IMPROVING THE WAREHOUSE LOGISTICS AT GAM BAKKER

Beeldman, S.J. (Sander, Student M-IEM)
Master Production and Logistics management

Title Improving the internal warehouse logistics at Gam Bakker

Author	Sander Beeldman
Education	Industrial Engineering and Management
Specialization	Production and Logistics Management
Company name	Bolk Logistics B.V.
Company address	Zuidelijke Havenweg 2 7554 RR Hengelo
Company Supervisors	Hein Langeveld Niek Tijink
University Supervisor	Dr. M.C. van der Heijden (1st supervisor) Dr. P.C. Schuur (2nd supervisor)

Date	27 September 2022

Preface

In front of you lies the research that has been conducted as the master thesis for the study Industrial Engineering and Management at the University of Twente. I have conducted this thesis at Bolk Logistics in Hengelo to improve the warehouse performance of Gam Bakker, situated in Westzaan.

First of all, I would like to thank my company supervisors Hein and Niek for giving me this opportunity and always being available for questions. Their commitment and knowledge have helped me a lot during my research and I am grateful for that. Second, I want to thank all employees at Gam Bakker, who have made the current situation clear and were open to discussions about the future situation. A special thanks to Cas, Bas and Bjarne as they have helped me a lot writing my report.

Secondly, I would like to thank my supervisors at the university, Matthieu van der Heijden and Peter Schuur, for their guidance during my thesis. Their feedback was very helpful and increased the level of the project a lot.

Lastly, I want to thank my family, my roommates and Dorte for their support during the thesis.

Management summary

Company description

Gam Bakker started as a transport company located in Westzaan and has started warehousing activities with a warehouse called Hoogtij 1. In September 2021, Gam Bakker opened Hoogtij 2, a second warehouse in Westzaan. This warehouse is dedicated to Company X, which stores its semi-finished products in 4 of the 5 halls and its end-product, powder, in the other hall. This research is focused on the warehouse performance of the halls that contain the semi-finished products, with a main focus on the storage and picking policies.

Problem statement

Gam Bakker uses shuttle racks in Hoogtij 2, which offer a high pallet density but limit the possibilities for storage and picking policies. As Gam Bakker is unexperienced with this type of rack, the current warehousing process contain multiple inefficiencies, which are explained below. The research goal is therefore:

Improve the storage and retrieval methods used by Gam Bakker, to decrease the waste and increase the throughput of the warehouse.

Gam Bakker has agreed with Company X that the minimum occupation of the warehouse will be around 78% within a year, which is twice the current occupation. An increase in occupation will lead to longer material handling times. This cannot be dealt with under the current storage and picking policies, due to inefficient usage of the workforce. Using a problem cluster, two core problems that limit the material handling times are identified:

- There is no well thought of storage policy
- The pick method is only based on the length of stay of the products

Current situation

The current storage policy has no data driven logic and pallets are stored at the nearest available rack within the lay-out limitations. This policy leads to the fact that there is no logic in allocating fast- and slow movers. Furthermore, racks often contain more than one lot number, which leads to inefficiencies as pallets often are ordered per lot number. The picking policy does not take the storage sequence of pallets into account, which means that pallets

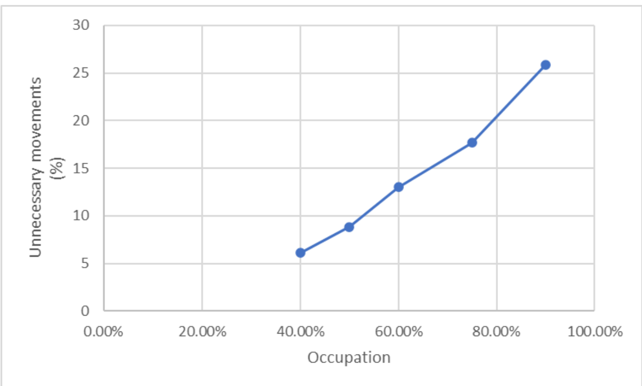

Figure 0-1 Unnecessary movements vs occupation

need to be rearranged before the ordered pallet can be picked. These policies lead to the following points of interest:

- On average 12.2% more movements are carried out than necessary
- As Gam Bakker lacks insight, the products with the most movements are unwillingly stored at the higher levels

The current occupation is approximately 40%, in case the occupation reaches the agreed levels (75%) the number of unnecessary movements increases even more (Figure 0-1).

Storage and picking policies

As there is little literature about the operational decisions that suit shuttle racks best, the storage and picking policies have to be created based on practical rules from literature. Various storage and picking policies have been created based on the current warehouse or process characteristics. These policies have been evaluated, with a simulation and expert opinion, based on:

- Warehouse efficiency
- Flexibility
- Up-to-date output
- Implementability

The combination of the storage policy based on lot number and picking based on sequence of pallets scores best of the initial policies. The percentage of unnecessary movements, at an occupation of 75%, decreased from 17.67% to 13.17% and the time to complete one outbound order decreased from 46 minutes to approximately 38 minutes. Although this policy is an improvement, sensitivity analyses result in an even better warehouse performance.

In case Gam Bakker performs the pallet selection of butter on quality instead of lot number, the percentage of unnecessary movements decreases to 6.00%. The average time to complete one outbound order decreases to approximately 20 minutes. A policy with knowledge about which containers will arrive, which pallets will depart and butter storage based on quality leads to 2.09% unnecessary movements. However, this policy is hard to implement due to Gam Bakker being dependent on third parties and therefore, does not suit Gam Bakker at this moment. The policy with the best results is a policy where we use all previous mentioned aspects and policies, combined with using no lay-out limitations, all products can be placed on all levels. As this policy demands a change in the lay-out of the newly built warehouse, this policy cannot be implemented in the coming years.

Conclusion and recommendation

To return to the research goal, various aspects have been found that can be adjusted to decrease the waste and increase the throughput of the warehouse:

- A storage policy based on lot number
- A picking policy that takes the storage sequence of pallets into account
- Pallet selection of butter based on quality

The first two aspects can be implemented immediately by Gam Bakker. The storage policy is based on lot number and this can be decided by the warehouse supervisor. A tool that gives storage suggestions is being developed and will be tested with the stakeholders. The picking policy will be implemented in a SQL-tool that suggests which pallets fulfil the orders best. This tool is currently being developed and should fulfil all requirements mentioned in this research.

The pallet selection of butter based on quality will take more time to be implemented. In case Gam Bakker wants to implement this process, a project group should be created that makes sure the new process fits both companies well.

Last, in case all other recommendations have been carried out successfully, Gam Bakker should focus on other possible improvements. This identified that using more information about inbound and outbound pallets can lead to a better performance. Changing the lay-out of the warehouse can have the same effect. Therefore, Gam Bakker should research these possibilities even more and try to implement these aspects if it is possible.

Contents

Table of figures

Table of tables

Glossary

Term	Definition	Introduced in Section
D&D (Demurrage and detention)	The time, in days, containers spend longer on the terminal than agreed with the shipping company. A fee per day has to be paid to the shipping company in case of D&D.	1.2.1
FIFO	An asset-management method in which assets produced or acquired first are used first	2.1.2
Kibbled	Chunks of cocoa butter, result of cacao blocks that are broken into pieces	1.2.2
LIFO	An asset-management method in which assets produced or acquired last are used first	2.1.2
Mass	Mass is the first liquid stage of processing cocoa beans. If processed (pressed) further it will turn into cake, while butter is a side-product of this process.	1.2.2
Shuttle rack	"A rack in which pallets are moved by a robotic shuttle, a kind of sled which runs on tracks just underneath the beams that the pallets sit on."	1.2
SKU	A distinct type of item tracked in inventory	1.2

1. Introduction

In this introduction chapter of the master thesis a company description of both Bolk and Gam Bakker is given, to explain the relationship between the companies and their role in the research. Thereafter, the research motivation as well as the problem statement and research goal is discussed. The scope is explained, to narrow the possibilities for the research questions that will guide this research. Last, the approach that is used during this research is explained to give an insight in data and sources used.

1.1 Company description

Bolk is a warehousing company in the broadest sense of the word, as it focuses on more than only the warehousing perspective. The company started in 1934 with the establishment of the Looms & Bolk company, which provided the transport for the drinks and coal trades. Bolk started the transhipment of shipping containers by train from Rotterdam to Almelo in 1985, at the invitation of NS goederenvervoer. One year later, a new site was built which provided space for planning, administration, a company house, and a storage. 10 years later a site on the Plesmanweg was bought, providing Bolk with more office space, storage, and warehouse facilities. After NS decided to stop the transport of container trains, Bolk was forced to operate the connection between Rotterdam and Almelo itself, which lead to the founding of Combi Terminal Twente. This company took care of the transport of sea containers by inland waterway, first from Emmerich and since 2001 from Hengelo.

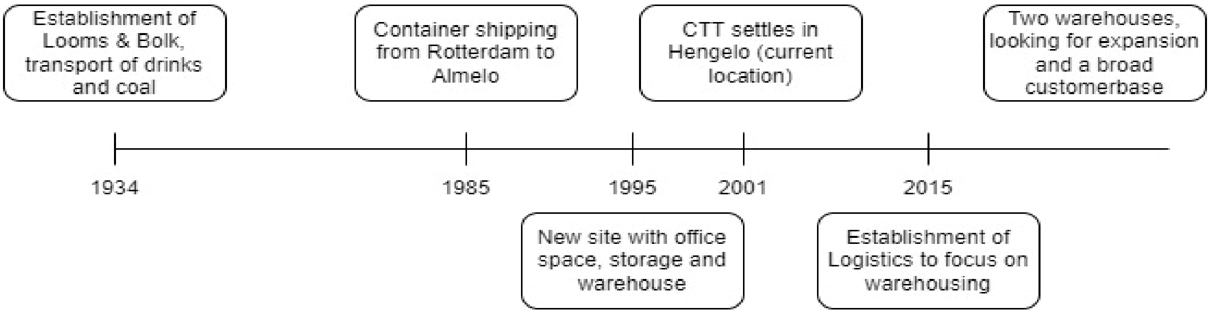

Figure 1-1 Timeline Bolk Logistics

In 2015 Bolk Logistics was established, with the purpose of focusing more on the warehousing activities. Bolk Logistics is situated in Hengelo, where the sea containers are handled by Combi Terminal Twente. The company has warehouses in Hengelo and Almelo at the moment but is looking at expansion possibilities. These warehouses are strategically located, which offers a fast and reliable connection to the European hinterland. An overview of these events can be seen in Figure 1-1.

Gam Bakker

Gam Bakker was founded in 1935 in Hoogkarspel, in which it started its transport activities for the agricultural sector. The main area of expertise is the cooled transport of products, such as seeds, flowers, nuts, and fruit. Gam Bakker mostly operates from and between the United Kingdom, Ireland, Germany, France, Belgium, and the Netherlands. Besides the transport department, Gam Bakker has bonded warehouses on two separate locations. A bonded warehouse offers the possibility for customers to import products without being obliged to pay import duties. Recently they have built a second warehouse, next to the existing one that is situated in Westzaan. This second warehouse is mainly used by one customer (Company X), that will use about 80% of the total warehouse capacity. The location in Westzaan is situated next to the terminal of CTVrede, that handles most of the containers that enter Hoogtij 1 and Hoogtij 2 (the warehouses in Westzaan).

Connection Bolk and Gam Bakker

The partnership between Bolk and Gam Bakker dates from the moment Gam Bakker investigated the possibility to build the third warehouse (Hoogtij 2). Due to several reasons Gam Bakker ran into problems to fulfil all the requirements for this warehouse. As Bolk had already encountered and solved these kinds of problems, Bolk's expertise was used to fulfil all the requirements. Since the start of this co-operation, employees of Bolk visit Gam Bakker on regular basis to assist Gam Bakker and improve their warehouse logistics.

1.2 Research motivation

Gam Bakker has built a new warehouse in Westzaan (Hoogtij 2), which is mainly used for the storage of semi-finished products of Company X. This new warehouse offers new space for approximately 25.000 pallets, which means that the storage capacity is 8.5 times bigger compared to the situation with one warehouse. The main part of the warehouse consists of shuttle racks, which best enhances the installation's productivity as the product density is maximized. As depicted in Figure 1-2, pallets can be stored and retrieved from only one side of the racks, which means that there is a Last-In-First-Out method. If two different SKUs are stored in one rack, the first SKU has to be removed if the second SKU has to be retrieved from the rack. This warehouse has been delivered in November 2021, after which the warehouse logistics started. In the current situation there is no pre-defined storage policy, as the warehouse manager chooses the storage location of the product on the spot. Due to this inconsistent storage method, products are not stored as efficient as possible. The most occurring types of waste are unnecessary transport movements and transport distances, which occur when a pallet has to be picked from the racks to free up space to pick order pallets. According to previous conducted research (Deen, 2021), once every three orders other pallets have to be removed before the demanded pallet can be picked. As the warehouse size has increased, these unnecessary picks lead to an absolute increase of waste. This in combination with the tight labour market, results in the fact that the current situation might not be futureproof. Gam Bakker wants to make sure that that all current and future workload can be handled while the costs are kept to a minimum.

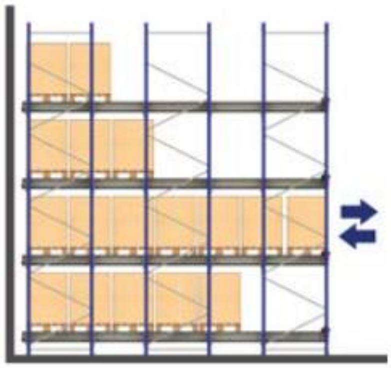

Figure 1-2 Shuttle rack (Verhoeven, 2018)

1.2.1 Logistical process Gam Bakker

The products are produced by Company X in Ivory coast, Ghana, Indonesia, and Brazil. The products are stored in containers, whereafter they are shipped to Amsterdam or Antwerp. The containers are unloaded and transported to CTVrede, the terminal situated across Gam Bakker. The containers are allowed to remain at the terminal for a maximum of 14 days, after which the container has to be returned empty to the terminal. In the case that a container does not return within the required 14 days, the company, either Gam Bakker or Company X, has to pay a fee to CTVrede. This fee is called demurrage and detention (D&D), which puts pressure at the logistic organisation of Gam Bakker as this fee has to be prevented. The containers are either transported to Gam Bakker or directly to the factory of Company X itself. Gam Bakker is responsible for retrieving the containers from the terminal, unloading the pallets into the warehouse, and returning the containers to the terminal. The pallets are kept in the warehouse until Company X notifies Gam Bakker which pallets are needed, whereafter Gam Bakker is responsible for retrieving the pallets and transporting the pallets inside a container to the factory of Company X which is approximately ten kilometres away. Gam Bakker is also responsible for the logistics at the docks of Company X, where they manage the loading and unloading of containers. This logistic procedure can be seen in Figure 1-3, where all the logistics outside the warehouse occur in containers and inside the warehouse occurs in pallets.

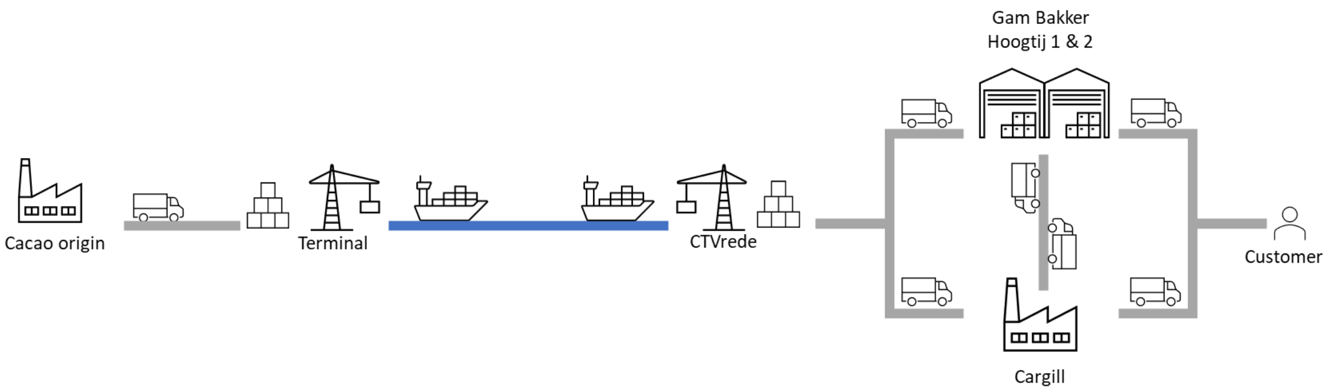

Figure 1-3 Logistics overview of supply chain Gam Bakker

1.2.2 Hoogtij 2

Hoogtij 2 is the newly built warehouse in Westzaan, which is located next to the existing warehouse, Hoogtij 1. As mentioned earlier, this warehouse is used for 80 percent for the storage of semi-finished products (butter, cake, kibbled, and mass) and the other 20 percent is used for the storage of end product. The cake (semi-finished product) has different kind of qualities of which four gradients are known by Gam Bakker. These qualities are defined as red, orange, green and grey, where grey means that rework is necessary. Green is the highest quality and suits on most machines, orange is medium quality, while red is the worst quality and can only be produced on a few machines. The throughput times of the qualities differ, as Company X mixes the different qualities to get the desired products.

