figure 2.3: Typical run through the export warehouse

2.3 Structure of the Warehouse

Company X currently has three warehouses that all have a different structure. These warehouses are the PGS-warehouse, the bulk-warehouse and the export-warehouse. The PGS-warehouse contains dangerous substances. This warehouse is specially built to store these substances and it complies with strict regulations. It contains primarily detergents. Every day, several orders are picked that contain only or mostly products out of this warehouse. These product are assigned to one picker by the team leader, so that this picker can stay on the side of the PGS-warehouse, while other pickers stay on the side of the export-warehouse. To get a clearer picture, see the map of Company X's warehouse (figure 2.1). Orders picked with products of the PGS-warehouse are shipped from the receivals side for around 95% of the time (Wevers, 2019). Because of this, Company X effectively has two I/O-points. The PGS-warehouse has standard racks with three levels, where products are picked from the floor- and first level. There are no fixed locations in this warehouse, however the warehouse is divided in several parts, based on the types of detergents.

The bulk-warehouse is the highest warehouse of the three, having seven levels where pallets can be placed on. These pallets are stored and retrieved with a small-ailes forklift. Products in the bulk-warehouse are not directly picked for orders, but are used as replenishments for the locations in the other warehouses.

The export-warehouse is the warehouse where this research focusses on. This warehouse covers the largest area of the three warehouses and is the most labor-intensive. The warehouse functions as one warehouse, yet it can be divided into two parts. This division can be found in figure 2.4. The two parts are seperated from each other by a wall with one opening. Besides, both parts can be reached from the I/O-point. The amount of layers differs in this warehouse, because the distance between layers has been adapted to the height of the full pallets that will be placed on this layer. The amount and type of layers can be found in the excel file 'warehouse information'. The racks are perpendicular to the wall that seperates both parts of the warehouse from each other. This is the case for both parts of the export-warehouse. In the first part, the racks are not attached to the walls on any side. This makes it possible for order-pickers to drive in S-shapes around the racks through this part of the warehouse (see the typical run in figure 2.3). In the second part of the warehouse, the racks are attached to the wall on one side. Therefore, pickers can not drive in S-shapes around these racks, but have to leave each aisle on the same side as they entered it. Therefore, pickers drive in U-shapes in this part of the warehouse.

When a new SKU is added to Company X's assortment, this product is allocated to first available place that is the closest to the I/O-point in the warehouse. When, after a while, the product appears to be a fast-running good, the products gets allocated to a new location that is closer to the I/O-point.

The first part of the export-warehouse is 50 meters wide and 20 meters long. The second part of the export-warehouse is 43 meters wide and 20 meters long. The second and newest part is higher than the first part. The export-warehouse contains a total number of 832 different 'base-locations'. The second part of the export-warehouse contains one rack with dangerous substances. This rack is placed against the wall that seperates the second part of the export-warehouse from the space with the I/O-point. Besides, there are two safes in the export-warehouse, that contain dangerous substances as well. On the next page, two figures of the export-warehouse are given, showing the racks from above. Each box respresents one pallet location. Figure 2.4 shows the floor-layout of the warehouse, while figure 2.5 shows the layout of the second layer.

Figure 2.4: Export-warehouse floor level

Figure 2.5: Export-warehouse second level

Type of location:		Fit for picking?	Description:	Colour in map:
Regular location	680	Yes	Regular base-location in the racks of the export-warehouse and hall of the I/O-point	
Floor-location	12	yes	Locations where a pallet can be placed on the floor, without a rack.	
Shelf-rack	62	Yes	Shelf-racks are racks in which small products can be placed and picked conveniently.	
Other	4	mixed	The other locations contain the showroom, a workplace for vacuums and the two safes for dangerous substances	
Location above aisle	66	No	The locations above the aisles can be found in both parts of the export-warehouse. They are not fit for picking	
Location X	7	No	These locations cannot be used, because of safety regulations	
Total:	831	Mixed	All locations	
Total picking locations	757	Yes	The regular locations + the floor locations + the shelf-racks and three of the other locations	

Tabel 2.1: Explanation of colours in the warehouse map

2.4 Products

Company X has a wide product assortment. The product-characteristics influence the decision where the product will be placed. The most important characteristics are discussed in the following sections.

2.4.1 Product Groups

The product range of Company X can be split up in nine different compartments. These compartments are mentioned in the introduction of chapter 1. Clients are usually linked to Company X through a specific compartment, for example the painting articles. However, clients often purchase products from multiple compartments, since several compartments contain products that or used by (almost) all companies, regardless of the type of company. Examples of these compartments are the work clothing articles and the canteen articles. Therefore, orders often contain product from one specific compartment and from multiple non-specific compartments. The compartment influences the complementarity between products and therefore the storage strategy. Placing products with a high correlation close together decreases the average travel distance.

2.4.2 Cube and Weight

Cube and weight are two product characteristics that play an import role in the order-picking process of Company X. These factors influence the order in which different products (orderliness) of one order are picked. From the semi-open interviews with the order-pickers, it appeared that the cube and weight of different products are considered for every order, before determining the sequence in which the different products will be picked. For small orders (2 to 4 products) the cube and weight normally do not influence the sequence, as the different products fit easily on a pallet. The larger and heavier the order becomes (in terms of cube and weight) the more important these factors are for determining the sequence. These factors play a major role in determining the sequence in which different order lines are processed. Company X had no data available concerning the cube and the weight of products at the start of the project.

In the section above, the impact of the cube and weight of products on the order-structure has been explained. Besides this impact on the order-structure, the cube and weight of products also influence the layout of the warehouse. In chapter 2.1, it was mentioned that products arrive on pallets or Arboxes, but also in individual boxes. A substantial part of the products are not stocked on pallets. Therefore, the export-warehouse contains many smaller places where these products can be placed: the shelf-racks and the intermediate layers. Most of the regular racks contain one or more intermediate layers, meant for these smaller products. When a new layout is designed, where every product is allocated to a specific location, the cube of the product needs to be considered, to make sure that the product is assigned to a location where it fits.

2.4.3 W-Products

One exceptional group of products in CL's warehouse are the W-products. These products are products that are picked by employees of the service counters. These employees only pick for a small part of the day and do not use stackers. At this moment the products that are picked by these employees are divided over the racks of export-warehouse 1. Most of these products are allocated to racks 11, 12 and 41. In the future, Company X wishes to put all W-products together in these racks and make the aisle between these racks a non-stacker zone, to ensure the safety of the pickers.

2.4.4 PGS-Products

Another group of products that need to be handled separately are the PGS-products. These products are on the list of dangerous substances in The Netherlands and are therefore treated different from other products. Safety regulations ensure that these products need to be placed on locations that are approved for the storage of dangerous substances. In the case of Company X are these locations the PGS-warehouse (see figure 2.1), rack 37 and the lockers of location 4009 and 4010. These products are not allowed to be stored at other locations.

2.5 KPIs

Company X has a small group of KPIs in place to measure the efficiency of the order-picking process. These KPIs are the number order-lines per employee (in different periods, per day and per month) and the number of order-lines per month (in combination with the number of employees per month) stated for several years.

These KPIs however, do not contain information that directly observe the efficiency of order-pickers, as many other factors influence the outcomes of these KPIs. Examples of these factors are: The number of lines that need to be picked per day, the type of activity's a picker has to do on a certain day (Only picking or also cleaning or working at receivals) and the type of picking a picker is doing (regular picking, picking PGS-products or batch picking).

To get a more realistic overview of the efficiency of the picking process, the travel distance per order is measured for a sample of 20 orders. The travel distance per order is the most appropriate KPI, as the goal of this research is to decrease the travel distance per order to improve the efficiency.

The travel distance in the orders is measured in the following way: First, an order with a number of order-lines between 1 and 10 is selected from the excel-file 'orders may 2019'. By selecting an order, the date and the availability of data about the pick-locations of the products are taken into account. The date is taken into account to make sure that not all orders are picked on one day, so that the orders give a good representation of reality. Furthermore, not all products that are picked have a fixed location. To be able to give an accurate number of the travel distance, orders that only contain products with a known location are selected. Then, the products are looked up in the locations sheet of excel file ‘warehouse information’. Subsequently, the travel distance of the first location is looked up in the travel distance sheet of the same excel file. Hereafter, the travel distance to the next SKU to be picked is determined. This process continues till all SKUs are picked. At last the travel distance from the last SKU to the I/O-point is looked up and added up by the other travel distances. This number is the total travel distance of the specific order. The order number, products in the order, locations of these products, date of the order, travel distances between the different SKUs, the total travel distance and the number of order-lines are recorded.

2.6 Summary

The warehouse of Company X can be split up in three different warehouses: the export-warehouse, the bulk-warehouse and the PGS-warehouse. The export-warehouse can on its turn be split up in two different parts that are separated by a wall. The export-warehouse is the part of the warehouse where this research focusses on. Products are picked manually by pickers who drive through the warehouse on stackers. Products are picked from the floor, the first layer and an intermediate layer. The pickers move through the warehouse to collect the orders, which is describes as a picker-to-goods strategy. Orders differ in size with an average size of 4.2 picking lines per order. The main KPI in this research is the average travel distance per order. This value of this KPI is calculated for a sample of orders.

CHAPTER 3: BOTTLENECK ANALYSIS

A vital part of each research is to detect the specific regions for improvement. In this part, the bottlenecks in the process of Company X and the possibilities for improvement are discussed. First an analysis of the core problem is provided. Hereafter, the requirements of Company X are discussed. At last, possibilities for improvement are discussed, supported by a Pareto analysis.