The part of the warehouse that is used for the storage of cake, mass, kibbled, and butter consists of shuttle racks. Those product groups consist of a total of 17 different active SKUs present during this research, of which some SKUs have different qualities and therefore the total number of different products is slightly higher.

1.3 Problem statement

As explained earlier in the research motivation, the main problems that are encountered by Gam Bakker are the transport movements and distances that could be avoided by using an efficient storage policy. The experienced problems and their probable causes can be seen in Figure 1-4. The reason behind the relationships and the problems are explained beneath the figure.

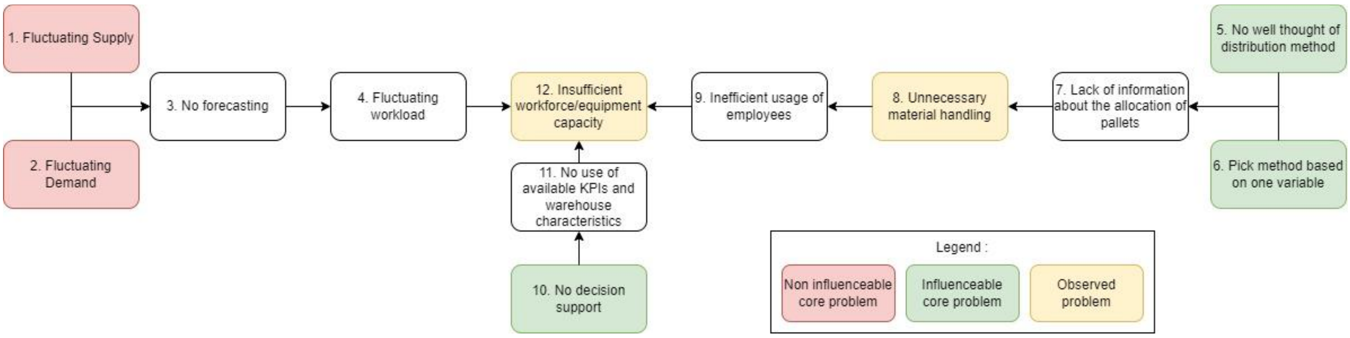

Figure 1-4 Problem cluster

In logistics and supply chain the profit margin is small, which means that the most important method of generating more profit is a reduction of workforce or at least let your workforce work as efficient as possible. As depicted in Figure 1-4, this symptom is experienced by Gam Bakker in the form of a lack of capacity (12), which is caused by various problems. For some procedures special equipment is necessary, which results in a constraint when the workload is not smoothed, under normal circumstances the current workload can be dealt with using the current available equipment.

Extra personnel is hired to cope with the fluctuating workload (4), as there are seasonal effects in the throughput of the whole warehouse. The workload is highly fluctuating, this in combination with the lack of control over this workload leads to high peaks and deep lows in demanded workforce capacity. This highly fluctuating workload is caused by the fact that the demand (2), as well as the supply (1), is fluctuating, while Gam Bakker does not make use of forecasts of the demand and supply to plan their workforce. Gam Bakker only knows how many containers are on the terminal and not how many containers are on ship, which means they can only see the supply for the coming 14 days. This leads to high peaks in workforce, as there is no smoothing in workload from Gam Bakkers side.

On the other side, there is the inefficient usage of personnel (9), caused by material handling that is not always necessary (8). For example, pallets first have to be removed from a pallet rack before the desired pallet can be retrieved, as different SKUs are placed in one rack. Which is caused by the fact that the storage and retrieval is not done by an algorithm or computerized model but by the head of the warehouse when the products are already at the docks. There is no well thought of distribution method (5), while the retrieval method is only based on the age of SKUs (oldest first) and does not consider other relevant variables (6) (throughput, location and picking time). There is no decision support for storing the pallets and therefore the pallets are placed according to the experience of the head of the warehouse. During an informal discussion with the head of the warehouse, it became clear that the pallets are stored at the nearest free rack that is available. There is no information about the pallets (7) and if this information would be available, there is not enough time for the warehouse manager to use this information for storing the pallets.

Lastly, the reasoning behind storage and retrieval might be logical, but as it is impossible to incorporate all relevant variables when scheduling without the use of available data and tools (11), pallets have to be picked multiple times before they leave the warehouse. Variables that could be used for storing and retrieving the pallets, are for example throughput time, expected demand, seasonal effects on the throughput time and transportation time between the racks and the docks. The reason behind this, is the lack of decision support (10) from the Warehouse Management System, as this is only used as a method to register the flow and placement of pallets/products. All data that is needed to calculate relevant KPIs is present, but as no calculations are done this data is not available and therefore the Warehouse Management System (WMS) cannot function as decision support.

Figure 1-4 shows five potential core problems. The supply (1) and demand (2) side cannot be influenced, as these are both influenced by third parties, and are therefore discarded as core problems. Furthermore, the lack of decision support of the Warehouse Management (8) has less potential compared with implementing a well thought of storage and retrieval policy, as this problem can be dealt with during the improvement of the policies. Therefore problems 4 and 5 are chosen as the core problems. The focus of this research is about these two remaining problems:

1. No well thought of storage policy
2. Pick method based on only the age of the product

The storage policy entails the lack of usage of information about the pallets, for example throughput time per SKU and desired quantities per order. The retrieval policy lacks usage of basic warehousing principles as minimal traveling time and batching of convenient SKUs.

1.4 Statement of research goal

The intention of this research is to produce a solution for the problems encountered by Gam Bakker. Therefore the research goal is:

Improve the storage and retrieval methods used by Gam Bakker, to decrease the waste and increase the throughput of the warehouse.

To improve the storage and logistics methods used by Gam Bakker, a storage and retrieval method is used as the basis for a new tool. To make sure this tool runs as good as possible, a proper indication of the inbound and outbound logistics is required. The inbound logistics can be determined based on information given by parties earlier in the supply chain, which makes this tool a visualization of already known variables. The outbound logistics can be changed by using the outbound orders placed by Company X as input for the tool. By using this data in a different way, the tool can adapt to the orders to improve the warehouse efficiency.

1.5 Scope

The problems that are identified commonly occur inside the warehouse; therefore the choice has been made to look mainly at the internal warehouse logistics. Hall 2A is not part of this research, as this hall offers less possibilities for improvement than the other halls. This hall is solely used for the product group powder, which means that this product group are not part of this research. As the rest of the warehouse (2B, 2C, 2D and 2E) is being used for only four distinct kinds of products (disregarding quality-gradients), there is not a further selection on product groups.

The inbound logistics is fluctuating and has a substantial impact on the rest of the process. Therefore, the estimate of the supply is inside the scope of this research, this can be done with already existing data. The demand of the goods is uncontrollable as the goods are demanded by third parties that have irregular demand of their own products. Therefore, the outbound logistics is inside of the scope as this influences the way of structuring the products inside the warehouse. This is done by forecasting the demand and making the supply more understandable.

Gam Bakker aimed to have the highest pallet density per cubic space, which is the reason they have chosen for shuttle racks. An explanation of shuttle racks can be found in section 2.1.2 but the type of rack cannot be changed and is therefore not part of this research. The storage method is part of the research, where there is freedom to change this if it benefits the warehouse operation. The material handling equipment used by Gam Bakker is not part of this research either as the equipment is already chosen and in place.

The storage and retrieval methods are the core of this research to make sure the lack of capacity is tackled. At the distribution side, a solution should be created to decide what the best location is for every pallet. On the retrieval side, a pick method is used to calculate or decide which pallets can be best picked when an order arrives at Gam Bakker. If these two methods function as can be expected, a rescheduling policy once per period should not be necessary, but this opinion can change during the research.

Lastly, the planning of workforce is outside of the scope, as this only is a consequence of the research and not a main focus. By solving other aspects that are inside of the scope Gam Bakker is able to adapt their workforce to these variables.

1.6 Research questions

The goal of this research is to close the gap between the current situation, where the current working method does not adapt to the warehouse circumstances, and the future situation where the working method minimizes the waste in the warehouse and maximizes the throughput. The research question that is answered during this research is therefore:

"How to improve the storage and picking policy, to decrease waste and increase the throughput of the warehouse?"

To achieve the research goal, a structured approach has been used to make sure all the relevant aspects of this case are explored and tackled. Therefore, the following research questions have been used, to come to a structured solution.

1. What is the current situation at Gam Bakker?
   1) What is the current global process flow?
   2) Which KPIs are used and which KPIs are relevant for evaluating warehouse logistics?
   3) What is the current process flow regarding the inbound logistics?
   4) What is the current process flow regarding the outbound logistics?
   5) What is the current demand and supply pattern?
   6) What are the current programs used by Gam Bakker?

2. What is stated in literature that applies to the current and future situation of Gam Bakker?
   1) Which warehouse characteristics apply to Hoogtij 2?
   2) Which retrieval and storage methods/algorithms are suitable for Gam Bakker?
   3) Which forecasting techniques apply to Gam Bakker?
   4) How to evaluate possible solutions?
   5) How to compare the different solutions?

3. How can we improve the warehouse logistics of Gam Bakker?
   1) Which policies can improve the warehouse logistics?
   2) What is the performance of the different policies?
   3) Which policy suits Gam Bakker best?

4. How to implement the proposed solutions at Gam Bakker?
   1) Which steps should be taken to implement the proposed solution?
   2) What will be potential complications?
   3) How can the potential complications be solved?

1.7 Approach

In chapter 2, the current situation of the warehouse logistics at Gam Bakker is analysed. This is be done by collecting and interpreting data that is already available (Warehouse Management System), observing the current processes and briefly interviewing the involved employees (planners, warehouse managers, working foreman and the IT-department). Supply and demand patterns can be explained more by information gathered directly from Company X as they are the owner of the products and therefore have an own vision on this demand and supply. The brief interviews that are conducted are done in cooperation with the employees at Gam Bakker that are responsible for the internal logistics. In this case specifically: the planners, the warehouse managers, the head of the warehouse and the IT-department.

The literature about the logistics, warehousing and forecasting aspects of Gam Bakker are discussed in chapter 3 of this report. This literature is chosen to close the gap between the current situation and the desired future situation.

Chapter 4 discusses ways to evaluate proposed solution and on which criteria a solution should be judged. Furthermore, the policies to be evaluated are created. These proposed policies are based on literature and own research.

In chapter 5 the evaluation of the performance of the policies with a method that suits this problem best are discussed. The evaluation method is chosen based on the findings in literature. The results of the evaluation are used to conclude which solution fits Gam Bakker best.

As the best solution has been chosen in chapter 5, chapter 6 discusses the implementation steps. Possible burdens for implementation, which have been identified during the research, are mentioned and ways to tackle these burdens are explained.

Last, chapter 7 consists of conclusions and recommendations for Gam Bakker about their warehouse logistics. This entails an answer to the research question as well as recommendations to further develop these logistics.

2. Current situation

In this chapter the current situation at Gam Bakker is discussed, which answers the research question: "What is the current situation at Gam Bakker?". First the current situation regarding the warehouse and its KPIs is explained. Thereafter, an analysis on the inbound and outbound logistics is conducted, to give a better insight in the day-to-day activities. In the last part, the demand and supply pattern as well as the programs currently used by Gam Bakker are discussed.

2.1 What is the current global process flow?

2.1.1 Process flow

The finished products are transported from Company X to their (end-)customers and only the finished-products that are transported to America are stored at Gam Bakker. The semi-finished products arrive in containers at Gam Bakker, where they are unloaded at the docks. The pallets are stored in the warehouse until Company X demands the pallets after which the pallets are picked, loaded into a container, and transported to Company X. As mentioned earlier, Gam Bakker is responsible for the internal logistics at their own warehouses after the products have arrived in Westzaan. The storage and retrieval of the pallets is therefore the main operation of Gam Bakker, of which the process flow is explained.

The containers arrive at the docks of Gam Bakker where the pallets are unloaded and placed on the docks, after which the pallets are stored in the racks. The location where the pallets are stored is decided by the working supervisor, who is responsible for the movements inside the warehouse. The pallets are retrieved from the racks upon order from Company X, after which they are placed into a container. This container is moved by truck to the factory of Company X. The lay-out of Hoogtij 2 can be found in Figure 2-1,where hall 2A is on the left and hall 2E is on the right. 2A is dedicated to the storage of powder and is therefore not be part of this research.

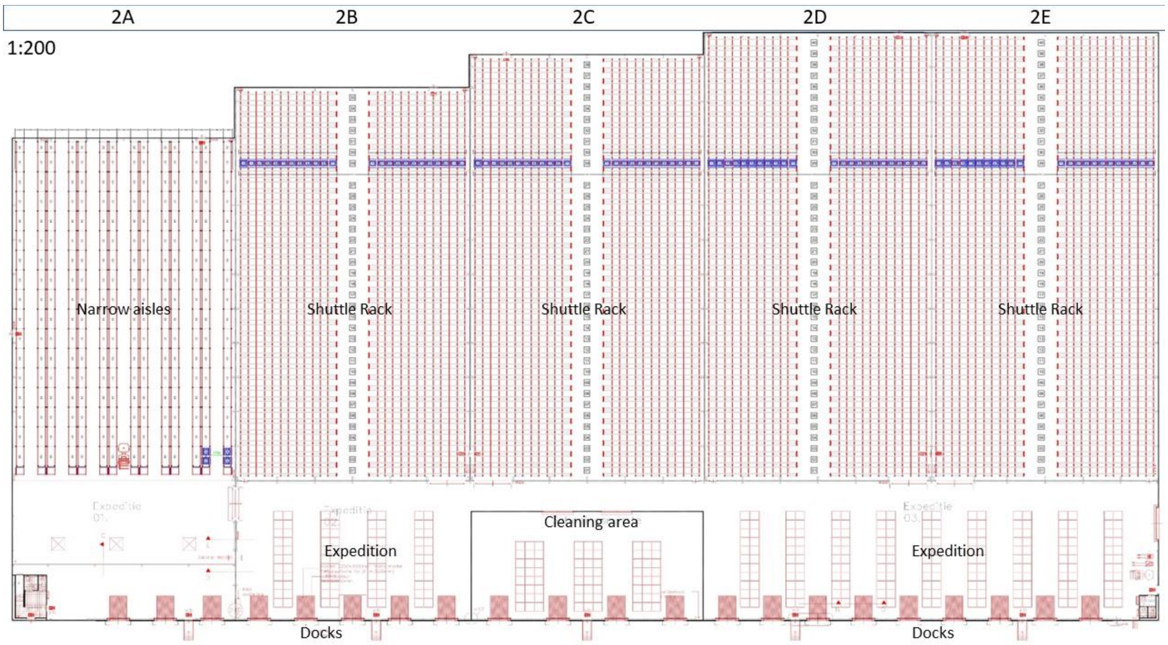

Figure 2-1 Lay-out Hoogtij 2

2.1.2 Racks at Hoogtij 2

Gam Bakker makes use of shuttle racks which enables high density product storage. Pallets are placed on a shuttle in the rack, which is able to transport them through the rack. This means that instead of one access point for every pallet, 11 or 12 pallets can be put away from one access point. This means that, looking at Figure 2-2, a product enters at number 1 and can be transported up to number 7. A major benefit of this system is that the number of aisles necessary to access the racks is decreased in comparison with a rack where every pallet place has its own access point. As there is only one access point, the retrieval policy is a LIFO-policy, as the last pallet stored is easiest accessible. This is a big limitation for the storage and retrieval policies as most policies are designed for a FIFO-policy.

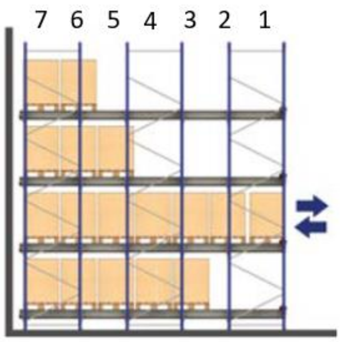

Figure 2-2 Shuttle Rack with location number

Figure 2-3 Example of a shuttle

An example of the shuttle that transports the pallets through the rack can be found in Figure 2-3. The shuttle lifts a pallet after which it can be transported through the rack. Gam Bakker currently has 3 of these shuttles, which means that if they need to move pallets through a rack, they have to transport a shuttle to the desired rack. Looking at Figure 2-4, the shuttle is present in rack A at the front of the rack. In case a pallet needs to be stored or picked in rack B, the shuttle has to be moved to this rack. The shuttle has to be picked from rack A and needs to be placed at “Entry” in rack B. This means that in case an order has to be picked from multiple racks, the shuttle has to be moved multiple times.

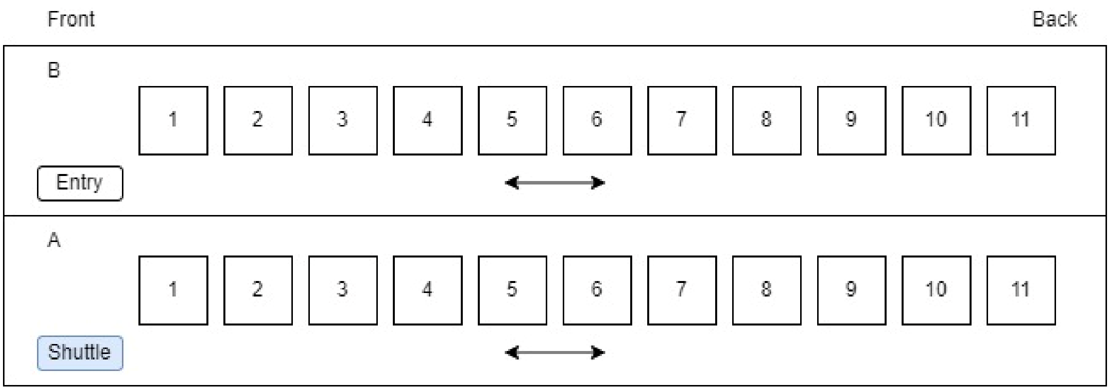

Figure 2-4 Example of a shuttle rack

2.2 Which KPIs are used and which KPIs are relevant for evaluating warehouse logistics?

2.2.1 KPIs relevant for evaluation

At the moment, KPIs are not being used for the warehouse logistics. The occupation rates of the warehouse are being monitored but not actively shared with the planners or warehouse managers. The evaluating of the occupation of specific halls is done by observation or calculated after such an observation has been carried out. As this KPI is not shared, it is not possible to constantly base the storage procedures on the occupation levels of the different halls.

To evaluate the performance of the warehouse logistics different KPIs can be used, these are listed below.

Inbound:

- number of pallets per rack and per height
- number of pallet movements
- number of different lot numbers per height (see section 2.2.2 below for a description of lot numbers)

Outbound:

- number of movements with regard to number of pallets
- number of orders that are picked
- number of pallets per order
- number of different lot numbers per order

The outbound pallet flow inside the warehouse would also be a relevant KPI to analyse. Unfortunately, there is no data available about these movements as all docks are in the system under the name “2 dock”. According to the planners at the warehouse, they only use pallets from the halls that are closest to the docks. Only in some cases pallets are used from the furthest hall, but this cannot be confirmed by data.

2.2.2 Lot numbers

Company X as well as Gam Bakker makes use of lot numbers to describe the products that are on the pallets. As these lot numbers are relevant for most of the processes and these numbers can be confusing, the numbers and their usage is explained. Company X gives lot numbers to their pallets throughout the whole operation. A lot number is not specific per container or day, but it is based on the production batch. This means that the same lot number can arrive on different days, but two different SKUs (even qualities) always have different lot numbers. Mostly, one lot number is the same for 100 to 200 pallets, these lot numbers are mentioned as lot numbers.

The lot numbers used by Gam Bakker are based on the external lot number and on moment of arrival, these lot numbers are called internal lot numbers. This lot number is used to describe the pallets when they are inside the warehouse. An outbound order is linked to the internal lot number, after which the employee picks a X number of pallets of internal lot number XXXXX. It is possible that one external lot number has multiple different internal lot numbers, as an external lot number can arrive on multiple days. The number of pallets per internal lot number varies between 16 and 26, as it mostly based on the size of the container. It is important to mention that Gam Bakker does know both lot numbers, while Company X only knows the external lot numbers. In the case that Gam Bakker is able to work with the external lot numbers instead of using their own lot numbers, the day of arrival is not relevant anymore as it is only used to determine the internal lot number.

2.3 What is the current process flow regarding the inbound logistics?

2.3.1 Storage method

The current storage method has no data driven logic behind the storage of the pallets. There is little to no data available about a container that arrives at the docks, until it actually arrives at the docks. The pallets are then stored based on the current lay-out (Table 2-1) where every product group has its own level. The working foreman has made a division based on restrictions of the racks (height and strength) as well as the indications given by Company X about the characteristics of the SKUs. Only kibbled pallets have a height of 2.3 meter and are thus the only pallets that cannot be placed on every level. These are the only restrictions, which means that the pallets are stored based on the first available rack within these limitations. This model can therefore be classified as a semi-random storage policy. Where the pallets are placed at the first available free rack in the warehouse, starting at the front of the warehouse (Figure 2-5, where the process starts with a container arriving at the docks). In case multiple racks fulfil all requirements, the rack closest to the docks is selected. All racks at level 1 are assumed to be closer than all racks at level 2 etc., this might differ in reality but it is used for planning purposes.

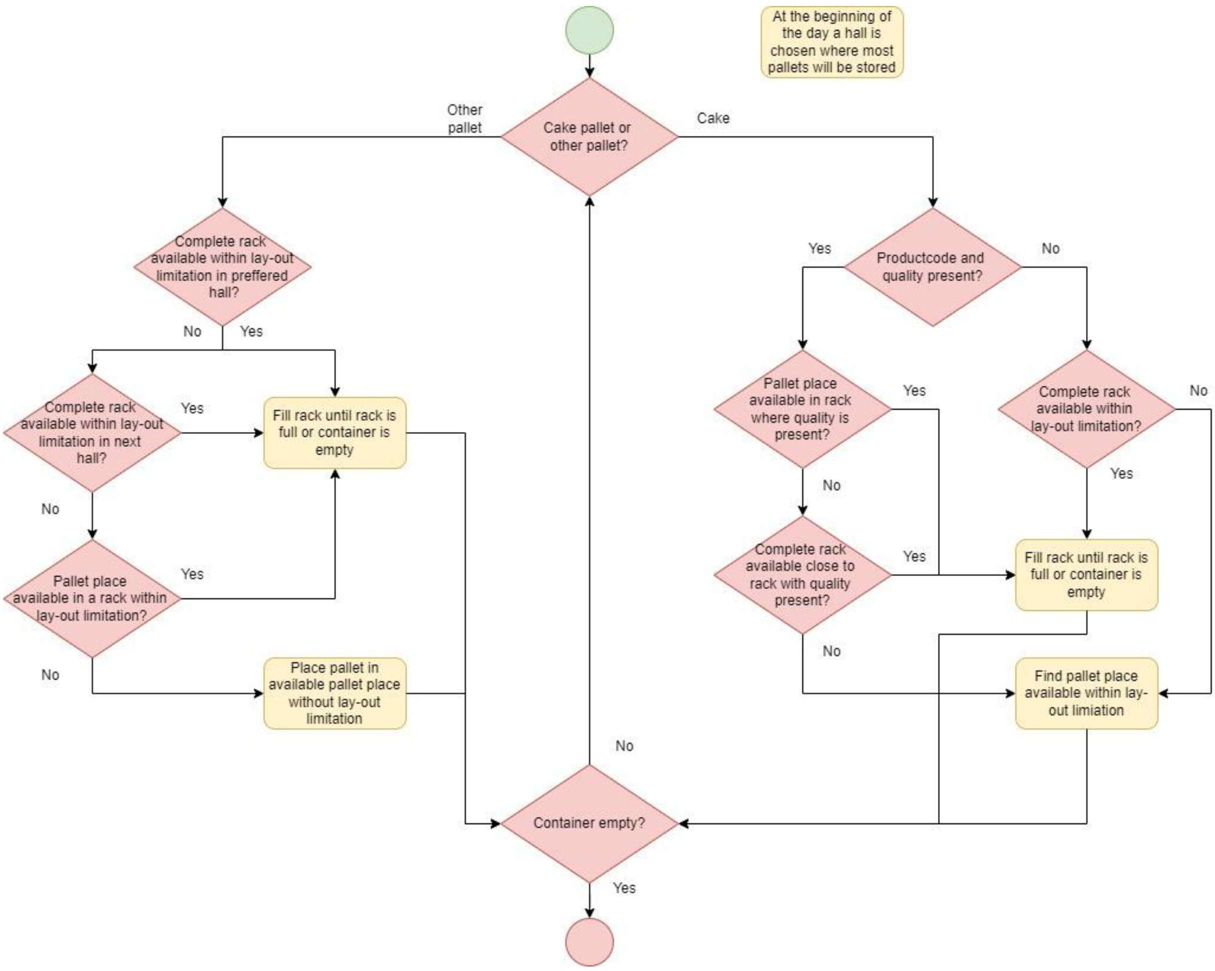

Figure 2-5 Current storage policy

Cake pallets can be stored based on their quality and therefore these pallets are clustered based with pallets from the same quality. For example, all cake pallets of quality green are placed in the front of the hall to make sure that different qualities stay separated.

Table 2-1 Lay-out of the warehouse

Level	Product Group	Height of level (m)
8	Butter	1.68
7	Butter	1.7
6	Kibbled	2.3
5	Kibbled	2.3
4	Cake	1.7
3	Mass	1.7
2	Butter/Mass	1.5
1	Butter	1.5

A pallet truck transports the pallets from the dock to the racks, after which a combi truck stores the pallets at the correct height. As Gam Bakker makes use of shuttle racks, the sequence of storing the products is relevant for the outbound logistics as well. In case a pallet is stored last it has to leave the rack first before the other pallets can be picked, this is called a Last-In-First-Out (LIFO) policy. The picking time per pallet for one trip only, so the storage or the retrieval are found in Figure 2-6, these times are used during the rest of this analysis.

Level	Rack								
	1	5	10	15	20	25	30	35	40
8	98.1	105.2	112.3	119.4	126.5	133.5	140.6	147.7	154.8
7	86.3	93.4	100.5	107.6	114.7	121.7	128.8	135.9	143.0
6	56.3	63.4	70.5	77.6	84.7	91.7	98.8	105.9	113.0
5	46.4	53.5	60.6	67.7	74.8	81.8	88.9	96.0	103.1
4	40.0	47.1	54.2	61.3	68.4	75.4	82.5	89.6	96.7
3	29.5	36.6	43.7	50.8	57.9	64.9	72.0	79.1	86.2
2	26.5	33.6	40.7	47.8	54.9	61.9	69.0	76.1	83.2
1	21.5	28.6	35.7	42.8	49.9	56.9	64.0	71.1	78.2

Figure 2-6 Picking times per rack and level in seconds

2.3.2 Analysis of inbound logistics

2.3.2.1 Usage of racks

First, an analysis has been conducted looking at the number of picks per rack in Hoogtij 2. Every time a pallet is stored at a rack is counted and the results can be found in Figure 2-7, where the green spots are less used and the dark red spots are the hotspots of the warehouse.

Most pallet movements occur in hall 2D, reason for this is the fact that the distance between the docks and this hall are smallest. This overview partly substantiates the statement of the working supervisor, that the nearest available rack is used once a pallet arrives at the docks. The hall with the most pallet movements is the one with the shortest distance, while this principle does not apply inside the hall. Most pallet movements occur in the middle of the hall instead of in the front. Reason for this is that the reach truck that places the pallets into the racks is standing in the middle of the hall, to create enough space for the pallet trucks to place the pallets in the aisle. When the reach truck would be at the front of the hall the pallets cannot be placed behind the reach truck, which means there would be not enough space to transport the pallets to the racks.

As Gam Bakker is only able to make the selection of pallets used for the cake orders, the cake pallets are the only pallets that are placed based on the location of pallets with the same quality instead of the nearest rack available.

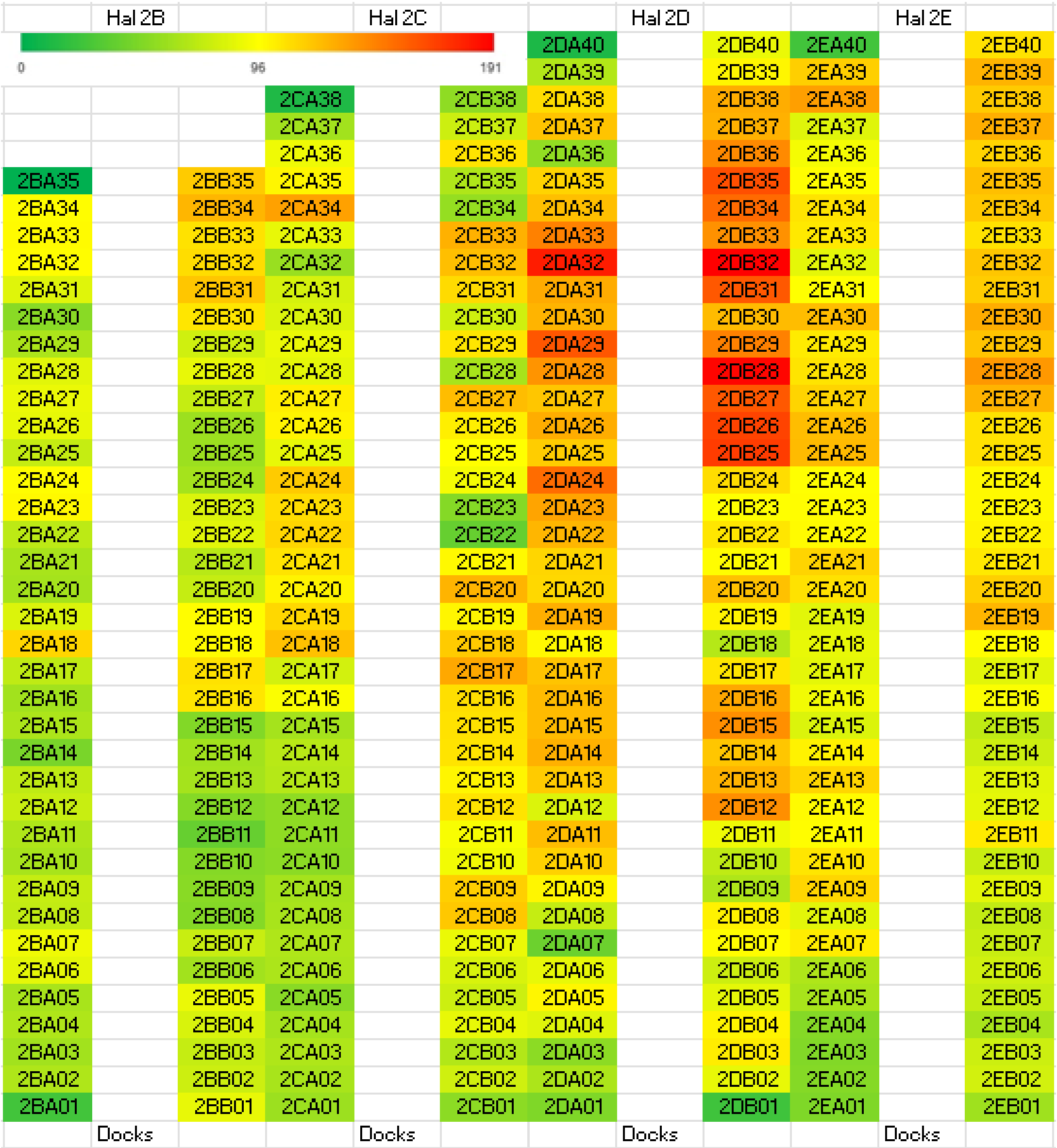

Figure 2-7 Number of pallet movements in past 6 months per rack

Second, the usage of the racks with regards to the height is analysed as well, these results can be seen in Figure 2-8. Again, a green spot is less used while a dark red spot represents the most used height.

Racks at height 7 and 8 are almost never used, which can be explained by the fact that the warehouse has an occupation of 50%. Therefore, the highest most difficult levels to reach are not used until the occupation reaches levels that it is necessary to use these levels to increase the capacity. A second thing that stands out is the fact that row five is used more than row four, where you would assume that the lower row is always used more than the upper rows. Reason for this is the chosen lay-out in combination with the fact that there are more kibbled pallets than cake pallets. Last, this analysis again confirms the fact that hall 2D is used the most, as the three highest values occur in this hall.