3.1 Main Bottlenecks

As it came forward in section 1.2 'Problem Identification', the core problem of this research is that the allocation of products is based on logical thinking and 'gut feeling' without support of quantitative models. Several years ago, there was an important change in the way the warehouse looked like. The bulk- and PGS-warehouse were not built yet. The export warehouse was not used for order-picking, but as a store, where customers could select the products themselves. Because of this functional use of the warehouse, products were stored in a way that customers could easily find what they needed. While the use of the warehouse changed, the structure of the storage did not change. Therefore products remained stored in groups of comparable products. The allocation design has not been systematically improved in recent years.

By participating in research it became clear, that products often had to be picked from the first layer. The method that is used to pick products from the first layer is explained in section 2.1 'Warehousing Process'. Picking these products takes considerably more time than picking products from the floor and is therefore undesirable. This is one factor that needs to be considered when allocating products.

Furthermore, visual inspections showed that the beams in most of the racks were adapted to the cube of the product on the place below. This may result in a high utilisation grade of the warehouse, yet it can decrease the amount of picking locations near the I/O-point. As some products with a large cube were situated near the I/O-point, taking up space that could otherwise be used for multiple SKUs. This factor influences the efficiency of the warehouse.

As it can be observed in the excel-file ABC-principle the 10 most picked products of the export-warehouse, are divided over all the three picking zones (A, B and C). In case of single-unit orders, a total distance of 353 kilometres could have been saved during the first 6 months of 2019 if the 10 most picked products would have been placed on the closest regular pallet locations.

3.2 Requirements

When Company X indicated which problems were involved, several requirements were mentioned. The following requirements can be derived:

- Reduction of the travel time for orderpickers
- Separate place for products picked by employees of the service counter
- Suitable cross-dock locations
- Take legal requirements into account
- Use the existing racks (preference)

At first, the goal of this research is to reduce the travel time, by dividing the products over the export-warehouse in such a way that the traveldistance and thus the travel time will be reduced. This is the main requirement. Furthermore, it is the only non-binary requirement, which means that the travel time can be reduced slightly or considerably. Other requirements are simply met or not.

Next to reducing the travel time, Company X would like to separate the products that are primarily picked by the employees who work at the service counters from the rest of the products. This measure would ensure that these employees can safely pick the products, without having to watch out for the stackers.

As there is currently not enough space dedicated to store products that will be only be located in the warehouse for a short time, the management wishes to find a more suitable place for cross-dock products. From the data-analysis it appeared, that a substantial amount of products were only picked once or twice during the first half year of 2019. Namely, 3193 of the 8717 products that were picked during this period, were picked only once or twice. These products are not picked enough to have a fixed picking location. Therefore, suitable cross-dock locations are necessary.

Besides the demands of Company X, the company has to deal with legal requirements as well. A substantial amount of the products sold by Company X contain dangerous substances and must therefore be stored seperately. Between products of different categories of these dangerous substances, there must be at least the length of one rack, because of safety reasons. These legal requirements need to be taken into account.

The last requirement Company X proposed, was to keep using the existing racks. This is a preference and not a hard requirement. Using the existing racks results in a much lower investment, which lowers the risks and presumably increases the Return on Investment. To determine whether this is a good decision, an analysis has been made (see section 5.3 'Alignment of the Racks').

3.3 Possibilities for Improvement

According to the pareto principle there is a regularity that 20% of the products are picked 80% of the time, 30% of the products 15% of the time and 50% of the products only 5% of the time (Esmeijer, 2012). Using the fact that a small group of product covers a substantial part of the total amount of picks, one can check whether a warehouse has a logical storage method. If these fast-running products are randomly allocated through the warehouse, there is a high chance that the allocation-design could be improved. From analysing the orders Company X handled in the first half-year of 2019, the following numbers appeared from the pareto analysis:

Percentage of products	Number of picks	Percentage of picks
First 20%	251,555	87.2%
Next 30%	28,390	9.8%
Last 50%	8,450	2.9%
Total 100%	288,395	100%

Table 3.1: ABC-analysis of products picked in 2019

This division shows, that 20% of the products is even accountable for more than 80% of the picks (namely 87.2%). Therefore, placing these 20% of the products in the front of the warehouse will have a considerable impact on the efficiency. When analysing where these products are located, it appeared that the locations of these products were far from optimal (see excel file ABC-principle). So there are certainly opportunities in allocating fast-running products closer to the I/O-point.

Another possibility for improvement is already mentioned in section 3.2 'Requirements'. Here, data-analysis showed that a significant amount of the products that were picked were only picked once or twice. As percentage of the total amount of picks is this 4.346/288.395*100=1,51%. This percentage is very low and therefore it is questionable whether these products deserve a fixed place in the warehouse. Reducing the amount of products that have a fixed place in the warehouse, results in more space for the fast-running products. Therefore, this is a major opportunity for improvement.

3.4 Summary

In chapter 3, the main bottlenecks of the warehousing process of Company X are discussed. It appeared that products are often located further away from the I/O-point than necessary. Furthermore, products that were picked regularly were frequently located on the first level, while it is more convenient to locate them on the floor. Also, the allocation of products is static, it does not get systematically improved over time.

Company X indicated several requirements for improvement of the warehouse. The main requirement is to reduce the travel time for order pickers. The other requirements can be found in section 3.3 accompanied with an explanation. In section 3.3 several possibilities for improvement are explained. Taking the bottlenecks, requirements and possibilities in mind, literature research could provide possible solutions for the problems Company X faces. Therefore, a literature study investigating different storage strategies can be found in chapter 4.

CHAPTER 4: LITERATURE REVIEW

Several different methodologies for allocating products efficiently are suggested in literature. In this theoretical perspective, the focus will be on strategies for a picker to parts warehouse where products are picked manually. Examples of these methodologies are placing complementary products (or product groups) together, using the ABC-principle or using the cube per order index. There are two basic slotting strategies that can be used: dedicated storage and random storage. Dedicated storage means that items are firmly coupled to specific locations, whereas random storage means that any location within the warehouse may be selected to store an item (Mantel, Schuur & Heragu, 2007).

4.1 Complementary Products

The strategy that Company X has applied for the current layout of their warehouse, is that complementary products are placed together. **Complementary products** are products that are sold separately but that are used together, each creating a demand for the other, for example, computers and computer programs (Cambridge, 2019). These products are often sold together and are therefore useful to place together. This strategy normally improves the efficiency of the warehouse compared to random allocation of products. Company X did not use this policy systematically, resulting in a mediocre solution. A systematic approach of this strategy is the **Correlated Storage Method (CSM)**, described by Frazelle (1989). He proposes a heuristic approach to group items into clusters. First, the most popular product is added to an empty cluster. Subsequently, the product with the highest total correlation is added to that cluster. This process continues until a certain capacity constraint is violated (Ruijter, 2007). After a number of clusters are generated, the clusters are ranked on total popularity. The most popular clusters are placed the closest to the I/O-point.

4.2 ABC-principle

Another strategy for allocating products is the **ABC-principle**. According to this principle there is a regularity that 20% of the products are picked 80% of the time, 30% of the products 15% of the time and 50% of the products only 5% of the time (Esmeijer, 2012). This is called the Pareto principle. According to this principle, the regularity with the ratio's above holds for many different situations, yet they are not definite values. The ABC-principle is a specific situation of the Pareto principle, where the ratio between a percentage of products and the percentage of times a product is picked is investigated. Using this regularity, one can design a warehouse, where the 20% of the products that are picked the most, are placed on the 20% locations closest to the starting point of the order-pickers. The 30% of the products that are picked the second most, will be located on the locations that are then the closest and the 50% of the products that are picked only 5% of the time will be located on the locations that are the furthest away. In figure 4.1 is shown how a warehouse that is organised based on the ABC-principle with crossways looks like.

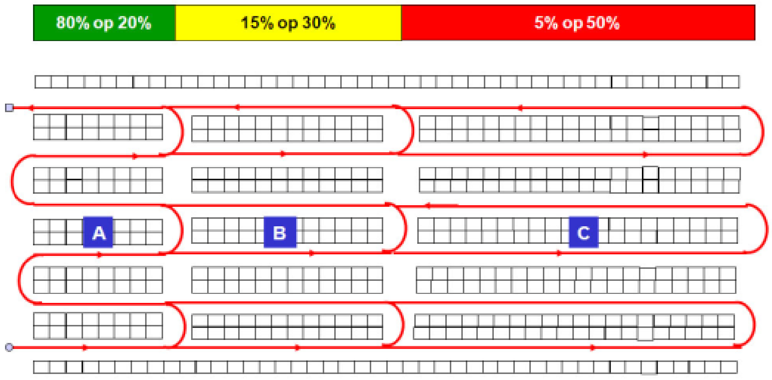


Figure 4.1: Warehouse-design ABC-principle (Source: Esmeijer, 2012)

4.3 Cube per Order Index

In practice, often a dedicated storage strategy based on the turnover rate of every SKU is applied. This implies that the allocation of SKU's to locations is based on both the popularity of the SKUs and the distances of the locations to the I/O point. These distances, in turn, strongly depend on only the layout. The most well-known example in literature of this kind of strategy is based on the **Cube per Order Index (COI)** of a SKU, which is the ratio of the number of locations occupied by this SKU and the pick frequency of this SKU (Mantel et al, 2007). This strategy is comparable with the ABC-principle, as it focusses on putting products with a high turnover close to the I/O point. Using the cube per order index as storage strategy is popular, as it is a method that does not require difficult calculations and is clear for each product. While the COI is in general a useful heuristic to come to a reasonably efficient solution, in case of (larger) orders that contain different products, the COI may yield poor results. Dr. P.C. Schuur even showed that the results of the COI as storage strategy are infinitely bad in a worst case scenario (Schuur, 2015). Therefore, the COI is fine to use in simple situations, in situations with single-unit orders, or as part of another strategy (CSM), yet not on its own in complex situations. One strategy that keeps the structure of orders in mind next to the product specific popularity are the OOS. These policies are explained in the next section.