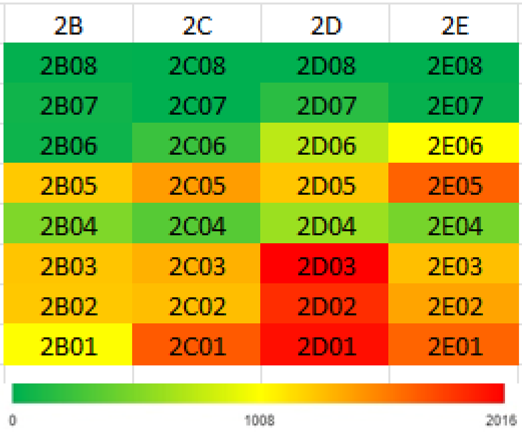

Figure 2-8 Number of pallet movements in past 6 months per height

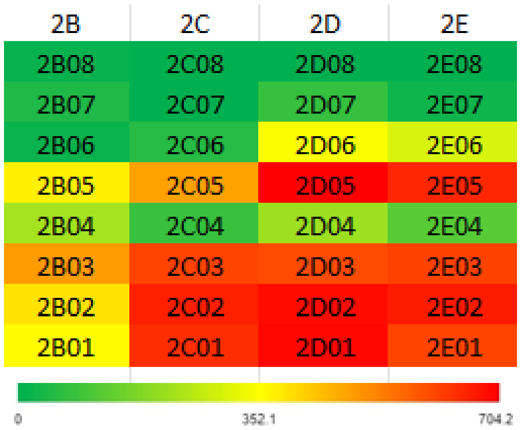

Figure 2-9 Average number of pallets if a height is used

An analysis has been conducted on how many pallets are present if pallets are present in a rack. Using this method, we do not measure the occupation of the racks but measure the way the racks are used. Figure 2-9 shows the number of pallets, a red cell means that more pallets are present and green that (almost) no pallets are present.

The number of pallets is more evenly spread than the number of pallet movements. The number of pallets is almost the same for the first three levels of hall 2C, hall 2D, and hall 2E. This confirms that the pallets in hall 2D have a shorter length of stay, as the number of pallets present is the same while the number of movements is higher. Again, the higher levels are less used.

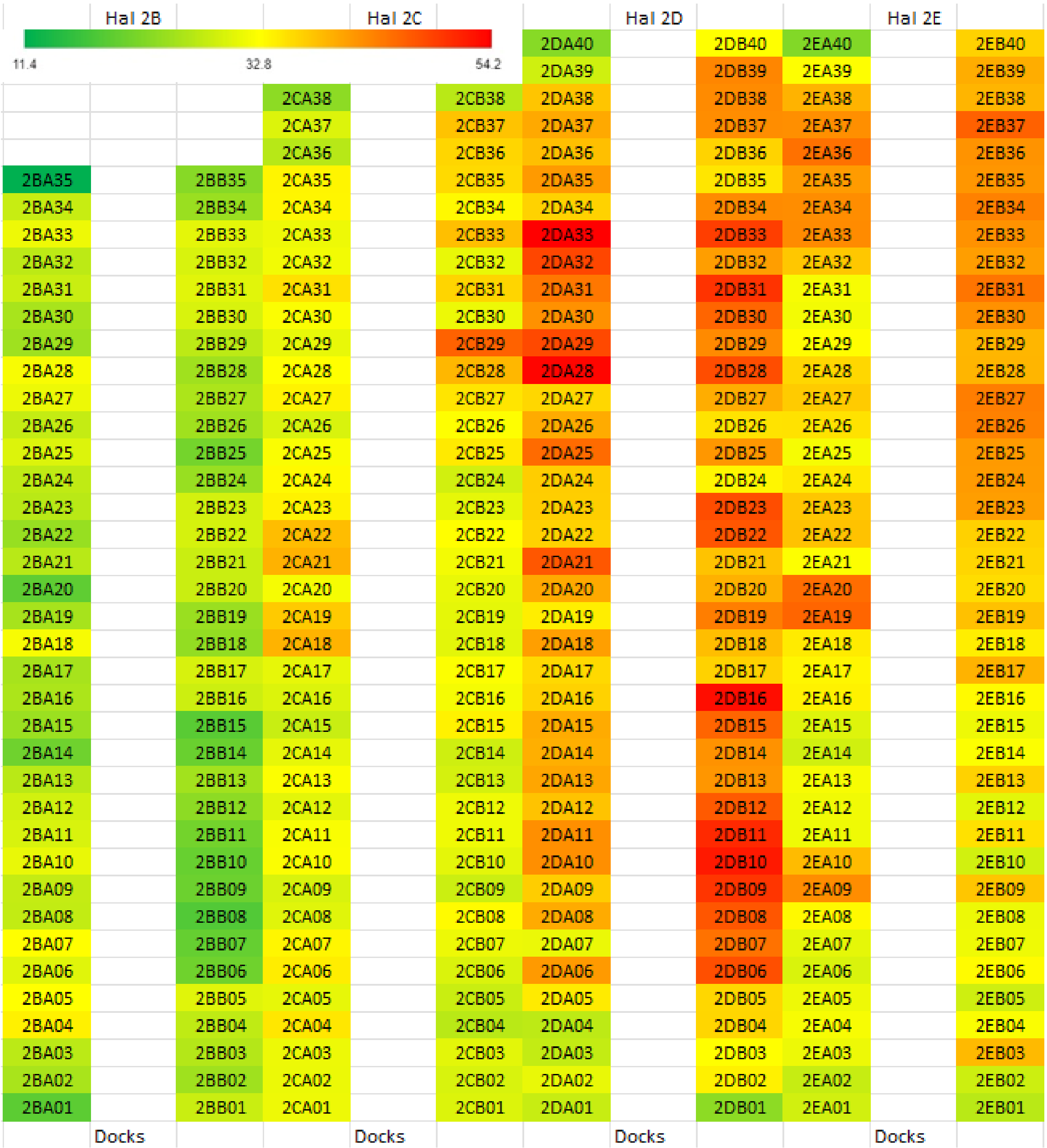

Figure 2-10 Average number of pallets if a rack is used

Using the same method for the racks, we get the overview that can be seen in Figure 2-10. The division in number of pallets is more evenly spread than compared with the pallet movements. This confirms the fact that the fast-movers are placed at the hot-spots of Figure 2-7, as more movements does not mean that more pallets are present, it only means that pallets have a shorter length of stay in the racks.

2.3.2.2 Homogeneity per rack

The number of different SKUs and different lot numbers per rack are analysed over the same 6 months as before (Table 2-2). The more different products or lot numbers are present, the higher the chance of sorting pallets.

The number of different SKUs decrease with an increase of height, but at level 5 this trend starts again. This is caused due to the same reason as explained earlier, level 5 is the lowest row that is able to store kibbled pallets.

Table 2-2 Average number of different SKUs and lot numbers per height

Height	# SKUs	#Lot Number
8	0	0
7	1	1.13
6	1.16	1.30
5	1.28	1.50
4	1.04	1.30
3	1.08	1.38
2	1.18	1.41
1	1.21	1.64
Average	1.18	1.43

As different SKUs always have a different lot number and one SKU can have more than one lot number, the number of lot numbers is always equal or more than the number of SKUs per height. The average is therefore 1.43, which is quite high given the fact that the occupation of the warehouse is not over 50 percent. The values follow the same pattern as the different number of SKUs as it decreases per height, where the pattern starts at again at height 5.

2.3.3 Which information is known about the incoming pallets?

As mentioned earlier, information about the incoming containers is only precisely known when the containers are already unloaded at Antwerp of Amsterdam. The planners gather this information, to get a small indication what will arrive at the terminal in the coming 1 to 2 weeks. When the containers are unloaded at CTVrede, Gam Bakker does not know the sequence of the containers at the terminal. The moment they decide to transport containers from the terminal to the warehouse, they send an employee to the terminal that makes a list of the containers by observation. In this way, the warehouse employees as well as the planners know in what sequence the containers arrive at the warehouse.

On the list that is provided for the working foreman, every container has its own paper with information per pallet. This entails product type, lot number, container number, internal lot number and SSCC-code. The quality is only known for cake-pallets and this means that the employees cannot store the other products based on quality.

2.4 What is the current process flow regarding the outbound logistics?

2.4.1 Retrieval

2.4.1.1 Current picking policy

The retrieval of pallets is guided by the employees that are at the office next to the warehouse. In case Company X needs specific products, they send a list to Gam Bakker with the lot numbers necessary for their operation. Gam Bakker links this to the lot numbers used by Gam Bakker itself, after which the pallets are retrieved. It may occur that for example 20 pallets of a lot number are requested while there are 40 pallets of that lot number present in the warehouse. In that case Gam Bakker is able to make a selection of the best suited pallets. Currently, due to incomplete information this is done by the WMS, which does not always pick the least time-consuming pallets. The current picking policy can be found in Figure 2-11, where the age of the pallets is determined by the first time a pallet is scanned.

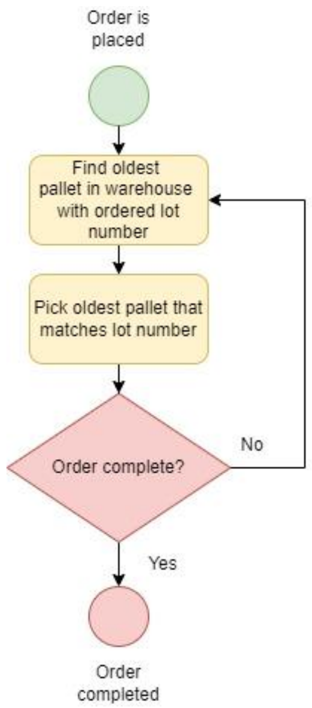

Figure 2-11 Current picking policy

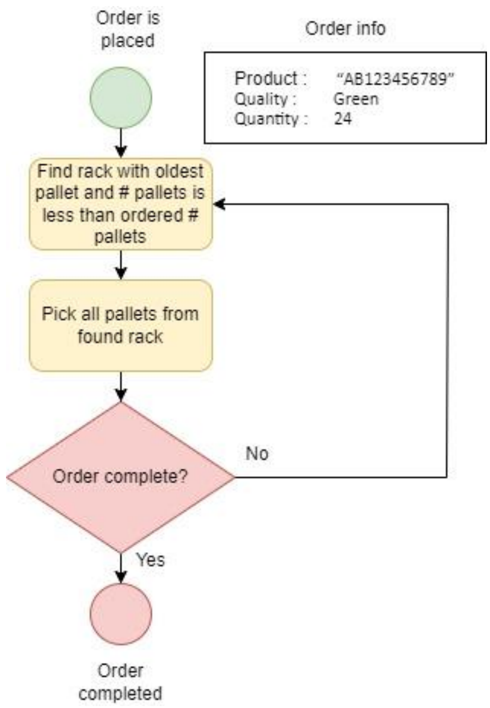

Figure 2-12 Current cake order selection

2.4.1.2 Cake order selection

The cake retrieval is done differently as Gam Bakker has more control in this process. Instead of a list of lot numbers, Company X sends a list of the type of product they need. For example: article "AB123456789", colour "green" and number of pallets needed is "24". In that case, a planner at the office proposes the pallets that fulfil the requirements and are easiest accessible for Gam Bakker. Only in case there is no rack that fulfils the requirement of having equal or less pallets than ordered, pallets are chosen from a rack without emptying the whole rack. If Company X accepts the proposal the pallets are retrieved, after which they are transported to Company X. The method currently used by the planners of Gam Bakker is displayed in Figure 2-12.

2.4.2 Analysis of outbound logistics

2.4.2.1 Number of unnecessary movements

The outbound logistics consist of the process that results in the pallets transported to Company X. From the moment Company X places an order till the moment the pallets leave the warehouse. There are two types of unnecessary movements, transporting pallets between multiple racks or removing a pallet from the rack when you need the pallet that is behind this pallet.

To calculate the number of movements that could be prevented, we stated that a pallet should be moved only once after the first time it was stored. In case a pallet is moved more than once, it is either in front of ordered pallets or is clustered with the same type of products. Therefore, there are two types of unnecessary movements:

- Type 1: Pallets that are placed in multiple racks throughout their time in the warehouse
- Type 2: Pallets that are picked from a rack as the pallet is in front of an ordered pallet

The first type occurs when a pallet is rearranged to make sure that it does not stand in front of other pallets or to cluster products. These movements are scanned and can therefore be easily calculated using the WMS database.
The second type is not registered, as a pallet is placed in the aisle, the ordered pallet is retrieved and the sorted pallet is put back into the rack. To calculate this type of movements, the number of pallets that are in front of other pallets that are ordered is counted. This process is visualized in Figure 2-13, where a pallet is only labelled as sorted in case it is not ordered on the same day and in front of ordered pallets. This results in 5 sorted pallets for the first scenario and 0 for the second scenario.

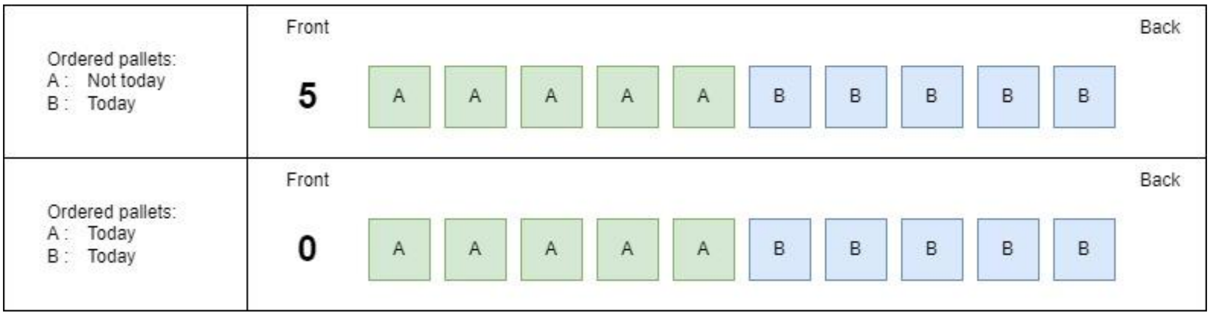

Figure 2-13 Example of sorted pallet

As all types of movements have been calculated, the results are depicted in Table 2-3. Type 1 movements are in column "Scanned" and type 2 movements are in the column "Sorting".

Table 2-3 Results unnecessary movements

Product	Scanned #	Sorting #	Total Unnecessary Movements #	Unnecessary movements
Butter	51	313	364	13.4%
Cake	28	46	74	20%
Kibbled	118	258	376	20.8%
Mass	60	82	142	4.9%
Total	257	699	956	12.2%

Cake and kibbled pallets have the highest percentages while they are on the higher levels in the warehouse. So, the pallets are not only moved more, but they are also harder to access. Using these values, it is possible to predict the number of movements that is unnecessary throughout an entire year. Company X estimates that approximately 80.000 pallets will go through Hoogtij 2, 9720 movements are unnecessary. This combined with the fact that a pallet takes approximately 2.15 minutes per movement, means that 348 hour per year is wasted on moving pallets that are not ordered.

2.5 What is the current demand and supply?

2.5.1 Demand

2.5.1.1 Total demand throughout the year

The reason for Gam Bakker to open a second warehouse in Westzaan is the growth Company X wants to realise in combination with the fact that the new location of the warehouse is saving transportation time. These two factors lead to the fact that the inbound and outbound of products has massively changed as more products arrive and leave the warehouse.

The trend according to Company X, can be seen in Figure 2-14. This trend is calculated as follows, the average of the forecast provided by Company X is taken over the whole period and the deviation is depicted in this figure. There are two peaks in demand, during the month August and during December. In both months this is caused by the mass and cake demand, as those rise during these two months. Company X shared indications of the new flow of products, but these indications do not correspond with reality as more products are used in reality and the ratio within these products is different than mentioned in these forecasts. Therefore, we can use the data to calculate the pattern, but specific values cannot be used as input of the analysis.

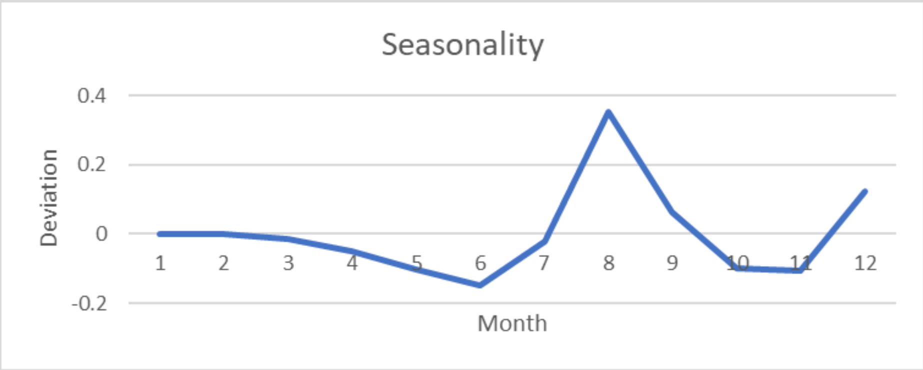

Figure 2-14 Seasonality in demand at Hoogtij 2 (Company X)

2.5.1.2 Orders

The demand of Company X can also be seen in the number of orders placed by Company X at Gam Bakker. The number of orders, size of orders, and the content of orders is analysed to get a better view of the demand at Hoogtij 2.

Figure 2-15 shows the number of orders per week for exactly one year. The number of orders has increased with opening of Hoogtij 2, as Hoogtij 2 increased the capacity of Gam Bakker. A trend is hard to derive as the increase can be caused by the larger warehouse instead of seasonality.

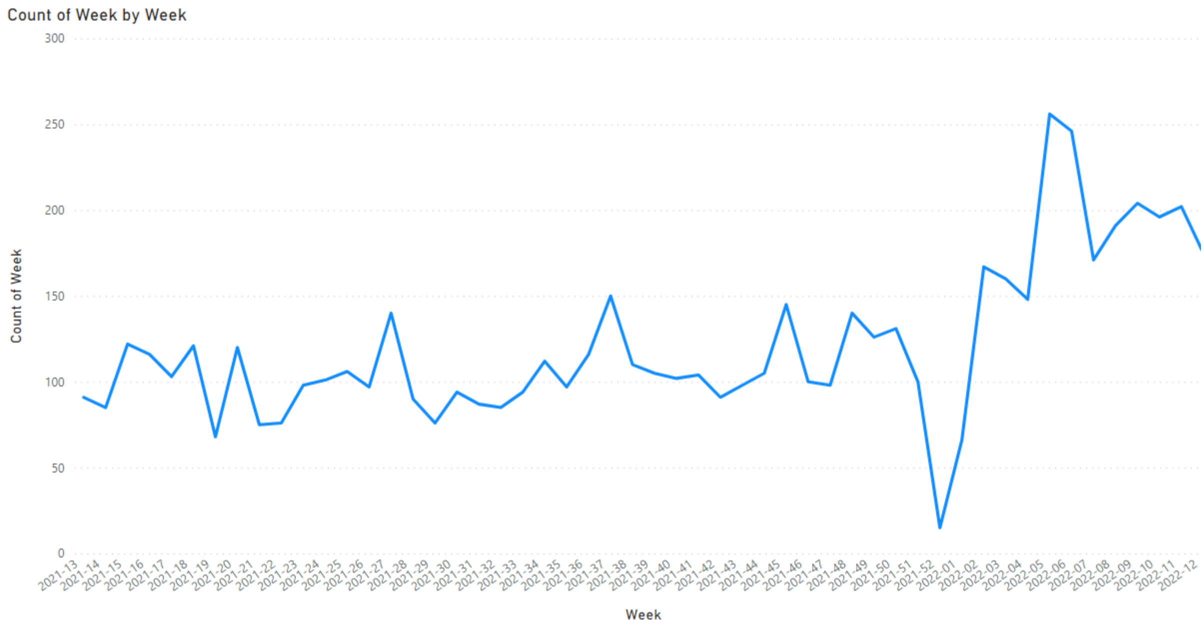

Figure 2-15 Actual orders per week (2021 week 13 - 2022 week 12)

The number of pallets as well as the number of lot numbers per order can be found in Table 2-4. The pallets per order are determined by the way Company X mixes the products in the factory. For example, butter is mixed in quantities of 28,000 kg which is exactly one container, which is the same as the size of one order. Looking at these numbers it is possible to complete all orders by emptying 2 racks except for butter, where at least 3 racks are necessary.

Table 2-4 Pallets per order and lot numbers per order

Product group	Pallets per order	Lot no. per order
Butter	28	1.82
Cake	19	2.20
Kibbled	18	1.79
Mass	21	1.63
Average	-	1.80

The lot number is the number known by Company X and this number is used by Company X to order their products. The difference per product group is low, only cake has a value that strongly varies from the other product groups. An order of cake contains on average 2.2 lot numbers, which can be explained by the fact that Gam Bakker choses these pallets themselves. Company X focuses on minimizing the lot numbers per order as all pallets of one lot number have the same characteristics and are therefore easy to combine. Second, Company X does not know the location of the pallets and it assumes that by minimizing the lot numbers it chooses the pallets closest to each other.

2.5.2 Supply

2.5.2.1 Information known about supply

The supply of the products that are produced in Brazil, Ghana, Indonesia, and Ivory Coast is the biggest part of all products inside the warehouse. The only other products are finished products that arrive from the factory of Company X and that are destined for America. As these products are outside of the scope, only the supply from the mentioned countries to Gam Bakke are analysed. As mentioned in section 2.5.1, the demand has a seasonality as some products are more demanded in the winter. This seasonality is not shown in the supply part at Gam Bakker. The data supplied by Company X is hard to interpret due to the recent start of the operation at Gam Bakker and therefore the conclusion for the supply has to be based on the expert opinion of employees of Company X. According to the head of the production department and the warehouse analyst of Company X, there should not be any seasonality on the supply side. The seasonality that occurs at the demand part is compensated by the inventory that is built up in the rest of the year. Once a product has arrived in Amsterdam or Rotterdam, Company X knows that these containers are on transport and will land in Westzaan within a maximum of 2 weeks.

2.5.2.2 Shipping days

As Gam Bakker is dependent on information from external parties, an analysis has been conducted to predict the arrival based on the of departure at origin. The shipments are carried out from four countries: Brazil, Ghana, Indonesia, and Ivory Coast. Due to a lack of available knowledge at this point, the only data that can be used is the data from containers shipped from Ivory Coast and Ghana. Fortunately, these are the two biggest product flow (97% of all products). Figure 2-16 shows that it takes longer to ship containers from Ghana than from Ivory Coast. Reason for this is the difference in location, as ships depart from Abidjan in Ivory Coast and from Lomé in Ghana, which is just further away from Europe.

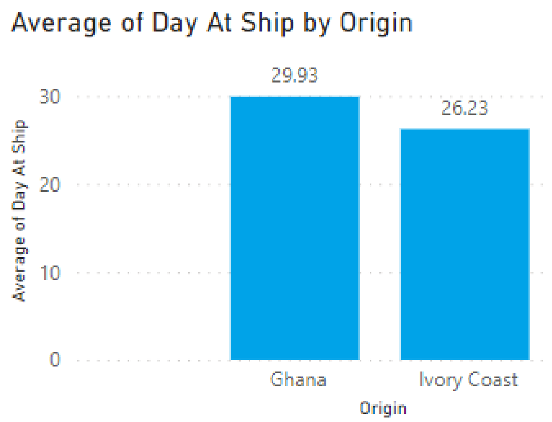

Figure 2-16 Average shipping days per country

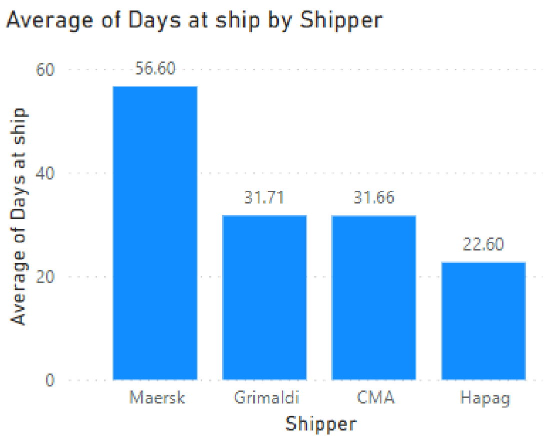

Figure 2-17 Average shipping days per shipping company

Figure 2-17 displays the average shipping time per shipping company. What stands out is that Maersk takes on average twice as long as Hapag to transport containers from the origin to Westzaan. It must be noted that this average can only be taken based on twenty containers, as the data for Maersk is scarce. In case Gam Bakker wants to predict when the containers will arrive, they should take these performance differences into account.

2.6 What are the current programs used by Gam Bakker?

The main program used at Gam Bakker is Microsoft Dynamics Navision, which is a supported by software supplier Rainbow. This program is used for most of the reports and as input for decision supporting tools. It offers a Transport Management function for the transport department and a Warehouse Management function for the warehouses.

Inside the WMS there is an option that allocates pallets to their racks. Currently, there is no input data for this function and thus this function is not used. This function offers the possibility to allocate the pallets into different zones and inside those zones place the pallets based on importance. These input variables should be imported manually and if a change in throughput or demand occurs, it should also be changed manually.

Since the cooperation between Gam Bakker and Bolk, various dashboards have been introduced to get a better overview of the processes at the terminal and the warehouse. These dashboards have been created and published in PowerBI as it offers a quick connection between the WMS used by Gam Bakker and dashboard itself. Furthermore, PowerBI is used as a tool to call off containers from the terminal, to make sure all stakeholders are aware of the containers picked by Gam Bakker.

2.7 Conclusion

In this chapter the global process flow of Gam Bakker has been discussed with its KPIs. As Gam Bakker has recently opened Hoogtij 2, the current logistics still need to be developed and have room for improvement.

Shuttle racks are used in Hoogtij 2 to store the pallets. This type of rack has as advantage that the pallet density is high, which means more pallets can be stored. However, a major downside of this rack is that it has only access point for multiple pallet places and therefore results in a LIFO-policy.
The storage of pallets is not based on KPIs or pallet information as this information is not present in the warehouse. The analysis made the following things clear:

- There is no logic in allocation of fast- and slow movers
- The current lay-out of the warehouse is based on height restrictions
- Racks often contain more than one lot number
- The pick method is only based on the length of stay of the products

These three points of attention lead to the fact that the warehouse efficiency is not as high as desired. The analysis of the outbound logistics made clear that there are various aspects that could be improved. The major points of interest are:

- There are two types of movements: rearranging and sorting of pallets
- On average 12.2% more movements are carried out than necessary
- The products with the most movements are stored at the higher levels (section 2.3.2.1)

These findings have an impact on the already scarce capacity of the workforce at Hoogtij 2. In the future this can lead to approximately 9700 unnecessary movements per year. In case these are prevented, Gam Bakker is able to have a higher throughput and be more attractive for customers.

The number of orders has increased and continues to increase with the opening of Hoogtij 2. This warehouse offers more capacity and therefore has a higher throughput. Company X orders based on lot number for all products, except for cake where quality is used. Once Company X places an order, it tries to minimize the number of lot numbers per order. In case Gam Bakker is able to choose pallets for an order, only happens for cake, the number of lot numbers increases. Reason for this is that Gam Bakker does not take the lot number into account but only looks at the location of pallets.

3. Literature

Findings in chapter 2 made clear that multiple aspects in the warehouse should be improved to increase the performance of the internal material handling at Hoogtij 2. This chapter makes use of literature to answer some of the problems found at Hoogtij 2. Section 3.1 describes the role of the warehouse and the decisions that should be made to design a successful warehouse. In section 3.2 the possible storage and retrieval methods are discussed as well as their characteristics that makes them suitable for Gam Bakker. The forecasting methods are discussed in section 3.3 and lastly, the evaluation methods with simulation are mentioned in section 3.4.

3.1 Warehouse characteristics

3.1.1 Warehouse design characteristics

The major roles of a warehouse include buffering the material flow throughout the supply chain in case of seasonality or disruptions, consolidation of products from multiple suppliers and value-added-activities such as labelling and product customization (Gu et al., 2006). Hoogtij 2 fulfils 2 of these characteristics as it has a relative constant input but deals with fluctuating output and offers value added activities as stickering products and flipping pallets if necessary. The role of warehouses has changed over the past years from solely storing products to actively participating in the supply chain. This change has started with the increase of prices for land, building, energy, and energy costs that have led to a decrease of safety stock (Richards, 2014). The production sector changed to a just in time and pull system, which makes the visibility of information from the warehouses more relevant. Just storing products in the warehouse is therefore not the only function of a warehouse and value-adding-activities are necessary to stand out in the warehousing sector. Based on this and the paper of Rouwenhorst et al. (2000) we can therefore say that a warehouse entails the following activities:

1. Receiving: the receiving part of the warehouse function can vary between actively transporting the containers to the docks or only being responsible for the products from the moment the containers actually arrive at the warehouse.
2. Transportation: the transportation within the warehouse is necessary to ensure that the pallets are at the place that minimizes the total travel distance of all the warehouse movements.
3. Storage: storing is mostly done based on the WMS, which takes various constraints into account. These constraints often entail throughput, height restrictions and weight issues. The WMS returns a specific rack or zone that benefits the internal logistics off the warehouse.
4. Order picking: order picking is done based on a list or the WMS system that gives an overview of the pallets to be picked and the place of these pallets. These pallets can be chosen based on various KPIs such as travel distance, age of the products and ease of access.
5. Value adding activities: as mentioned earlier, value adding activities are a relatively new part of the warehouse function, which makes it possible for warehouse to be more attractive than competitors. This can be done for example by stickering, flipping pallets, cleaning incoming goods or re-bagging products.

6. Shipping: shipping occurs outside the warehouse from the moment the pallets are ready to be transported. In most cases this is the responsibility of the product owner or a third party, but in some cases the shipping process is the responsibility of the warehouse owner.

Shuttle-based storage is mainly applied to SKUs with a high usage frequency (Zhao et al., 2020) as it is able to store pallets or products with a high density. Within shuttle-based storage there are two different configurations to handle all the material handling. Tier-to-tier shuttles, where the vertical movements are done with a lift (in Gam Bakkers case a forklift) and the horizontal movements with a shuttle. The other method, tier-captive, has operational flexibility but when one shuttle breaks down no shuttle of that tier can be picked (Ekren et al., 2015). According to Ekren et al. (2015), the usage of a shuttle system performs well when using a class-based storage policy. This policy works best when the warehouse consists of multiple levels and when the number of aisles increases.

3.1.2 Warehouse design decisions

The complexity of designing a warehouse is high (Heragu et al., 2005) and according to Carla et al. (2008) the decision-making process can be categorised in three phases: strategic stage, tactical stage, and the operational stage. Each phase is described, with the possibilities that are present at Gam Bakker.

The first phase of the decision process is the strategic phase where the long-term decisions take place. These decisions mostly have an influence on the storage and order picking process, as these processes are the basis for the whole operation. Most fundamental questions are: do we create reserve areas and what type of storage do we prefer? In the case of Gam Bakker, the choice has been made to use a reservation area at the docks and to use shuttle racks as a storage method. Only for hall 2A a different choice has been made to use narrow aisles instead of shuttle racks.

The second phase of the design process is the tactical phase where mid-term decisions are made within the limitations caused by the strategic choices. For the storage and retrieval method this part consists of dimensioning the chosen storage method, various methods are explained in the next section. For example, if an ABC-method is chosen, the products per categories are defined to make sure that the strategic choice is followed by the correct tactical choice. Other choices that can be made during this phase are for example the number of docks and the lay-out of the warehouse. As these kinds of choices have already been made, we have no influence on these parts of the tactical design process.

Last, the operation stage where the day-to-day decisions have to be made within the boundaries set by the two previous stages. The assignment of products to the correct place in the warehouse, batch formation in the orders received, and sorting tasks per operator are examples of these decisions. As the tactical phase is not completely finished for Hoogtij 2, all the operational choices can be altered. Which gives a lot of possibilities for the solutions that we would like to propose.

3.2 Which storage and retrieval methods are suitable for Gam Bakker?

As mentioned in section 3.1.1, a shuttle rack benefits most from particular kind storage methods, namely class-based storage. This section discusses storage methods and their characteristics that can be useful for Gam Bakker.

3.2.1 Storage methods

As mentioned in the previous section, there are multiple storage methods where each method has its own benefits and characteristics. This section provides an overview of three methods: random, dedicated and class-based storage.

Random storage is a method in which any SKU can occupy any location (Ballestin et al., 2020) and where there are no restrictions on location and height. In practice this results in the fact that the pallets are stored at the nearest available rack, which occurs at Hoogtij 2 at the moment. An example is the Duration of Stay policy, where products are stored based the expected length of stay in the warehouse as opposed to the SKU identifier (Curry, 2013). This method is useful for when there is a broad range of products, that is too large for the number of racks. It requires less space than when a product has a dedicated pick location (ERIM, 2022) but a disadvantage can be the large travel time caused by randomly storing products (Petersen S. G., 1999).

Dedicated storage is the opposite of randoms storage as every product has its own set of dedicated rack locations (Gu et al., 2010). In principle the idea behind this is that the fast movers are dedicated to racks that result in the least travel time or combined storage and retrieval time. Logically, an advantage of this method is the decrease of travel time compared with random storage, but a disadvantage is the waste of space in case of seasonal demand (Gu et al., 2010). This storage method suits best for a product mix with less variety and low seasonal demand, to decrease the waste of space.

Class-based storage is a mix between dedicated storage and random storage, as it assigns SKUs into storage classes based on demand or lead time and randomly assigns storage locations within each storage zone (Petersen et al., 2004). In case this method is used with few classes the travel time reductions are close to those obtained by dedicated storage (Gu et al., 2010). Thus class-based storage suits best for a product mix with low variety but it can handle some seasonal demand. The broadest known example of class-based storage is the ABC-method where the categories are based on the turnover. Category A consists of product with a high turnover rate and the number of locations is small (ERIM, 2022). B and C products consist of products with a longer throughput time and with more space needed compared with A-products.

3.2.2 Retrieval methods

The first retrieval that is discussed is the 'Pick to Clean' method, this system optimizes the number of empty racks after picking while keeping the least number of locations to pick from in mind (IBM, 2021). This way of working results in a 'clean' warehouse while still focusing on reducing the total time it takes to retrieve the desired pallets.