4.4 Order Oriented Slotting policies

The strategy of the COI is optimal for orders with one SKU per order. However, many companies pick orders that contain more than one SKU's per order and so does Company X. The COI works reasonable for situations with a few SKU's per order, yet there are policies that focus on orders with multiple SKU's. These policies are **Order Oriented Slotting policies (OOS)**. Order oriented policies include the factor that multiple products often go together in one order next to an SKU's own popularity. The order oriented slotting strategy allocates items in such a way that total travel distance is minimal, given a routing policy and a set of orders (Mantel et al, 2007).

4.5 Direct Link Method

Lastly, there is another method of allocating products, that simultaneously considers slotting and routing. This strategy is called the **Direct Link Method (DLM)**. This strategy, devised by Van Oudheusden et al (1988), takes into account that if product i and j occur on the same order, that it does not necessarily mean that these products need to be picked after each other. This strategy takes the most variables in mind of the different strategies and should therefore yield the best results if properly implemented. However, this is a complex method and was designed for an automatic storage/retrieval system. It would be very complex to implement this strategy in a warehouse where humans pick the products and determine the order sequence.

4.6 Summary

All these storage strategies have their advantages and disadvantages. The most important factors are how convenient the specific strategy can be implemented and much variables are taken into account. The ABC-principle is for example simple to implement, but does only take one variable into account: the pick-frequency. The DLM takes a lot more variables into account, yet it is also much harder to implement the DLM. Therefore a trade-off must be made between what will provide the best results and yet is possible to implement. In chapter 5, various storage strategies are elaborated. In chapter 5, explanations are given for why certain strategies are elaborated and others not.

CHAPTER 5: SOLUTION DESIGN

In the chapter solution design, different possible solutions to improve the efficiency of the warehouse of Company X are explained. First, the different storage strategies that came forward in the literature study are discussed. For the ABC-principle and the CSM, a strategy that is tailored to the requirements of Company X is proposed. Furthermore, a change in the alignment of the racks is analysed.

5.1 ABC-principle

The ABC-principle is one of the most straightforward ways to allocate products in a warehouse. The ABC-principle is a popular strategy, because it allows more freedom than the COI and is easier to generate than the CSM and the OOS. The information that is needed to create an allocation-design with the ABC-principle is the amount of times each product is picked in a certain (representative) period and the travel distance to each location. After determining which locations are A-locations according to their travel distance and determining which products are A-products according to their pick frequency, the products can be divided over the locations. This same process holds for the B- and C-products.

5.1.1 Data-Analysis Products

From 1-1-2019 till 19-6-2019, 8798 different types of products were picked, divided over 311,099 picks. The 20% of the products that were picked the most were responsible for 87.80% of the picks, the next 30% of the products were responsible for 9,42% of the picks and the last 50% of the products were responsible for 2.78% of the picks. This shows that a small group of products is responsible for a substantial part of the picks. Therefore, a change in storage strategy can have a considerable impact on the average travel distance.

When the PGS products are filtered out, 8717 different types of products were picked from 1-1-2019 till 19-6-2019, divided over 288,395 picks. The list with all products and the amount of types they were picked can be found in excel-file 'ABC-principle'. In this file, one can also find the layout of the warehouse in the situation that the ABC-principle is applied. In this situation, all the products that were picked during the period mentioned above are used in the analysis. The products that were not picked during this period are left out.

Percentage of products	Number of picks	Percentage of picks
First 20%	251,555	87.2%
Next 30%	28,390	9.8%
Last 50%	8,450	2.9%
Total 100%	288,395	100%

Table 5.1: ABC-division by pick frequency

5.1.2 Matching Cube and Space

To determine how many products will be placed on the A, B and C-places respectively, the amount of space available per place needs to be matched to the space needed by each product. The current warehouse has a complex layout where each rack has a different combination of layers and their corresponding heights. However, these layers are not fixed and can easily be changed in position.

To match the cube of SKUs with the available space at possible warehouse locations, three methods can be used:

- Use the exact cube of every SKU and match it with the exact space available at possible locations.

- Reasonably estimate the cube of SKUs and match it with an estimation of the available space at possible locations.
- Estimate the cube and available space for a total class of products and locations and make sure these two (nearly) match. After assigning a class of products to a group of locations, assign products on the spot to locations that match.

The first method is substantially better than the second two options, yet it requires a lot more data. As Company X did not have the required data available to use the first method. This research had to look for other options to effectively match SKUs with locations.

To match the locations and in SKUs based on the cube and space in a reasonable way, both groups can be split up in two groups. The SKUs can be split up in pallet-size SKUs and box-size SKUs. Furthermore, the locations can be split up in pallet-place locations and box-size locations. Where floor locations and locations on the different regular layers are pallet-place locations and where the intermediate layers and the shelf-racks are box-size locations.

The way how the locations are split in different sections can be found in the excel-file 'warehouse information'. In terms of floor-locations, the warehouse contains 699 regular locations and 63 shelf-racks. Yet, above many of the regular floor locations, one or more box-size locations can be found.

As the data about the cube and space is not available at the moment this research is being written, it is not possible to match the cube of SKUs to the spaces in the warehouse exactly. There is enough data to estimate the space available at every location, yet not enough to estimate the cube of different SKUs. Therefore, the third option is the only option left. This option is acceptable in the case of the ABC-principle, as products are not assigned to a specific location with this strategy, but to a certain area. As a result, the person who ultimately distributes the SKUs over the area can assign these to locations that fit in terms of cube and space.

5.1.3 Initial Plan ABC-division Company X

Before the start of this project, Company X had already initiated a plan to introduce the ABC-division in their warehouse. The division of their warehouse looked the following way:

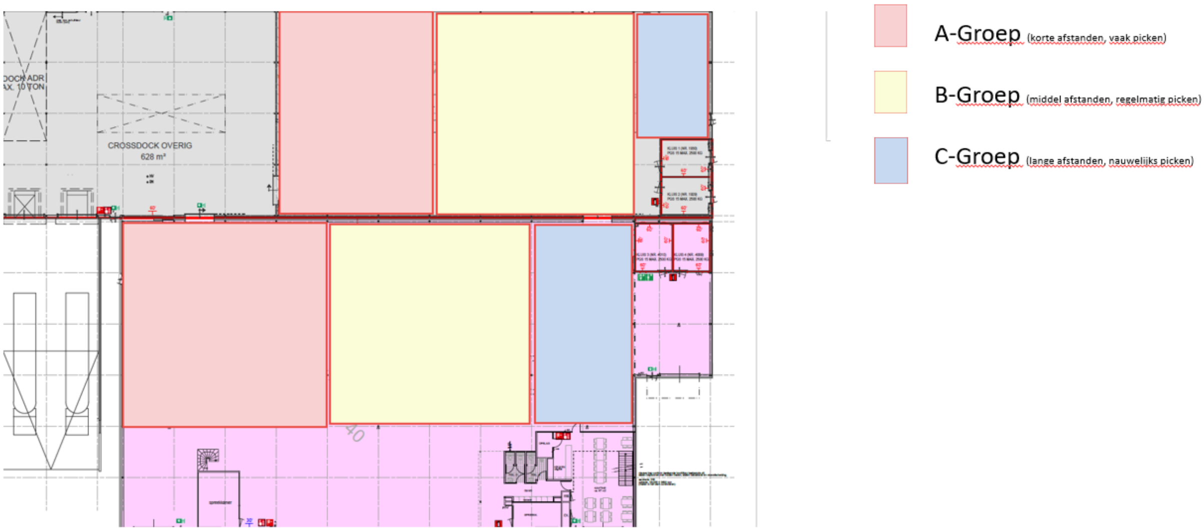


Figure 5.1: Warehouse-design Carel Lurvink with ABC-principle (Source: Carel Lurvink B.V.)

This division takes in mind the fact that Company X's warehouse has two different parts where the products are picked. One thing it does not take in mind is the fact that places in the front of an aisle that is located further away from the I/O-point can be closer to the I/O-point than places at the back of aisle that is located nearer to the I/O-point. That is why ABC-divisions are usually structured as a pyramid. This pyramid-like structure is shown in figure 5.2, where the I/O-point is in the middle at the bottom of the figure.

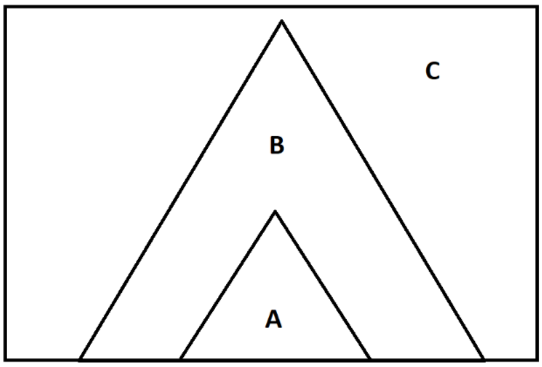


Figure 5.2: Pyramid structure ABC-division

5.1.4 Newly Proposed Layout Based on the ABC-Principle

Furthermore, the division in figure 5.1 does not take specific locations in mind, as well as locations that are specifically assigned for one product category. Therefore, a new ABC-division was created in this research to manage these problems. The locations above the aisles are not taken into considerations, as these locations are not meant for picking. The division we propose is the following:

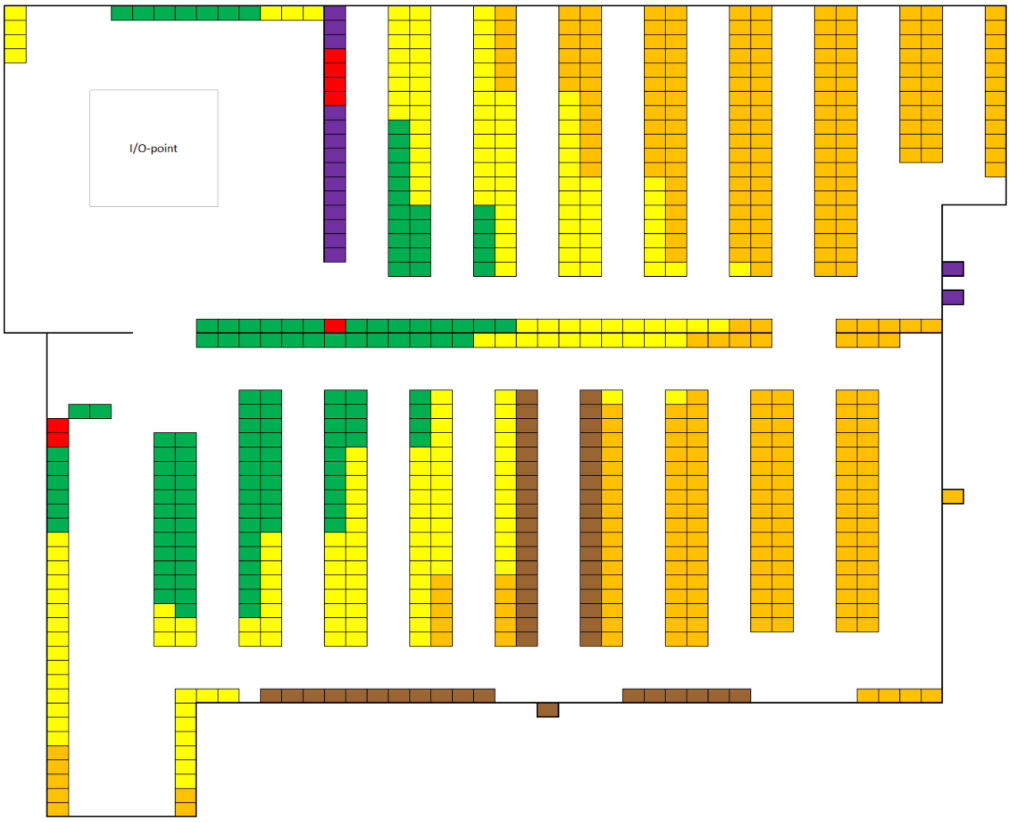


Figure 5.3: ABC-division Company X

The colours of the cells have the following meaning:

Type of location:	Nr.	Description:	Colour in map:
A-locations	135	The first 20% fast-runners	
B-locations	210	The next 30% semi-fast-runners	
C-locations	344	The last 50% slow-runners	
PGS-locations	16	Products on the PGS-list	
W-locations	54	Products to be picked by walking pickers	
Location X	7	These locations cannot be used, because of safety regulations	
Total:	766	All locations	

Table 5.2: Explanation of the ABC-division

With this division, the fact that products that are located at the front of an aisle are located closer to the I/O-point than locations at the end of an aisle is taken into account. Therefore, we can see a 'pyramid' structure in the warehouse. Large parts of the first aisles are used for A-products, while smaller parts of later aisles are also appointed to A-products. This division is based on map where the travel distance to every location is calculated. By dividing the travel distances in three groups based on the ABC-principle, while taking into account the X-, W-, and PGS-locations, figure 5.3 was derived from the figure 5.4:

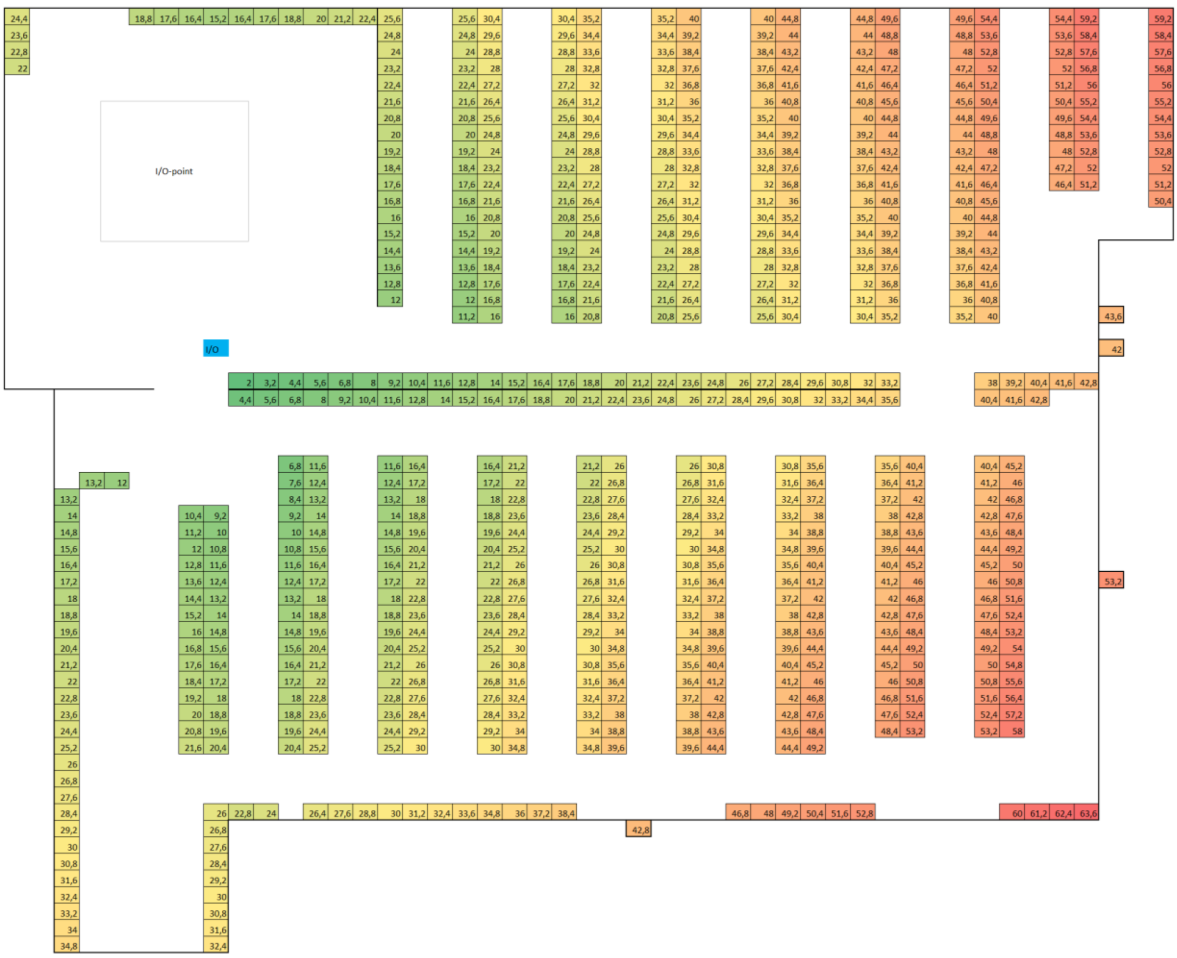


Figure 5.4: Travel distances warehouse Company X

Figure 5.4 is constructed by measuring the distance to every location from the I/O-point (the blue cell). The colours represent visually the distance from the I/O-point, where a short distance is coloured green, an average distance is coloured yellow and a long distance is coloured red. To see how the different distances are determined, see in excel-file 'warehouse information' the sheet 'travel distance calculation'.

5.2 Correlated Storage Method

As described in the literature review, the correlated storage method (CSM) is a heuristic that can be used to effectively allocate products, when the products can be divided in groups with high complementarity. In the case of Company X, this could be an effective method, as the company has several product groups that are almost mutually exclusive and several product groups that are included in many orders, regardless of the type of company that orders the products. As described in section 2.4.1, clients often purchase from one specific compartment and one or more of the general compartments. Using these compartments to split the assortment of Company X in several groups, and clustering these groups in the warehouse, is a logical method. This method could be combined with the correlated storage method, to make sure that the different compartments are certainly correlated adequately to cluster them together and to make a distinction in popularity between the different compartments. The different clusters can then be divided using the COI: the most popular clusters will be located the closest to the I/O-point and the least popular the farthest away, while taking the amount of clusters filled by a certain group taken into account.

5.2.1 Different Product Groups

The following nine clusters can be deduced from the product assortment: cleaning items, painting articles, safety articles, work clothing, cleaning devices, canteen articles, packaging materials, sauna and wellness articles and façade maintenance. These nine clusters can be split up into three groups: client-specific, non-specific products and mixed.

Client-specific	Non-specific	Mixed
Painting articles	Work clothing	Cleaning items
Sauna and wellness articles	Canteen articles	Safety articles
Façade maintenance articles	Packaging material	Cleaning devices

Table 5.3: division of product groups

Currently, the products are divided over these group to different departments, yet this division cannot be found in the database of Company X. Therefore, not all products will be allocated to a specific group in this research. However, acquiring these data is one of the recommendations of this research.

5.2.2 Dividing the Warehouse in Clusters

The warehouse could be split up in approximately 18 clusters, whereof 14 have a similar size. This division is made based on the characteristics of the current structure of the warehouse.