Second, the 'Least Pick' method focuses, as the name implies, in the least number of picks it takes to completely fulfil the order opposed by the customer. This method results in the least travel time but can lead to problems when filling the racks with other products.

Another method that is commonly used is the nearest neighbour method (Chow et al., 2006) where, after choosing a starting point, the orders fulfilled with the nearest neighbours. This has the advantage that the starting point can be chosen on any preferred criteria while the rest of picks focus on the least travel distance.

3.2.3 Fast-pick area

One strategy to improve the warehouse efficiency is the introduction of the fast-pick area (Kong et al., 2008). The most ordered SKUs are placed in a concentrated picking area to improve the picking density (Bartholdi et al., 2008). This area is restocked from the bulk-storage where the less popular products and the reserve stock of the popular product are placed (Figure 3-1). The selection of products that are placed in the fast-pick zone is based on labour efficiency, where the labour efficiency is calculated by $\frac{picks\ per\ year}{\sqrt{flow\ (m^3) per\ year}}$. The SKUs with the most picks per flow are placed in the fast-pick area. This means that the products in the forward-pick area have a low volume compared with their pick frequency.

Determining the optimal size of the fast-pick area is done by calculating the "saving realized when a pick is done from the forward area rather than the reserve" (Schuur, 2021). Increasing the fast-pick area means more products are efficiently picked but the costs per pick increases.

The most important benefits of using a fast-pick area are:

- Reduce costs of fulfilling an outbound order
- Decrease the time to complete one outbound order

Using this method can lead to a decrease of up to 48.7% to complete one outbound order (Kong et al., 2007). This policy performs best in a situation where the forward-pick area can be replenished in bulk quantities and the actual picking is done in smaller quantities. For example, products are transported from bulk to the pick-area on a pallet, but the actual products are picked individually.

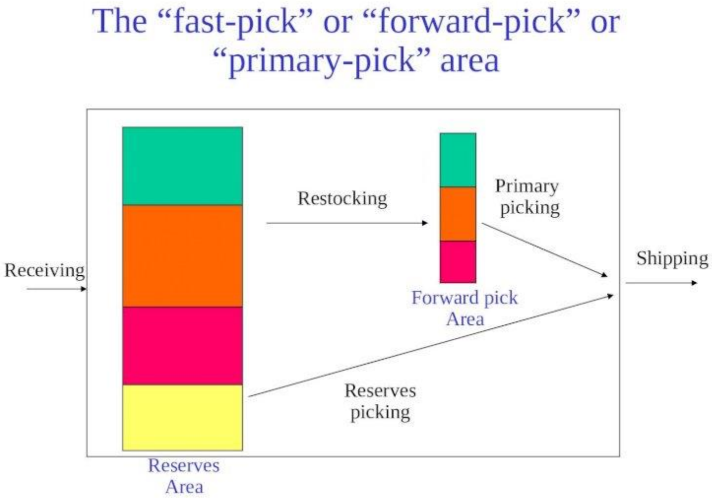

Figure 3-1 Concept of Fast-pick area (Bartholdi & Hackman, 2008)

3.2.4 Storage and retrieval at Hoogtij 2

As the three different type of storage methods and three retrieval methods have been discussed, we can conclude on the current situation at Hoogtij 2 and the possibilities literature offers. Regarding the storage methods, random storage is the current working method at Hoogtij 2 as pallets are placed at the nearest available rack. This leads to unnecessary travel distances and movements that could be avoided, especially when the occupation is as low as 40%. Dedicated storage could be an option when looking at the number SKUs as this number is low. Unfortunately, the disruptive container market in combination with small seasonal effect, would lead to a waste of space in one period and a shortage of space in the other period. The last storage method, class-based storage, would best suit the current situation at Gam Bakker. It suits itself for a small number of SKUs and is capable of dealing with small seasonality. As mentioned earlier, the fluctuating supply of pallets should be dealt with to improve the usage of the warehouse.

Currently, Gam Bakker focuses on the oldest pallet that would fit the desired order, after which a version of the nearest neighbour method is applied. The retrieval methods that are available all have advantages that could improve the situation at Hoogtij 2. In case of high occupation of the warehouse, the 'clean to pick' method would result in as much as empty racks as possible, which makes the storage of the pallets easier. The least picks would result in the least travel distance between the different racks. But, as it does not focus on total handling time, it does not suit the current and future situation at Hoogtij 2. The last method, nearest neighbour, would lead to the shortest distance between the first chosen rack and the rest of the racks necessary for the order. A combination of 'Clean to pick' and nearest neighbour would suit Gam Bakker best. As Company X requires Gam Bakker to not let pallets have a throughput time of more than a year, the nearest neighbour would tackle this problem. If this method would be combined with 'clean to pick', the warehouse would be easier to fill compared with order retrieval methods.

3.3 Which forecasting techniques apply to Gam Bakker?

The inbound of products that arrive at the terminal before entering the warehouse fluctuates between the 15 and 300 per week at Hoogtij 2. Therefore, a forecast could benefit the decision making of storing the products in the warehouse and it can even result in letting the containers as long as possible at the terminal. Various forecast methods are discussed to conclude which method suits Gam Bakker best.

3.3.1 Historical data

The prediction of historical data forecasting models is based on travel time of the same historical process, this model assumes that conditions are constant throughout the period (Williams et al., 2003). This is an important requirement since the predictions do not use any smoothing parameters into account. Related to the container transport, this would mean that a standard average transport time is considered for a particular transporter from a particular harbour. This value would be added to the departure time at the harbour to calculate the arrival time at the destination. This model is outperformed by some algorithms but it does also outperform other algorithms such as multilinear regression (Jeong, 2004).

3.3.2 Time series

Time series models base their prediction on historical time periods and assume that a pattern or patterns happen occasionally over time (Atlinkaya et al., 2013). These patterns in combination with mathematical functions are the basis of the forecast created. An assumption for this model is that there is a relationship between historical data and real-time data. In case this relationship is interpreted wrong or the relationship is changed, the results will significantly differ from the reality.

3.3.3 Forecasting at Gam Bakker

Currently, Gam Bakker does not forecast any of the material flow, inbound as well as outbound. There is little to no data available regarding trends and indications. The indications that are shared by Company X do not correspond with reality, looking at absolute numbers as well as throughput times of products. To deal with this lack of knowledge the forecasting models that are used as input for possible solutions, should be able to adapt to the current situation instead of using fixed forecasts. Looking at the possibilities at Gam Bakker, using the historic time for shipment could be added to the departure time at the harbour to predict the arrival time at the terminal. The outbound logistics could be forecasted by using the historic throughput times over a certain recent period. As Company X expects slight fluctuation over the outbound logistics, while in reality their indications do not match reality, this model should be adaptive. The data over recent periods should represent the current situation best.

3.4 Simulation models

As an evaluation of proposed solutions in the real world takes a lot of time before sufficient data can be gathered about the performance, simulations are used for this purpose. In a simulation it is easier to switch between multiple configurations than when using a deterministic model. Two types of simulation models are discussed shortly, to give an overview of possibilities for evaluating the solutions.

Time-oriented simulations are simulations where the time passes continuously, which best represents the real world. When you follow a part throughout the system, you will not detect leaps in time (Mes, 2021). Discrete event simulation (DES) only considers actual events, which means that time is not continuous. An example of this is a product entering a machine, while the next event is the product leaving the machine. A major advantage of DES is therefore that it can skip through time and can therefore simulate various kind of configurations within minutes instead of days.

3.5 Multi-criteria analysis

The evaluation of possible solutions always results in conflicting criteria that are difficult to compare. For example, it is hard to compare the order time per year with the implementability of a solution. A solution for this is the multi-criteria analysis method, which supports decision making for complex decision problems.

The weighted summation is the most used MCA method according to Janssen (2001). The requirements are standardized, for example 1 till 10, and the overall score is the weighted average of all different scores. Another, more complex, method is the Evamix method that is mostly experienced as a "black box" by stakeholders and therefore less popular. As "simple methods, such as weighted summation perform well in most cases", this method is applicable for most complex decision problems.

3.6 Conclusion on literature

Recently, the field of warehousing has changed as value adding activities are becoming more important to outperform the competition. At Gam Bakker this can be seen by labelling the pallets or cleaning incoming goods.

Hoogtij 2 is recently built, where the strategic and tactical decisions have been made for the coming years. For example, the type of racks (shuttle racks) has been decided (strategic) and the current lay-out of the racks will not be changed in the short-term (tactical). The operational decisions can be altered as is recognized that most improvement can be achieved at this aspect.

As already mentioned, class-based storage does suit Hoogtij 2 best as shuttle racks perform best under this storage method. There is a variety of class-based storage methods, but the ABC-method fits Gam Bakker best. At Hoogtij 2 there is no knowledge about the turnover of products but only about the product characteristics such as throughput, volume, and order size. These characteristics can be used to define the storage classes at Hoogtij 2 that will result in better and more logical internal movements.

Another option could be the usage of a fast-pick area, where the first few rows of a rack can be seen as fast-pick and the rest as bulk. This method has the following disadvantages, causing that we do not choose this option as a possible solution:

- One outbound order should be collected over multiple racks, which increases the shuttle transport
- Pallets should be replenished from bulk, which causes extra movements

- This method suits products best that are replenished in bulk, while the pallets are transported individually

Furthermore, it is remarkable that there is little to no literature about the operational side of shuttle racks. As we are limited to solutions for the operational phase, we cannot rely on literature models and should use the practical rules from literature for our own solution.

Lastly, the evaluation of the proposed policies is partly done with simulation, as this method is able to gather sufficient data in a short time. Discrete Event Simulation is used as it can evaluate multiple configurations in minutes instead of days. The results of the simulation and the other results of the policies are scored by using weighted summation as this method performs well and is understandable for most stakeholders.

4 Warehouse policies

In chapter 2, the current performance of the internal warehouse logistics has been analysed. The most urgent changes should be made to the storage and retrieval policy, as Gam Bakker has influence on these two processes. These policies are then used as the bases for a tool to support the employees of Gam Bakker at the work floor. This chapter will describe the various aspects this tool requires to make sure it is a solution for the encountered problems.

4.1 Requirements for storage policy

The storage policy that are used at Hoogtij 2 should fulfil multiple requirements that are set by the employees of Gam Bakker self or defined by research. These requirements are listed with an explanation why they are important for Gam Bakker.

4.1.1 Warehouse efficiency

The most urgent reason for conducting this research is the inefficiency of the movements in the warehouse. Pallets are transported multiple times, pallets are in front of pallets that need to be picked and pallets are placed in racks that should not be used with such a low occupation of the warehouse. Therefore, the most important requirement for the proposed solution should be the efficiency of the movements in the warehouse. This efficiency should result in a lower occupation of the workforce or the fact that with the same number of employees more pallets can be handled.

4.1.2 Up-to-date output

The second requirement that the solution should fulfil is the fact that it should be possible to use the storage method and the tool in real time. The tool that is based on this storage method will be used on the work floor and not as a planning tool. Most containers that arrive at the dock are expected to arrive that day, but the sequence in the arrival of pallets is not exactly known. For example, in case the terminal crane is on the left side of the terminal it will start loading containers on the left side, in case the crane is on the other side it will pick another stack of containers. As this differs per instance, it should be clear what the destination(s) of the pallets should be when they arrive at the docks, the output should always be up to date.

4.1.3 Flexibility

As Gam Bakker has little influence on the sequence of containers that arrive at the docks, the tool should be able to handle sudden changes. When the occupation of the warehouse is low, a complete rack can be reserved and not used until the container arrives at the warehouse. But in case the occupation of the warehouse is higher, it decreases the options to allocate pallets which should be prevented. Furthermore, the tool should be able to keep the warehouse as flexible as possible. When filling one hall of the warehouse completely while the rest of the halls are empty, the flexibility decreases. As there is only space for one reach truck (pallet truck with higher reach) per hall, it would mean that the other pallet trucks would be unused, while there is enough work to use more than one truck at a time. By keeping in mind the occupation level of the halls when filling the halls, the warehouse stays flexible.

4.1.4 Implementable

The last requirement is the implementability of the tool as the employees have no interest in a tool that is time-consuming and the tool should be able to communicate with the programs that are already in place at Gam Bakker. To make sure that the tool is not time-consuming the advice given by the tool should be available in a few clicks or in one scan of the container. Second, it should be easy to understand and not be ambiguous for the employees to read. Furthermore, the data used for the tool should be gathered from the already existing databases and programs. Gam Bakker uses Navitrans as their warehouse management system, which means that the tool should be able to get the data out of that database.

4.2 Quantification of the requirements

The requirements have been given in section 4.1, but not the KPIs that are used to measure the performance of the tool on these requirements. Per requirement the KPIs used to measure the performance are mentioned as well as the reason for using this requirement.

4.2.1 Warehouse efficiency

The warehouse efficiency is measured by using three different KPIs as can be seen in Table 4-1. The transport time per pallet gives an indication about the time it takes for employees to carry the most important part of their work, the inbound, internal movements, and outbound. The transport time is not the total average time an employee handles one pallet, as Gam Bakker also has value adding activities which are not part of the simulation. These value adding activities should not be removed from the process as it is one of the key characteristics of a warehouse as mentioned in section 3.1.

The number of movements per pallet before it leaves the warehouse would be two in the optimal scenario: once when entering the warehouse and once when leaving the warehouse. The closer the average number of movements is to two, the better the policies perform.

Last, the number of racks used for one order is used as a KPI in the analysis. As Gam Bakker makes use of shuttle racks, every rack used needs to be equipped with a shuttle. In case multiple racks are used for one order, the shuttle has to be transported from one rack to another. As every movement is a burden for the capacity of the workforce, minimizing the number of racks per order will decrease the usage of the workforce.

4.2.2 Flexibility

The time for completing one outbound order is seen as the moment the first pallet is picked until the moment the last pallet arrives at the docks. During this period, the employee is occupied fulfilling this order and is not able to fulfil different tasks. By making sure the time for completing one order is as short as possible, the employees are able to switch between tasks easier, which enhances the flexibility of the workforce. In case the time to complete one order is high, employees will notice the inefficiency which can lead to dissatisfied personnel.

As the indications provided by Company X are not representative for the actual product flow in the warehouse, the system should be able to deal with sudden change in product ratio.

This can be done by having as many completely unused racks as possible. This is measured by calculating the occupation of a rack if a rack is used. The higher this score, the more racks are completely unused, which increases the flexibility.

Table 4-1 KPIs per requirement for the solution

KPI	Description	Requirement
Transport time	The average total time one pallet is actively transported inside the warehouse in minutes	Warehouse efficiency
Number of pallet movements	The average number of movements per pallet	Warehouse efficiency
Number of racks per order	Average number of racks that is used for fulfilling one outbound order	Warehouse efficiency
Order completion time	Average amount of time to complete one order in minutes	Flexibility
Occupation of rack if used	The average occupation over all racks that are being used (percentage)	Flexibility

4.2.3 Up-to-date output

As mentioned in section 4.1.2 another requirement is the desire to have a solution that is able to work real time and that it is not only a planning tool. This characteristic means that the solution is not only a tactical solution but also an operational solution. It should be able to deal with unexpected changes as well on the long-term as short-term. This can be measured by the degree of interactivity and robustness that the solution offers. The tool solution should be able to change its tactical as well as operational decisions based on the available data.

4.2.4 Implementable

The last requirement entails the fact that the solution should be easy to implement, as the employees of Gam Bakker do not benefit from a tool that is time-consuming and it should be interactive with the already existing systems. The proposed solution is evaluated by using an expert opinion and is therefore discussed with the employees that will work with the solution. A group of 2 people from Bolk, that have experience with implementing warehouse improvement tools, and three people of Gam Bakker is asked to evaluate this requirement. The policies have been compared with each other and were ranked based on their professional expertise. The performance of the policies relative to each other became known due to this method, after which the minimum and maximum scores were determined, to calculate the range in which the scores should be placed.

The interactivity between the solution and the already existing systems is hard to measure in numbers. A solution does or does not interact with other programs and it will not result in a score of for example 80%. The requirement is therefore discussed based on logic and not with hard numbers. The easier it is to let the solution interact with already implemented programs, the better the solution fits the current situation at Gam Bakker.

Table 4-2 Qualitative requirements

Measurement	Description	Requirement
Robustness	Adaptability to changing parameters	Up-to-date output
Expert opinion on implementability	A score that indicates the easiness to use the solution	Implementability
Interactivity between programs	A rating based on the interactivity between the already used programs	Implementability

4.3 Multi-criteria analysis

To evaluate the policies a multi criteria analysis is used to get final scores. As mentioned in section 3.5 the method suits the scoring of different type of KPIs and requirements best.