5.2.3 Dividing the Products over the Clusters

The different product-groups would be divided over these clusters. First, it must be determined which products will have a fixed location and which not. Then, for the products that will have a fixed location in the warehouse, different product groups that have a fixed location, or fixed aisle in the warehouse need to be filtered out. These groups are the PGS-products (see main constructs), the W-products (see section 2.4.3) and the vacuum cleaners. Hereafter, the regular products that will have a fixed location in the export-warehouse are left. For every product it needs to be determined in which product group it belongs. These groups are mutually exclusive, which means that no single product can be in multiple product-groups. Hereafter, the total amount of space that each product-group needs has to be calculated. After calculating the amount of space needed for each product group, it needs to be determined how many clusters of the warehouse have to be assigned to each product group. The next step is to divide the products of each product-group to the different clusters based on their COI. The most popular products will fill the first cluster, until this cluster is full, then the next cluster is filled with less popular products and so on. The excel-fil ‘ABC-principle’ can be used to determine which product is allocated to which cluster, as this file contains information about the amount of picks per product during the first half year of 2019. Using the amount of picks per cluster, the clusters can be ranked from the most popular to the least popular cluster (COI-based). The most popular cluster will be located in the aisle that is the closest to the I/O-point, the second popular cluster to the aisle that is the second closest to the I/O-point and so on.

5.2.4 Dividing the Products in a Cluster over the Available Places

In each aisle, the same process takes place, only slightly more complex. For each product, the cube it occupies in a rack is determined. Using this information, the product will be divided in products that need a floor-location or not. If it does not need a floor-location, it can be allocated to an intermediate layer. Picking from these layers is convenient and it takes up less space, leaving more space for other (larger products) or for more intermediate layers with small products. If it appears that products of one cluster only contain a small group of products that need a floor-location, then there will be a significant amount of space be left to allocate to intermediate layers, resulting in substantially more space for other products. This way, more products can be kept in storage with the same amount of space. After the space for each product-group has been calculated and the structure of the rack is determined, the products can be allocated to locations in the aisle. This is again COI-based, meaning that the product with the highest popularity will be located the closest to the I/O-point (at the front of an aisle) and the product with the second highest popularity at the location that is the second closest to the I/O-point. In the clusters, the intermediate layers that are located above a certain floor-location, share the same travel distance. In allocating products to these locations, they are equal. Whether the product will be allocated to the floor-location or the intermediate layer depends solely on its cube. Locations on the first layer (the layer at 1,80m which is above the intermediate layer(s)), do not share this equality in priority when allocating products with the space underneath it. It is less convenient to pick from these locations and therefore these locations will only be used after the floor-locations and the intermediate layers are filled.

5.2.5 Decision Tree

To make the information in the three sections above more clear, a decision tree is given below. Using the ‘pinball machine’-model of Gwynne Richards, different steps and decisions determine for each specific product in which location it will end up. The different steps and decisions and where these decisions lead to are shown in figure 5.5.

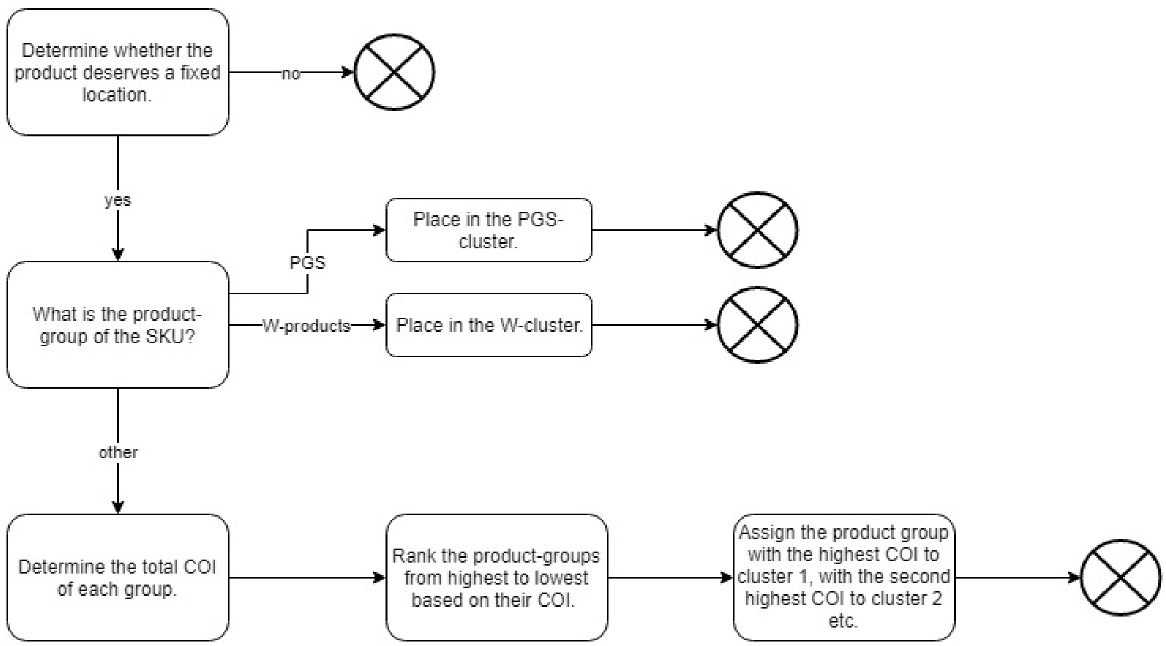


Figure 2: Decision tree cluster determination

The first decision tree stems from section 5.2.3. This figure shows how a certain product is assigned to a certain cluster. The next roadmap stems from section 5.2.4 and shows how a certain SKU is assigned to a certain place in the cluster that it is assigned to (figure 5.6).

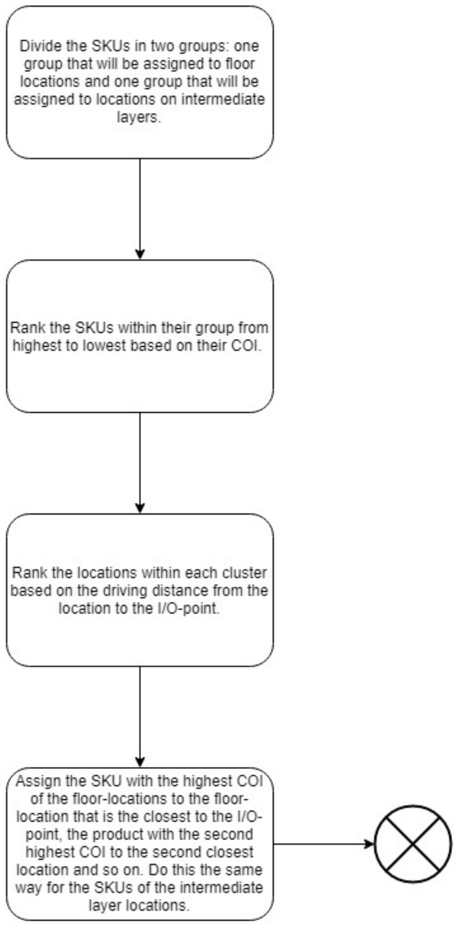


Figure 5.6: Roadmap to allocate SKUs within a cluster

5.3 Alignment of the Racks

One of the ideas to improve the efficiency of Company X's warehouse was to change the direction of the racks. Currently, the racks are placed perpendicular to the direction of travel. A change of direction could change the number of available picking locations and the average distance to a location.

To determine whether this would be a positive change or not, an analysis in excel was made. This analysis revealed that a change of direction would result in a small increase in the average travel distance. The average travel distance with the racks aligned in the longitudinal direction would increase from 31.3022 to 31.3125. The number of floor locations would decrease from 736 to 720. The calculation of these numbers and a schematic overview of the layouts with different alignments of the racks can be found in the excel file 'warehouse information'. In figure 5.7, one can see how a change in direction of the racks influences the travel distances in the warehouse.

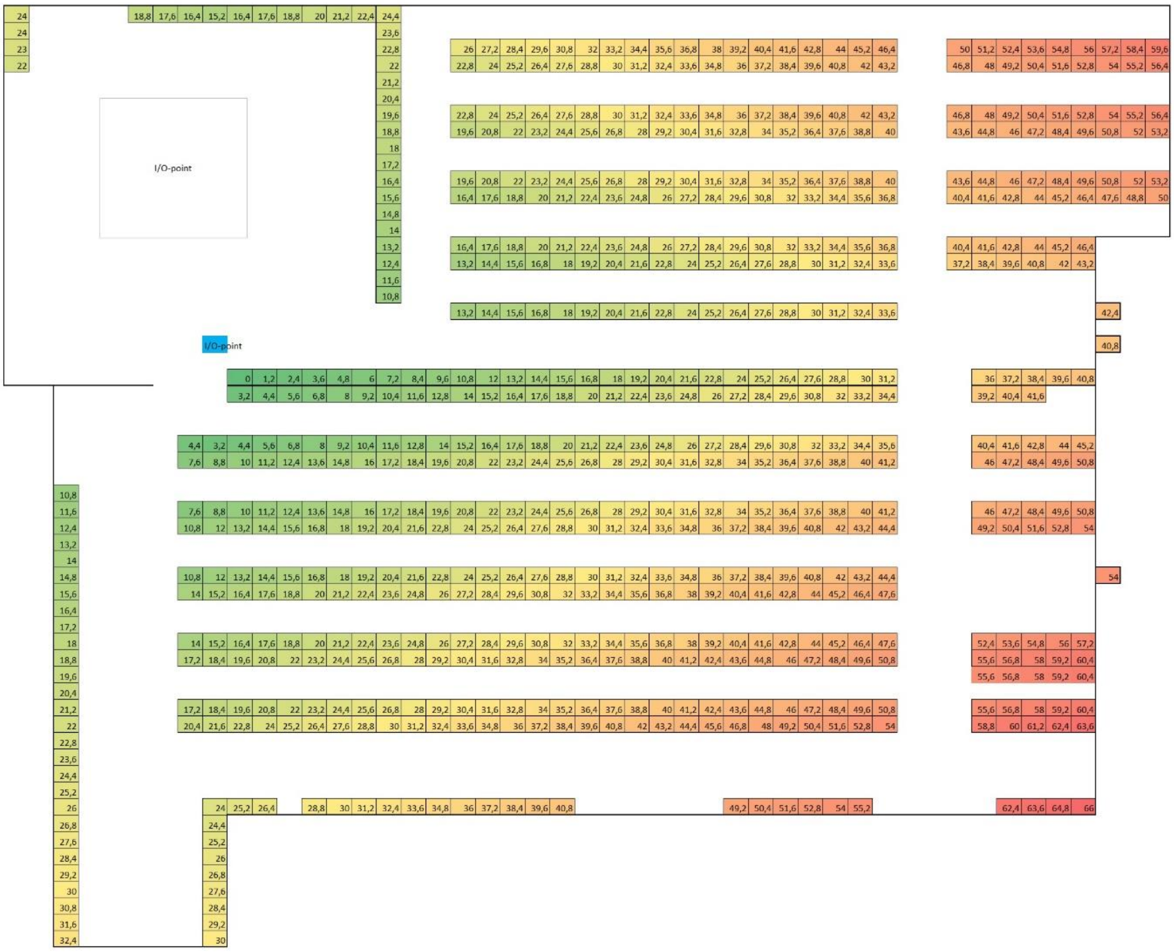


Figure 5.7: Travel distances in the export-warehouse with a change in direction of the racks