4.3.1 Score of individual KPIs and qualitative requirements

In case KPIs could be used to score the requirements, the scores have been normalized, which means that all the scores are relative to other policies. The best performing policy gets a score of 10, while the worst performing policy scores 0. An example formula is given for a KPI where a lower value is better. The formula is follows, where the actual score is the score of KPI itself:

$$Score = \frac{(maximum - actual\ score)}{|maximum - minimum\ |}$$

In case a higher value is better the minimum and maximum values in the formula should be switched.

The qualitative requirements cannot be measured with KPIs and therefore a different scoring system is used. These requirements are not normalized as all policies have benefits and disadvantages. A score of 0 means that it is not implementable or that is not in real time, while 1 means that it is already implemented or it is fully real time. In between means that it has some burdens before it gets a score of 1, these burdens are discussed in section 0.

4.3.2 Evaluation of all requirements

Using the method described in the previous section the requirements can be scored separately, but to score all requirements together we need a different method. In cooperation with the stakeholders, it is decided to use weighted scores because some requirements are more important than others. The criteria “Warehouse efficiency” and “Flexibility” have been given the same weight 0.3, while the others are weighted 0.2. Reason for this is the fact that the practical influence of the solution is more important than the problems that might occur when creating such a solution.

Weights per KPI have also been used within the requirements, as not all KPIs are equally important for either the internal process or for the employees (Table 4-3).

Table 4-3 Weights within requirements

Requirement	KPI	Weight
Warehouse efficiency	Transport time	0.2
Warehouse efficiency	Number of pallet movements	0.4
Warehouse efficiency	Number of racks per order	0.4
Flexibility	Order completion time	0.8
Flexibility	Occupation of rack if used	0.2

Keeping in mind that the internal process should function as good as possible, weights have been given within the requirements. The KPIs that have a direct influence on the employees have been given a higher weight than other KPIs. For example, in case the racks are not completely filled employees will not directly notice this. In case it takes longer to complete one outbound order, the employees will notice it which can influence their satisfaction.

4.3.3 Target per requirement

As the requirements and the way of evaluating them has been discussed, minimal scores of some requirements can be given (Table 4-4). These minima can be used to compare the results with the intended improvements.

Table 4-4 Target per requirement

Requirement	KPI/measurement	Minimum	Reason
Flexibility	Order completion time	40% decrease	Mentioned in 3.2.3, gains up to 48% can be gained by using different policies
Warehouse efficiency	Number of unnecessary pallet movements	50% decrease	Set as goal by stakeholders
Implementability		5.0	Lower scores are too hard to implement

4.4 Policies

As one of the major problems at Gam Bakker is the lack of decision support at the warehouse, a new storage policy is needed to make logical decisions. A variety of storage policies has been created to make sure multiple kind of solutions are thought of. These policies are then compared with each other to get an overview of the benefits and disadvantages per policy. To evaluate the potential gains a policy has compared with the current method, we first need to evaluate the current storage policy. This policy is also used in section 5.2 to validate the model as it should be a good representation of the current KPIs.

4.4.1 Storage policies

4.4.1.1 Current policy

The current storage policy is the semi-random policy mentioned in section 2.3.1, the process flow can be seen in Figure 2-5. This policy is used for comparison with reality and as validation policy.

4.4.1.2 Lot number storage

As mentioned in section 2.4.1, the orders that are placed by Company X are based on lot number. This only differs for cake, as Gam Bakker is able to choose the pallets based on quality. Due to the fact that Company X does not know the location of each pallet, they try to minimize the number of lot numbers per order, to minimize the number of locations. Due to the fact that pallets with the same lot number are divided over multiple containers, one lot number can be scattered across the warehouse. This leads to extra transporting time per order, as one order has to be picked over multiple halls instead of one hall. Furthermore, pallets that have the same quality but a different lot number should not be placed in the same rack. This prevents the scenario where one of the pallets is ordered, resulting in the fact that the other pallets have to be sorted before the correct pallet can be picked.

Therefore, the improved storage policy consists of placing pallets based on the lot numbers. This policy has the same process flow as the current cake policy, except the quality clustering is switched with lot number clustering. The major decisions that lead to the best destination for the pallets can be found in Figure 4-1. In case a lot number is not present, we first look in the least occupied hall for an available rack. When the least occupied hall has no solution for a container, we look in the second least occupied hall and continue looking for options until the container is empty. In case multiple racks fulfil the desired requirements, the one which is closest to the entrance/exit point of the warehouse is chosen. Where is used that all racks on level 1 are closer than level 2 etc.. This is not always the case in reality, but for simulation purposes this assumption is made.

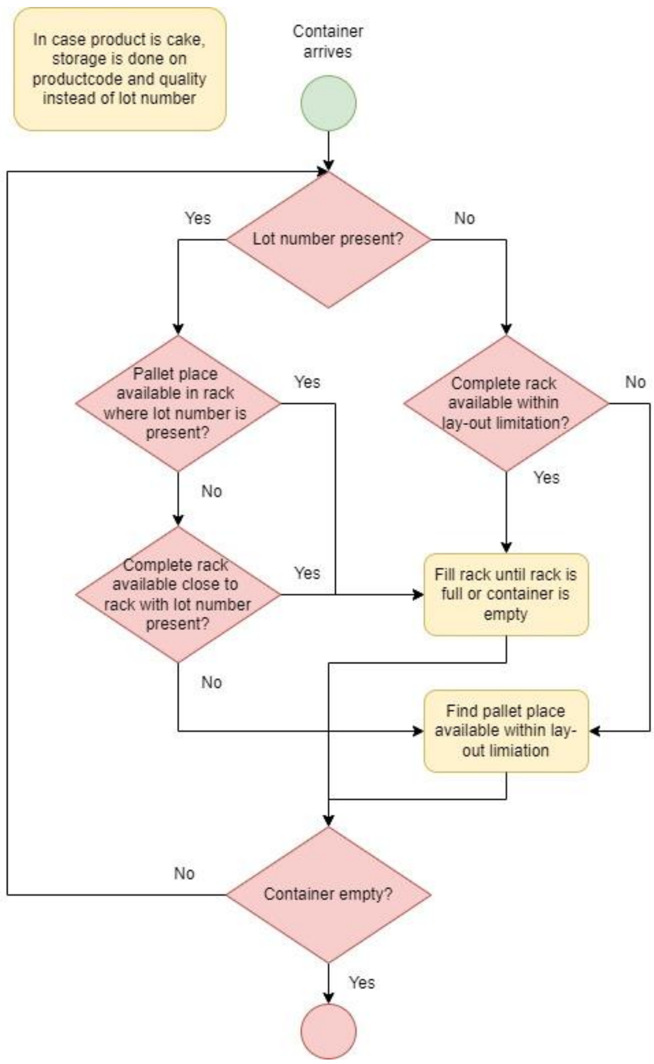

Figure 4-1 Lot number storage

4.4.1.3 Accurate knowledge about arriving containers

In the case Gam Bakker has accurate knowledge about the arrival of containers, a different storage policy is used (Figure 4-2). This policy sorts the list of all pallets that will arrive on one day based on lot number. All pallets are thereafter allocated to racks according to the storage policy described in the mentioned figure. Once the pallet actually arrives at the warehouse, the same allocation method is used to check whether a closer distanced rack has become available in the meantime. If this is the case, the pallet is allocated to a new rack. Again, in case multiple racks fulfil the desired requirements, the one which is closest to the entrance/exit point of the warehouse is chosen.

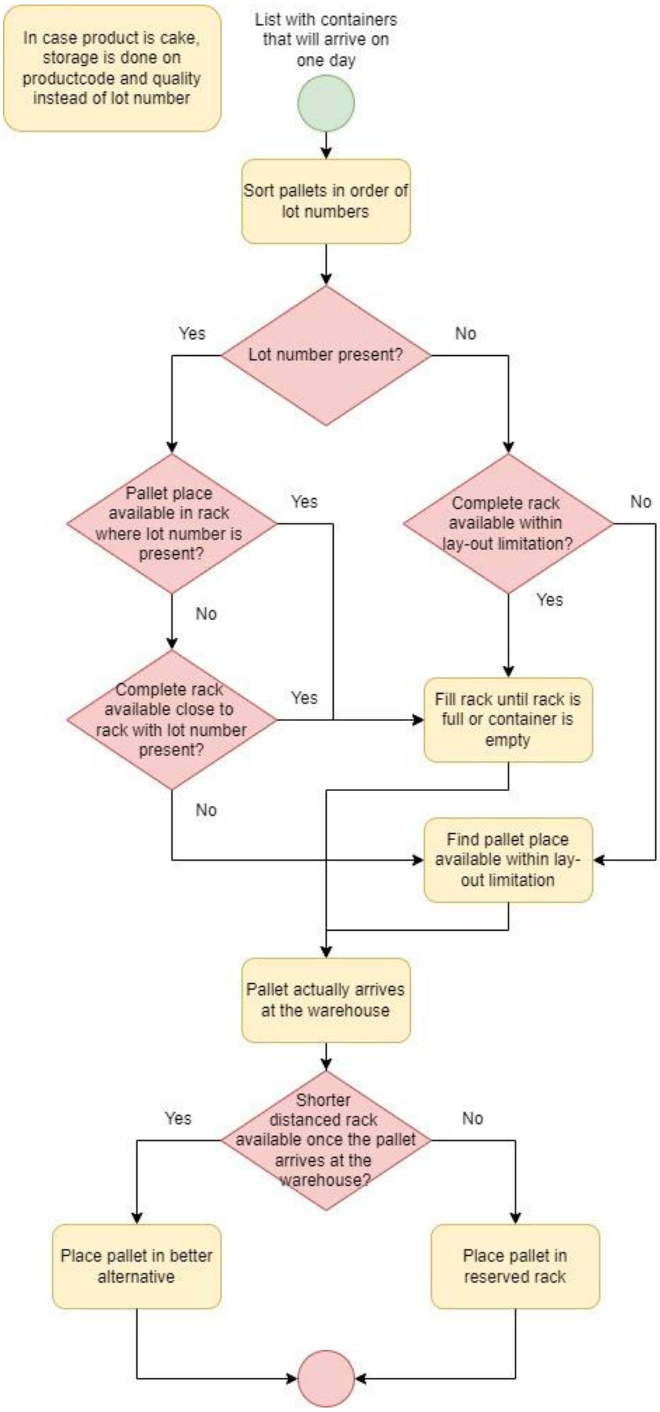

Figure 4-2 Container arrival known

4.4.1.4 Accurate information about outbound pallets

In case we exactly know which pallets will depart from the warehouse and we know the time that they will depart from the warehouse, the process flow of the storage policy does not change. The only thing that changes, is that we know when a rack becomes available and when this rack can be used for other pallets. If an inbound pallet arrives later at the warehouse than the outbound pallets departs, we can plan the inbound pallet in the rack that becomes available. It increases the number of racks that can be used when reserving racks at the start of the day.

4.4.2 Picking policies

4.4.2.1 Current picking policy

The current picking policy is the picking policy mentioned in section 2.4.1.1, the process flow can be seen in Figure 2-11. This policy is used for comparison with reality and as validation policy.

4.4.2.2 Sequence picking policy

Under the current policies, the choice of pallets to be picked cannot be based on the sequence that the pallets are stored in the racks. Due to a lack of information, it is not known what the sequence of the pallets in the racks is and it is thus impossible to always choose pallets that are accessible without sorting pallets that are in front of the desired pallet. As sorting pallets increases the number of movements per pallets, it has a negative impact on the capacity of the workforce in the warehouse. By taking into account the sequence of the pallets in the rack, we can prevent picking pallets that lead to the sorting of pallets in front. In case the ordered product is cake, the process flow is slightly different which can be seen in Figure 4-4. This process is the same as the current process but mentioned for clarity.

In case a pallet needs to be picked based on lot number, the focus should be on finding a pallet that is first on thus easiest accessible. This can be done by sequencing all pallets in the warehouse, in case they are stored last in that rack they get number 1, in case they get stored second to last they get number 2 etc.. The process flow of this picking method can be found in Figure 4-3, where we prioritize on finding pallets in the first row. In case the ordered pallets are not in the first row, we continue looking in the second row etc. until the order is completed. In case multiple racks fulfil the desired requirements, the one which is closest to the entrance/exit point of the warehouse is chosen.

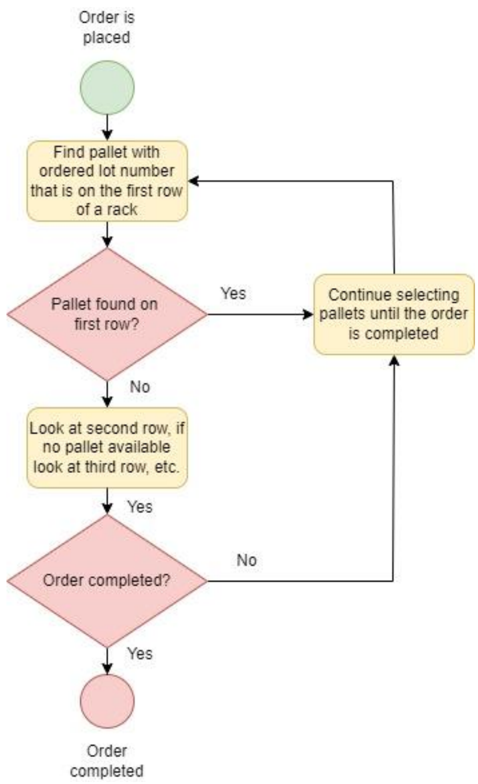

Figure 4-3 Picking policy with sequence

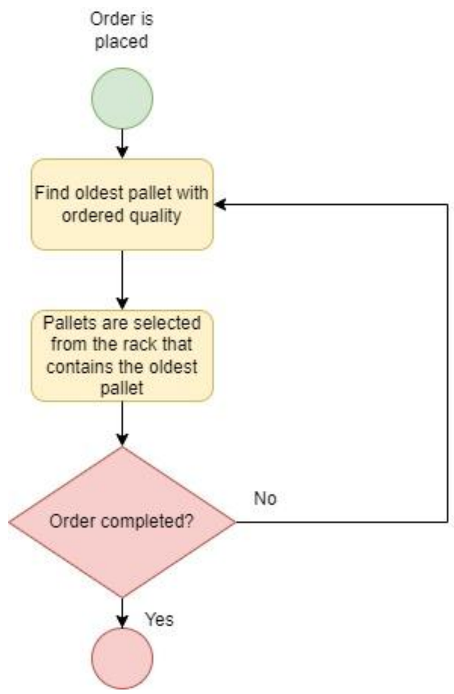

Figure 4-4 Picking policy for cake

4.5 Policies used in the simulation

In the previous section, the storage and picking policies that could lead to an improvement of the internal warehouse logistics have been discussed. As the performance of these policies is evaluated partly by simulation, an overview is given of the used combination of policies in Table 4-5.

Table 4-5 Combination of policies

Name	Storage policy	Picking policy	Occupation (%)	Remarks
Current 0.4	Current	Current	0.4	
Improved 0.4	Lot number	Sequence	0.4	
Current 0.75	Current	Current	0.75	
Improved 0.75	Lot number	Sequence	0.75	
Butter on quality	Lot number	Sequence	0.75	Butter stored on quality
Inbound known	Lot number	Sequence	0.75	Inbound known
Inbound known+ outbound known	Lot number	Sequence	0.75	Sequence of inbound & outbound known
Inbound known + outbound known + butter on quality	Lot number	Sequence	0.75	Butter stored on quality + inbound and outbound known
No restrictions	Lot number	Sequence	0.75	All remarks combined + no lay-out limitations

The results of the "current 0.4" simulation are used as the base scenario. As most KPIs cannot be calculated with the data present, this simulation, which has been validated, is the basis for the other scenarios.

The occupation of 0.4 represents the current situation in the warehouse, while an occupation 0.75 is the agreed occupation of the warehouse and therefore represents the future circumstances best. The influence of the occupation of the warehouse on performance of the warehouse is discussed in section 5.4.4. On both occupations an improved warehouse policy is used to show the possible gains that can be achieved by changing picking and storage policies by Gam Bakker without third parties.

All the other policies involve third parties, either Company X or CTVrede, while we keep the improved 0.75 policy as the basis. "Butter on quality" means that the storage and picking of butter will not be done on lot number but on product code and quality, the same as cake. "Inbound known" means that we exactly know which pallets will arrive at the warehouse. "Inbound known + outbound known" is a policy where we exactly know which pallets will arrive at and depart from the warehouse. The last policy, "Inbound known + outbound known + butter on quality", stores butter based on quality while the inbound and outbound of the warehouse is exactly known.

The last simulation has no restrictions regarding the lay-out of the warehouse and is a combination of all sensitivity analyses. There are no restrictions for the products to be placed, so every product group can be placed on level 1 to 8. This simulation should represent the optimal solution possible for the warehouse situation of Hoogtij 2. This simulation is hard and maybe even impossible to achieve due to the combination of assumptions made. Furthermore, Gam Bakker will not change the lay-out of the warehouse as Hoogtij 2 is recently built.