5.4 Order Oriented Slotting and Direct Link Method

In chapter 4, several storage strategies were suggested. These storage strategies included the ABC-principle and the Correlated Storage Method that are discussed in the previous sections. Other strategies that were suggested are order oriented slotting (OOS) and the direct link method (DLM). These two strategies are not further analysed for the situation of Company X. The reason for this is the following: storage strategies follow a certain principle. This principle implies that there are on the one hand storage strategies that are not difficult to implement, but take only one or a few variables into account and are therefore far from optimal (yet far more sophisticated than random storage). On the other hand there are storage strategies that take (many) more variables into account, yet are a lot more difficult to implement. The first group, strategies with little variables that are not difficult to implement, contain the ABC-principle and the COI. The second group, strategies with more variables that are difficult to implement, contain the OOS and the DLM. The CSM finds itself more in the middle, as it contains multiple variables and is neither straightforward nor difficult to implement.

The strategies that are extensively analysed are the ABC-principle and the CSM. The ABC-principle can be seen as a version of the COI that allows more freedom for the person who ultimately distributes the products. Why this strategy is favourable over the COI is explained in section 5.1.2. The reasons that the OOS and the DLM are not extensively analysed are the following. First, both strategies are difficult to implement, which results in higher investment costs than with the ABC-principle and the CSM. As the OOS and DLM take more variables into account, the end-results that would be achieved with the implementation of these strategies are very likely to be better than with the ABC-principle, the COI and the CSM. However, a trade-off must be made between investment costs and expected return on investment (ROI). With a larger warehouse, the ROI of implementing a certain storage strategy would be higher, while the investment costs stay approximately the same. That is the reason why larger companies are more likely to implement a storage strategy that requires a higher investment costs, that yield better results. Therefore, the OOS and DLM are more convenient for large warehouses, while the COI, ABC-principle and CSM are more convenient for small-size and medium-size warehouses. As the export-warehouse of Company X finds itself in this second category, the research has chosen to use the ABC-principle and the CSM as bases for possible allocation-designs.

Another reason that the DLM is not used as a base for a proposed allocation-design is the fact that this strategy is designed for automated storage/retrieval systems. The picking-process in Company X's warehouse is manual and therefore not suited for this strategy.

5.5 Short Term and Long Term Strategy

In this chapter, two different solutions were extensively analysed. The first one is the allocation-design based on the ABC-principle and the second one is the allocation-design based on the CSM. The strategies yield different results and need different data as input. Therefore, I propose the following. As the ABC-principle is less difficult to implement than the CSM and requires only the pick-frequencies of products and the distances of locations to the I/O-point, data that is already available, I recommend to implement the strategy based on the ABC-principle on the short term.

The CSM takes more variables into account and would in all probability result in a more efficient layout in terms of minimising the travel distance for order-pickers. However, the cube of all SKUs is needed to effectively allocate the products with this storage strategy. Therefore, I recommend to implement the strategy based on the CSM on the long term, after the crucial data has been collected.

5.6 Summary

In the chapter solution design, several storage strategies are analysed and explained. The ABC-principle and the correlated storage method are used as bases for allocation-designs that are tailored to the situation of Company X. The ABC-principle divides the products in three different classes based on how frequently the products were picked during 2019. Hereafter, the products are distributed over the locations that are assigned to each class (A, B or C). The company keeps the freedom to distribute the products within the class themselves, ensuring that products are assigned to locations where the product fits in terms of cube and space, while keeping in mind complementarity between products and their popularity in terms of pick frequency.

The second strategy that is used as a base for a tailored allocation-design is the correlated storage method. This method divides the products in a number of product-groups and the locations in the warehouse in a number of clusters. The popularity of each group is calculated using the COI, and the most popular product group is assigned to the cluster that is the closest to the I/O-point, the second most popular product group the cluster that is the second closest to the I/O-point and so on. Hereafter, products within a product-group are divided over products that should be placed on the floor and products that should be placed on intermediate layers, or in shelf-racks, based on the cube and weight of the product. Within these groups, products are ranked based on their individual COI and locations are ranked based on the distance of the location to the I/O-point. The most popular product is assigned to the location within the cluster that is the closest to the I/O-point, the second most popular product is assigned to the location in the cluster that is the second closest to the I/O-point and so on. This process continues until all clusters are filled.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

The final chapter of this study focuses on the conclusion and recommendations for Company X. The core of this research is summarized and the most important conclusions are explained. Hereafter, the recommendations that stem from this research are explained. This chapter will end with a discussion that will analyse the main features of this research, including the limitations of this research.

6.1 Conclusions

In this study, we tried to answer the main research question, which is:

What is an efficient allocation of products in the export warehouse and associated routing, so that the average travel distance per order is reduced?

To answer this question, first the current warehousing process of Company X was analysed. In this analysis, the structure of the warehouse and the order-structure were analysed. This analysis should have given the reader a solid apprehension of the warehousing process at Company X. Hereafter, the main bottlenecks were identified and the requirements of the company were formulated.

By means of literature study, several storage strategies were analysed. These storage strategies were evaluated and considered for a possible solution. After evaluating the different storage strategies, two strategies came forward as most convenient for Company X's situation: the ABC-principle and the Correlated Storage Method.

The ABC-principle is convenient to use as this strategy is straightforward and uncomplicated to implement. Furthermore, the principle leaves a lot of freedom to the person that actually allocates the products. Besides, it is very well possible to combine the ABC-principle with other requirements, such as a specific place for the W-products, PGS-products and cross-dock products. Therefore the ABC-principle is a satisfying method to use to allocate products efficiently in a warehouse. In this research, a layout for the export-warehouse of Company X is proposed using the ABC-principle in section 5.2.4. The products that will be located on the A, B or C-locations are listed in the excel-file 'ABC-principle'.

However, the ABC-principle has also several drawbacks. This storage strategy does only take one product-characteristic into account: the pick frequency. The correlation between products is not taken into account just like the cube and weight. Furthermore, while the pick frequency is taken into account, when the products are effectively allocated to one of the locations in their area, the person who allocates the products still has the freedom to place the product anywhere in the predefined area, as it is only recommended to keep the pick frequency into account in allocating the products within a certain area, next to the complementarity and the cube and weight. Therefore, products with a very high pick frequency can be allocated to a place that is farther away than a product with a (still high but) lower pick frequency. Also, it is very well possible that products that are picked together very often are not located closely to one another. Therefore, this storage strategy is advantageous, yet certainly not optimal. However, as it is a certain improvement with respect to the current situation and a strategy that is convenient to implement, the advice is to implement this strategy for the short term. It is the best strategy that can be implemented with the available data.

The second storage strategy that is analysed as a possible solution for Company X is the Correlated Storage Method (CSM). This strategy is explained in section 5.3. The CSM takes more variables into account than the ABC-principle and offers products a specific location. The extra variable that is taken into account is the correlation between products. Different SKUs are often correlated, and it is therefore useful to place these products together. The CSM does so by grouping different products with high correlation and distributing these groups as a whole over one or more clusters in the warehouse. Within these clusters, SKUs are allocated based on their COI (see section 4.3 for an explanation of this product-characteristic) with products with the highest COI up front and with the lowest at the back of an aisle. With this strategy, products with a high pick frequency are located close to the I/O-point near to products they are correlated with.

The CSM is a clear strategy, and implementing it is doable. However, when one wants to implement the strategy, the cube (and to a lesser extent the weight) of different products has to be taken into account. What the role of these characteristics is, is explained more elaborately in section 5.3.3. As these data are currently not available, they need to be collected first, to effectively implement the CSM. How these data can best be collected is explained in section 6.2.1. As the CSM allows less freedom for the person who will effectively allocate the products than the ABC-principle does, while taking more variables that influence the travel distance per order into account, it will result in a more efficient allocation than with the ABC-principle. Furthermore, the allocation-design that would result from implementing the CSM would offer a more structured layout, as products with a high correlation (which are normally similar products) are located near each other.

6.2 Recommendations

After discussing the results from this research and tearing conclusions, several recommendations follow. These recommendations are based on the researchers interpretation of the results. After discussing the results that follow from this research, several suggestions for further research are opted.

6.2.1 Collect Data about the Cube and Weight

The data about the cube and weight of all products is very important to allocate products properly in a warehouse. The data about the weight of different products that have or will have a fixed location needs to be known, to make sure that legal restrictions about the weight load of racks are met. The data about the cube is necessary to make sure that products actually fit into the place they are assigned to. Furthermore, these product-characteristics influence the sequence in which an order is picked. This sequence influences on its turn the storage strategy. Therefore, it is important to collect the data and use it to efficiently allocate the different SKUs.

It is straightforward how the data about the weight should be collected and saved. Only the mass of the SKU matters in this situation. How the data about the cube should be collected and saved however is not as straightforward. I recommend that the data about the cube is not simply collected in cubic meters, but in the three different dimensions. This is important, because the cube in cubic meters could for example be small enough to fit the product in a shelf-rack, yet if one of the dimensions is significantly larger than the others, it could still not fit in such a space. This is for example the case with brooms. Brooms have a small cube in terms of cubic meters, yet they have a complicated shape that ensures that brooms do not fit on the most regular locations. If products are stocked per piece, the dimensions of the product have to be collected. Nonetheless, most products are stocked in loads. For products for which that is the situation, the dimensions of the load need to be taken into account.

After collecting the appropriate dimensions, I recommend to split the SKUs in two groups (as explained in section 5.3.3). One group of SKUs with larger dimensions, and one with smaller dimensions. Hereafter, the dimensions of the SKUs should be expressed in terms of location size. For example, some SKUs only take up the space of a fourth of one location. In this case the location size dimension of the product is 1/4th. Expressing the dimensions in location-size will make it more convenient to distribute the products over the available locations.

6.2.2 Implement the CSM after the Data about Cube and Weight is Collected

The second recommendation that is made is that this research proposes to implement the CSM when the data about the cube and weight of SKUs is collected. As it is explained in sections 5.5 and 6.1, the CSM generally offers a better solution than the ABC-principle does, as it decreases the degree of human influence and it takes more variables into account. Therefore, a preference of the CSM over the ABC-principle comes forward in this recommendation. However, the data about the cube and weight is a requisite to implement the CSM in the proposed way. Therefore, these data need to be collected first, which results in the recommendation of section 6.2.1.

As it takes time to collect the data about the cube and weight, the next recommendation is to implement the ABC-principle on the short term. The reason why this strategy is preferred on the short term is clearly explained in section 5.5.

6.2.3 Change in the Direction of the Location Numbers in the Aisles

The routing of the current situation is based on the locations of the products. It does not keep cube and weight in order. Furthermore, it does not cope with the fact that not all racks have a logical number. It is a tolerable routing algorithm, yet it is not optimal. A simple solution to improve the algorithm would be to reverse the order of numbering the locations per rack (so that the lowest location in number is closest to the I/O-point) and to renumber racks 38, 39, 40 and 41. The numbers of each rack can be found in excel-file ‘warehouse information’ sheet ‘base + info’.

In addition, it would be advantageous for Company X to include the cube of products in the routing algorithm. Currently, order-pickers determine the sequence themselves, where they keep the cubes of different products in mind. Naturally, it would be favourable to automate this, by letting an algorithm determine the sequence of picking, taking into account the locations of products as well as the cube and weight. This would be a suggestion for further research. One way to improve the current routing by taking into account the weight would for example be to select products that weigh more than 8 kilograms first, as these products with a high weight need to be placed at the bottom.

6.3 Suggestions for Further Research

Every research is limited to a certain amount of time and is therefore not able to cover all aspects of a certain subject. Frequently, interesting subjects for further research came across, of which several are discussed in the following sections.

6.3.1 Investigate which Products should have a Fixed Location

The first suggestion for further research is to investigate which products in the assortment of Company X should have a fixed location in the warehouse. This decision depends on several variables. The first and most obvious one is the pick frequency of the product. Furthermore, the turnover that a certain product provides and the cube of the product also influence the decision whether to provide the product with a fixed location or not. If a product has a high turnover and a small cube, then it is more convenient to place the product in the warehouse than when the opposite is true, independent of the pick frequency. Furthermore, the customer’s desires also influence whether a product should have a fixed location or not. For example, a certain product could occasionally be ordered by a specific customer, but it does have a high priority for that customer. The customer would then like to receive the product very quickly. Company X can respond to this by having the product continuously in stock. Also, the delivery time of a product influences the decision whether a product should have a fixed location or not. It is more important to have products with a long delivery time already in stock than products with a short delivery time.

6.3.2 The influence of the Cube and Weight on the Pick Sequence

Another suggestion for further research is to investigate the influence of the cube and weight on the pick sequence. From this research it appeared that these factors certainly have an influence. Therefore, they influence the storage strategy as well. Products that need to be picked first, should be located at the start of a run through the warehouse in order to maintain a short travel distance. If it appeared that the cube and weight have a strong impact on the sequence, than the cube and weight should certainly be taken into account when the products are allocated.

6.3.3 Investigate the Possibility of a Change in Direction of the Racks

A third suggestion for further research is to investigate the possibility of a change in direction of the racks in the warehouse. From this research it appeared that a change in direction of the racks, from perpendicular to the outer walls to parallel, would have a positive impact on the amount of available locations and on the average travel distance. However, the impact would be small and therefore not worth the investment. Nevertheless, this is only an assumption and therefore we suggest to investigate the possibility, to draw a final conclusion about this option. If the investment costs are lower than expected, it could be a profitable investment.

6.4 Validity and Reliability

Reliability is part of the validity of research. Reliability in research means that repeated measurements produce identical results (Heerkens, 2015). The reliability in this research is high for the quantitative research. The data in the WMS is fixed and does not allow different interpretations.. For the literature study, the reliability is slightly lower, as other researchers could interpret sources differently, or could select different sources based on the same criteria (as some of the criteria are slightly subjective). As the interview is semi-open, the answers are open for interpretation. Because different researchers could interpret the answers differently, the results from this research could vary moderately.

Interval validity in research means that the measurements are actual measurements of what is intended to measure (Heerkens, 2015). This research mostly aims on discovering practical existing knowledge, relations between variables and information about the products of Company X. When the average travel distance for a sample of order is measured, it is important to understand the sequence in which the different products are picked. Otherwise, a total different distance is measured than the driver has truly travelled. To ensure that the internal validity is guaranteed, data from the WMS is retrieved that shows the sequence in which the different products are picked. This way, the truly travelled distance is measured.

The construct validity aims on a proper operationalisation of the variables. In this research, the efficiency of the order-picking process is expressed by the main KPI: the average travel distance per order. This indicator gives a good representation of the efficiency of the order-picking process. A threat to construct validity is one-dimensional operationalisation.

The external validity determines whether the research holds outside the scope of the research. As this research is specifically aimed at Company X’s warehouse, the results will not hold for other companies. However, the problem-solving approach used in this project should hold for other situations where products have to be allocated in an efficient way in a warehouse of similar size.

6.5 Limitations

As mentioned in the 'Validity and Reliability' part, this research is aimed at solving a problem for Company X, therefore this research does not provide a generally applicable solution. As the data about the cube and weight of products was not available, this research was limited to designing a storage strategy, without absolutely allocating specific products to specific locations. Also the routing could not be analysed thoroughly, as the cube and weight of products both influence the sequence in which products are picked. This fact became clear by participating in research.

6.6 Summary

At the end of this research, one can conclude that several storage strategies can improve the efficiency of the warehousing process of Company X. The strategies proposed in this research for the short term and long term are based respectively on the ABC-principle and the Correlated Storage Method. To effectively allocate the products in the warehouse, data about the cube and weight of different products is necessary. Furthermore, researching which products should have a fixed location in the warehouse and which should not, could provide a more balanced and logical set of products in the warehouse, with products that are picked regularly or are important in an other way. At the end the validity and the limitations of this research are discussed. There are not many threats to the validity of this research, as the threats are limited in several ways. In terms of limitations, the research is limited by the fact that important data was not available.

SOURCES

BusinessDictionary. (n.d.). What is order picking? definition and meaning. Retrieved April 29, 2019, from http://www.businessdictionary.com/definition/order-picking.html

BusinessDictionary. (n.d.-b). Definition Stock Keeping Unit. Retrieved May 2, 2019, from http://www.businessdictionary.com/definition/stock-keeping-unit-SKU.html

Cambridge Dictionary. (n.d.). ALGORITHM | meaning in the Cambridge English Dictionary. Retrieved April 29, 2019, from https://dictionary.cambridge.org/dictionary/english/algorithm

Cambridge Dictionary. (n.d.-b). COMPLEMENTARY PRODUCTS | meaning in the Cambridge English Dictionary. Retrieved April 30, 2019, from https://dictionary.cambridge.org/dictionary/english/complementary-products

Caron, F., Marchet, G., & Perego, A. (1998). Routing policies and COI-based storage policies in picker-to-part systems. *International Journal of Production Research*, 36(3), 713-732. doi:10.1080/002075498193651

De Ruijter, H. (2007). *Improved storage in a book warehouse*. Retrieved from https://essay.utwente.nl/58067/1/scriptie_H_de_Ruijter.pdf

Drury, C.G. (1988), Towards more efficient order picking, IMM Monograph No. 1, The institute of Materials Management, Cranfield, U.K.

Esmeijer, G. (2012, November 5). Wat is de optimale lay-out in een magazijn? Retrieved April 30, 2019, from https://privacy.vakmedianet.nl/logistiek/?ref=https://www.logistiek.nl/warehousing/blog/2012/11/wat-is-de-optimale-lay-out-in-een-magazijn-101129460

Frazelle, E.H., Sharp, G.P. (1989), "Correlated assignment strategy can improve order picking operation", *Industrial Engineering*, Vol. 4, pp. 33-37

Heerkens, J. M. G. (2015). Microlectures – Validity Retrieved from https://vimeo.com/album/2938606?page=1

Hwang, H., Oh, Y. H., & Lee, Y. K. (2004). An evaluation of routing policies for order-picking operations in low-level picker-to-part system. *International Journal of Production Research*, 42(18), 3873-3889. doi:10.1080/00207540410001696339

KNAW; NFU; NWO; TO2-federatie; Vereniging Hogescholen; VSNU (2018): *Nederlandse gedragscode wetenschappelijke integriteit*. DANS. https://doi.org/10.17026/dans-2cj-nvwu

Le-Duc, T., & De Koster, R. B. M. (2005). Travel distance estimation and storage zone optimization in a 2-block class-based storage strategy warehouse. *International Journal of Production Research, 43*(17), 3561-3581. doi:10.1080/00207540500142894

Mantel, R. J., Schuur, P. C., & Heragu, S. S. (2007). Order oriented slotting: a new assignment strategy for warehouses. *European J. of Industrial Engineering*, 1(3), 301. doi:10.1504/ejie.2007.014689

Oxford Dictionaries. (n.d.). warehouse | Definition of warehouse in English by Oxford Dictionaries. Retrieved April 29, 2019, from https://en.oxforddictionaries.com/definition/warehouse

Schuur, P. C. (2015). The worst-case performance of the Cube per Order Index slotting strategy is infinitely bad – A technical note. *International Journal of Production Economics*, *170*, 801-804. https://doi.org/10.1016/j.ijpe.2015.05.027

The definition of allocate. (n.d.). Retrieved April 29, 2019, from https://www.dictionary.com/browse/allocate

Van de Poel, I., & Royakkers, L. (2011). *Ethics, Technology, and Engineering: An Introduction*. Chichester, Engeland: Wiley.

van Oudheusden, D. L., Tzen, Y. -. J., & Ko, H. -. (1988). Improving storage and order picking in a person-on-board as/r system: A case study. *Engineering Costs and Production Economics*, 13(4), 273-283. doi:10.1016/0167-188X(88)90013-4

Warehousing Definition - What is Warehousing. (n.d.). Retrieved April 29, 2019, from https://www.shopify.com/encyclopedia/warehousing

Appendix

A1 Interview with Internal supervisor

1. When a truck with goods arrives, how is it determined which product goes to the bulk warehouse and which product goes to the export warehouse?
   A: *Regular products will be moved to the export warehouse (around 90% of the products). Products with a long delivery time are ordered in large quantities. These products are moved to the bulk warehouse.*
2. Are there any fixed locations in the bulk warehouse for different products?
   A: There are no fixed locations for different products in the bulk warehouse.
3. How does a replenisher indicate where he placed an SKU?
   A: The replenisher scans the EAN-code of the location where he placed the SKU. (Every location has its own EAN-code)
4. Is it possible to find the picking time per order and order of picking products in one order in historical data?
   A: Maikel (ICT) should be able to provide more information about this.
5. Is there a product list with all products that are standard available in the warehouse?
   A: Yes, can be derived from Navision
6. If a new product is added to the existing product range and this product is received for the first time, who decides where it will be placed and how is that determined?
   A: The logistics department decides where the product will be placed. They determine the place where the product will be placed on type of the product.
7. How did the current allocation-design arise?
   A: The export warehouse first was a store where customers could come and pick products themselves. Therefore, products from the same product type where placed together, so that customers could find the products they needed easily. When the style of use of the warehouse changed, the product allocation remained the same. Occasionally, the location of a product was changed.
8. Different companies are served on different days. Is there a list with the information which company is served on which day?
   A: Björn (the teamleader) has such a list.
9. Do companies without a fixed delivery day receive their products within 24 hours if they order these products before a certain time of day?
   A: Yes, they receive the products they order within 24 hours if they order them before 4 p.m.
10. Which products are picked by walking pickers?
    A: There is a list of products that are picked by the service counter employees.
11. One part of the shipments leaves from the IJzersteden and one part from the Marssteden, how is it determined which order leaves from which side?
    A: Orders that are meant for the company Kleentec contain primarily PGS-goods and are therefore shipped from the IJzersteden. Other orders that contain solely PGS-goods (or for a substantial portion) are also shipped from the IJzersteden. All the other orders are shipped from the Marssteden.
12. How are the different orders assigned to different pickers?
    A: The orders that will be shipped from the IJzersteden (and thus contain many PGS-goods) are assigned to one picker, so that he can stay on the side with the PGS-warehouse and the

second I/O-point. The other orders are assigned one by one to the rest of the pickers based on priority. The priority is normally based on a FCFS system. However, in special situations, an order can receive a higher priority.

13. What does the fleet of trucks look like?
A: Company X owns three reach trucks and seven stackers. From these trucks, on average two reach trucks and six stackers are used at the same time. At the receiving side, two reach trucks and two stackers are used.

A2 Systematic Literature Review

In this systematic literature review, one knowledge problem of this research is solved by means of a literature study. The difference between this systematic literature review and a normal literature study is, that all steps of searching and selecting the literature are denoted and explained. This way, the search for literature can be repeated to find the same results. This research is executed the following way.

1. Research question and key theoretical concepts
2. Scope: requirements and plan
3. Execution of the Searching process
4. Literature review: applying criteria and conceptual matrix
5. Theoretical perspective

A2.1 Research Question

The research question that is reviewed in this systematic literature review is a knowledge problem that is central in this research. This knowledge problem is earlier mentioned in the chapters 'Sub-questions' and 'Knowledge Problems'. The research question is the following:

Which heuristics and quantitative methods are suggested in literature about allocating products in a high throughput warehouse in an efficient way?

The key theoretical concepts in this situation are the following: Warehousing, optimization, heuristics, manual order-picking, ABC-principle, the cube per order index (COI), order oriented slotting (OOS), correlated storage methods (CSM) the Direct Link Method (DLM) and storage policy.

A2.2 Scope: Requirements and Plan

For this research, sources are needed that focus on optimizing a warehouse from a similar size as Company X's warehouse. It is necessary that the sources focus on minimising the average picking time per order, or the average distance covered per order. Furthermore, it is necessary that the sources focus on a physical warehouse and preferably with humans picking the products. To find the sources, the databases Scopus and Web of Science are used. If these databases do not provide enough sources, then Google Scholar will be used as well.

These requirements provide the following criteria:

Number	Inclusion criterion	Reason for inclusion
1	Optimisation algorithm used in similar situation	The most important goal is to find sources that show an example of how an algorithm should be constructed in a similar situation, so sources with such an algorithm are included.
2	Articles with information about the ABC-principle	As Company X first wanted to implement the ABC-principle, it is important to include articles that offer information about this principle.

Table A.1: Inclusion Criteria

Number	Exclusion criterion	Reason for exclusion
1	Articles that are not written in English or Dutch	The articles must be in a language that the researcher fully understands.
2	Articles that focus on warehouse-design instead of allocating products	As the warehouse itself already exists in this research, articles that focus fully on the design of a warehouse will be excluded
3	Articles that are not accessible	Articles that are not accessible cannot be used in this research. In this research it is not possible to pay for articles.
4	Articles without citations	To be sure that the articles used are relevant, articles without any citations will be excluded from this research.
5	Articles that focus on a high utilization grade	A high utilization grade is not the goal of this research, while it is an indicator of an efficient and effective warehouse. Articles that focus on utilization will be excluded from this research.

Table A.2: Exclusion criteria

A2.3 Execution of the Searching Process

In the following table, the search strings and the number of results per search string is shown. These results are then filtered using the inclusion and exclusion criteria.

As warehousing is the central overlapping subject in this research, this term is used in all searches. These searches are then completed with a term that is relevant for this particular research. After

Search string	Scopus	Web of Science
“warehousing” AND “abc”	24	18
“storage policy” AND “manual pick*”	30	1

Table A.3: search strings

After filtering the duplicates out and applying the inclusion and exclusion criteria, a small number of articles remained. Several relevant articles that were cited in these articles were added. Together they form the following list:

A2.4 Literature List

Abbasi, M. (2011). Storage, Warehousing, and Inventory Management. *Logistics Operations and Management*, 181–197. doi:10.1016/b978-0-12-385202-1.00010-4

Caron, F., Marchet, G., & Perego, A. (1998). Routing policies and COI-based storage policies in picker-to-part systems. *International Journal of Production Research*, 36(3), 713-732. doi:10.1080/002075498193651
Frazelle, E.H., Sharp, G.P. (1989), "Correlated assignment strategy can improve order picking operation", *Industrial Engineering*, Vol. 4, pp. 33-37
Hwang, H., Oh, Y. H., & Lee, Y. K. (2004). An evaluation of routing policies for order-picking operations in low-level picker-to-part system. *International Journal of Production Research*, 42(18), 3873-3889. doi:10.1080/00207540410001696339
Le-Duc, T., & De Koster, R. B. M. (2005). Travel distance estimation and storage zone optimization in a 2-block class-based storage strategy warehouse. *International Journal of Production Research, 43*(17), 3561-3581. doi:10.1080/00207540500142894
Mantel, R. J., Schuur, P. C., & Heragu, S. S. (2007). Order oriented slotting: a new assignment strategy for warehouses. *European J. of Industrial Engineering*, 1(3), 301. doi:10.1504/ejie.2007.014689
Van Oudheusden, D. L., Tzen, Y. -. J., & Ko, H. -. (1988). Improving storage and order picking in a person-on-board as/r system: A case study. *Engineering Costs and Production Economics*, 13(4), 273-283. doi:10.1016/0167-188X(88)90013-4

A2.5 Conceptual Matrix

	ABC-principle	COI	OOS	CSM	DLM	Routing Policies
Abbasi, M.	X	X				
Caron, F., Marchet, G., & Perego, A		X				X
Frazelle, E.H., Sharp, G. P.				X		X
Hwang, H., Oh, Y. H., & Lee, Y. K.		X				X
Le-Duc, T., & De Koster, R. B. M.	X	X				X
Mantel, R. J., Schuur, P. C., & Heragu, S. S.		X	X			X
Van Oudheusden, D. L., Tzen, Y. -. J, & Ko, H. -.					X	X

Table A.4: Concept Matrix