4.6 Conclusion

The requirements of the to be developed solution, the way to evaluate the requirements, and the proposed policies have been discussed in this chapter.

To compare the different proposed solutions various requirements have been stated, that will differentiate the policies. The following four requirements are used:

- Warehouse efficiency
- Flexibility
- Up-to-date output
- Implementability

These requirements are evaluated partly in a simulation and partly based on expert opinion. The requirements that can be expressed into KPIs are the warehouse efficiency and the flexibility, these are measured by the simulation. The up-to-date output feature and implementability are qualitative requirements and the evaluation is therefore based on expert opinion. This group of people should consist of employees of Bolk, as they have experience with implementing warehousing policies, and employees of Gam Bakker, as they have to work with the proposed solutions. The scores are finalised into an overall score that is calculated by using a multi-criteria analysis as this method suits different types of requirements best.

The proposed policies that are evaluated are based on a change in storage and picking policy. As sensitivity analyses is also part of this research, the following methods are evaluated in chapter 5:

- Improved storage and picking policy
- Improved policies and butter stored on quality (sensitivity)
- Improved policies, inbound known (sensitivity)
- Improved policies, inbound and outbound known (sensitivity)
- Improved policies, butter stored on quality, and inbound and outbound known (sensitivity)
- All sensitivity analyses combined and no warehouse lay-out limitations (benchmark)

5 Performance of policies

As explained earlier, it is time-consuming to measure the proposed solutions in reality. Therefore, a simulation has been developed to evaluate the proposed solutions and conclude which solution leads to the best results.

5.1 Simulation model

The process that has been simulated are all internal movements that are directly involved in the storage and picking of a pallet. The global process consists therefore of the arrival of a container, the storage of the pallets that are inside the container, the creation of an order after which the pallet are retrieved and all the movements of pallets caused by this process. The global process flow can be found in Figure 5-1. The numbers 1, 2, 3, and 4 are the points in the simulation that either the policies are performing or that historical input is used. These points are explained to makes sure the simulation is understood.

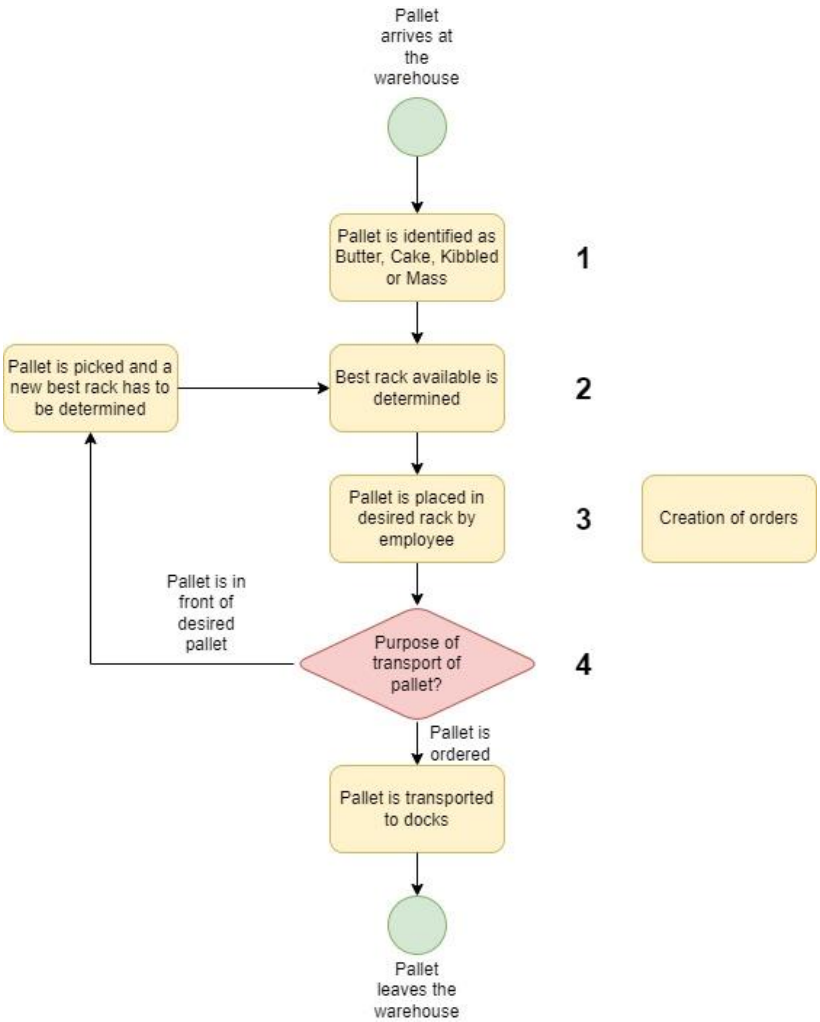

Figure 5-1 Simple Process Flow of simulation

1. Creation of pallets
   Containers are created at the source according to a Poisson distribution, which represents the arrival of containers best (appendix C). As the pallets are stored individually and not as a container, the decision has been made to simulate the arrival of a container as the

arrival of the pallets. In other words, the source does not create one container at a time, it creates the content of the container at once, for example 20 pallets of cake. Pallets are labelled as a product based on historical data, the chances of a pallet being named, for example, butter can be found in Table 5-1. The number of pallets per "container" is also based on historical data and has a deviation of maximum 2 pallets.

2. Storage policy
   Thereafter is determined what the next destination of the pallets should be. This is done by the used policy (current or storage on lot number). It follows the steps that are described in section 4.4.1 after which it gives the next destination to the pallet. The pallet is moved to this destination when all pallets of one "container" have been given a next destination.
3. Order creation
   Orders are not created until the warehouse reaches the desired occupation (either 0.4 or 0.75) to simulate the warehouse performance as accurate as possible. After the occupation reaches that level, outbound orders are created based on historical data. The inbound of pallets keeps the same during the whole simulation. For every product group present in the warehouse, there is a specific chance that pallets are ordered. Such an order consists of constant number of pallets per container (section 2.5.1.2) and a varying number of containers per day. The output of this method is a list of orders with the same template as Company X uses.
4. Picking policy
   The picking policy is triggered in case orders have been created. This policy uses the policies described in section 4.4.2 to select the pallets to be picked. The list of pallets to be picked is used to actually pick the pallets from the racks and transport the pallets to the docks. In case a pallet is not ordered but stored before a pallet that is ordered, this pallet is picked and placed in another rack. The decision on where to store that pallet is done by the same storage policy used at point 2. The only difference is that we first look in the same hall to place the pallet.

Table 5-1 Overview of ratio between products

Product	Portion
Butter	0.55
Cake	0.08
Kibbled	0.14
Mass	0.23

A more detailed explanation as well as picture of the simulation can be found in Appendix C. The model is altered for every single storage policy as this results in the difference between the simulations. The adjustments are only made to one specific method as this one is responsible for choosing the best rack possible. All other methods stay intact and fulfil their role the same in every simulation.

5.2 Simulation configuration

5.2.1 Warm-up period

As the simulation is a non-terminating system, where the results of tomorrow are caused by the actions of today, we have to take a warm-up period into account. A warm-up period is the period where the simulation is not in a steady-state and does therefore not give the correct representation of results. For calculating the warm-up period, we use Welch's graphical method to compute the period that occurs before we reach the steady state (Mahajan & Ingalls, 2004). The graphs used to come up with the warm-up period can be found in Appendix C, where we conclude that we need a warm-up period of 50 days. By rule of thumb, we use a simulation length ten times as long as the warm-up period, 500 days, to make sure we collect sufficient data to base our results on.

5.2.2 Number of replications

To conduct experiments with the proposed simulation, the number of replications needs to be confirmed. The number of replications ensures that the results of the experiment are significant, which means that if the desired number of replications is 5, we need to run the model 5 times before we can use the results. Per replication, a warm-up period is used to ensure that there is no correlation between the different simulation runs, which could lead to incorrect results.

We make use of the sequential approach, which was taught during the Simulation module and is described by Law et al (1991). This approach entails "perform replications until the width of the confidence interval, relative to the average, is sufficiently small" (Mes, 2021). Using a confidence-interval of 95%, the number of replications necessary before the results are statistically significant is 3. The calculations behind this conclusion can be found in Appendix C. As a minimum of 5 replications is recommended, 5 replications are used for this research.

5.3 Validation

Before the solutions can be evaluated by conducting experiments with the simulation, the model has been validated to make sure the solutions drawn from the simulation can be assumed correct. According to Mes (2021), "validation is the process of checking whether the simulation model is an accurate representation of the actual system for the particular objectives of the study". In other words, is the simulation a good representation of the reality.

The only KPI that is sufficient to validate the simulation model is the number of movements per pallet. This KPI is therefore used as the bases for validation and compared with the results of the simulation. The transport time per pallet is another KPI that could help us validate the model. Unfortunately, the exact transport time is missing and would not give a good representation of reality. As the time it takes to sort pallets in reality cannot be calculated by the data available, the transport time of the simulation would always greatly differ from reality. Therefore, it is not possible to validate the simulation model by using the transporting time.

The simulation has been validated twice:

- Using exact historical data of one hall
- Running the simulation with the current occupation (40%)

5.3.1 Validation of one hall

The first method entails that all inputs, arrival of containers and ordering of pallets, are copied from reality. The arrival of containers was used as input for the simulation, which means that at the same time a pallet arrives in reality it arrived in the simulation. The list of pallets that were ordered throughout is the simulation period is used as the order list that triggers the picking method (section 5.1). As the input of the real warehouse and the warehouse in the simulation were the same, a simulation model that is valid should have the same results as in reality.

The model runs for 215 days, as this is the period from the 15th of November 2021 till the 16th of May 2022. The information collected during the simulation is exported to Excel to get the necessary data out of Plant Simulation. In hall 2B an average of 10.8% of the number of movements is unnecessary at Hoogtij 2. In the simulation 12.9% of the number of movements is unnecessary, which is a difference of 2.1%. The percentage of unnecessary movements observed in the simulation and measured in reality can be found in Table 5-2. Looking at mass the number of observed unnecessary movements is twice as large as in reality. Reason for this is the fact that the simulation was bounded by the current lay-out (Table 2-1), while in reality the employees deviated from this lay-out. Level 4 was strictly used for Cake, level 5 and 6 is only used by kibbled and butter must be on the lower levels due to the low quality of the pallets. As mass is not as strictly bounded as the other product groups, mass is placed on more levels than intended according to the warehouse lay-out (Table 2-1). With the chi-squared test, a p-value of 0.729 is found, which means that we cannot reject the hypothesis that the means of the KPI observed in reality and in the simulation are the same.

Table 5-2 Percentage of unnecessary movements hall 2B

Product	Reality (%)	Simulation (%)
Butter	13,4	11,4
Cake	20,0	21,9
Kibbled	20,8	23,8
Mass	4,9	9,0

5.3.2 Validation by using the current policies

The other validation method is running the simulation with same occupation as in reality (0.4) and letting the simulation model create the arrival of products and orders. This method not only takes the storage and picking policies into account, but also the configuration of the simulation.

The model runs for 500 days, which includes the warm-up period and the necessary run-length (section 5.2). Using all these parameters as input for the model, we measured the number of movements per pallets and compared them with reality for the whole warehouse.

As can be seen in Table 5-3, butter and mass do correspond well with the reality while cake and kibbled seem to deviate more from reality. The overall percentage of unnecessary movements is 11.3 according to the simulation, while in reality this is 10.5. When doing a chi-square test to test if there is statistical difference, we come to the conclusion that there is no statistical difference as the p-value is 0.717. We cannot reject the hypothesis that there the means are the same and therefore can continue working with this simulation.

Table 5-3 Percentage of unnecessary movements Hoogtij 2

Product	Reality (%)	Simulation (%)
Butter	13,4	10.8
Cake	20,0	25.14
Kibbled	20,8	15.9
Mass	4,9	5.5

5.4 Results of the simulation

The different combination of policies has been discussed in 4.4 with an explanation why these combinations have been chosen. These policies were implemented in the simulation model after which the model has run according to the parameters stated in section 5.2. the results are discussed in the order of the simulations, as this results in a logical narrative.

5.4.1 Policies with 40% occupation

The results, with the KPIs discussed in section 4.2, of both policies under a 40% occupation can be found in Table 5-4.

Table 5-4 Simulation results occupation of 40%

	Average Movements	Unnecessary Movements	Transport time (m)	Average racks per order	Order time (m)	Rack Occupation
Current 0.4	2.12	6.11%	00:56	3.58	17:06	82.55%
Improved 0.4	2.01	0.26%	00:45	2.71	13:08	87.92%

Recall that the current number of unnecessary movements in reality is much higher than the “current 0.4” method. Reason for this is that the pallets are stored and picked as intended (Figure 4-4), while in reality this is not already achieved. The process flows are not completely different, but the execution of the method is done better in the simulation than in reality. As this picking method is being improved in reality, it would not give a realistic improvement if we did not implement this picking policy in the simulation. The cake movements were 20% in reality, while in the simulation we get a value of 2.3%. Furthermore, the storage and picking actions are always executed according to the policy, while in reality the decisions can deviate due to human error. Lastly, in the simulation level 7 and 8 are used when no preferred place is available in the levels below, while Gam Bakker has not used level 7 and 8 up till May 2022. This means that the number of movements decreased even further, but there was a slight increase in transport time. As the number of movements per pallet decreased substantially, the average transport time is also less.

The difference between the current policy and the improved policy is significant. The percentage of movements decreases from 6.11% to 0.26%, while the relative decrease is 95,74%. The same occurs when looking at the transport time per pallet where the average time decreases by 23.92%. Furthermore, the time to complete one order decreases with almost 4 minutes to 13:08 minutes, which cannot be compared with reality as such data is not available.

5.4.2 Policies with 75% occupation

Table 5-5 Simulation results occupation 75%

	Average Movements	Percentage Movements	Transport time (m)	Average racks per order	Order time (m)	Rack Occupation
Current 0.4	2.12	6.11%	00:56	3.58	17:16	82.55%
Improved 0.4	2.01	0.26%	00:45	2.71	13:08	87.92%
Current 0.75	2.35	17.67%	01:45	5.25	46:25	85.15%
Improved 0.75	2.26	13.17%	01:25	4.70	38:23	89.34%

Table 5-5 shows the results from the simulation with an occupation of 75%, which is close to the contractual occupation level. As the occupation level increases in the simulation a bit after the first orders are created, a starting occupation of 75% represents the reality best.

The difference between the percentage of movements with an occupation of 40% and an occupation of 75% is major. The number of movements increases from 6.11% to 17.67%, which is an increase of 189,2%.

The improved policies outperform the current storage and picking policies on all KPIs. The unnecessary movements decrease to 13.17% which is a relative decrease of 25.47%. The flexibility increases slightly as the time to complete one outbound order is slightly less. Although all KPIs are worse than under the current occupation, this policy is an improvement compared with the current storage policy.

5.4.3 Sensitivity analyses

Table 5-6 Simulation results sensitivity analyses

	Average Movements	Percentage Movements	Transport time (m)	Average racks per order	Order time (m)	Rack Occupation
Current 0.75	2.35	17.67%	01:45	5.25	46:25	85.15%
Improved 0.75	2.26	13.17%	01:25	4.70	38:23	89.34%
Butter on quality	2.12	6.00%	01:07	3.24	20:45	90.03%
Inbound known	2.09	4.55%	01:22	3.27	22:23	90.24%
Inbound known + outbound known	2.06	2.81%	01:20	3.10	20:03	89.42%
Inbound known + outbound known + butter on quality	2.04	2.09%	01:07	2.90	16:11	88.04%
No restrictions	2.01	0.53%	01:05	2.65	14:48	87.84%

As mentioned in section 4.5, multiple sensitivity analyses have been conducted. One where the butter is also stored and picked based on quality, as Gam Bakker tries to convince Company X into implementing this method. The other sensitivity analyses measure the importance of knowledge about the inbound and outbound orders at Hoogtij 2. The last sensitivity analysis is a combination of all realistic adjustments to the warehouse operations (butter on quality, inbound and outbound known). Lastly, a benchmark simulation has been used to see what the performance of the optimal solution could be.

5.4.3.1 Storage on butter quality

Using quality instead of lot number for butter results in an increase of performance for all KPIs. For example, the percentage of unnecessary movements decreases with 54.43% compared with the “Improved 0.75” method, which was already the best performing policy. Not only butter improves but also mass improves on all KPIs. Reason is that as mass and butter share racks in the current lay-out (Table 2-1), a more efficient usage of racks by butter offers more space for mass. As can be seen in Figure 5-2, more available racks lead to less unnecessary movements.

5.4.3.2 Knowledge about inbound and outbound orders

5.4.3.2.1 Inbound

Exactly knowing which containers arrive on a day result in less movements as zones can be reserved for pallets instead of only racks. The rack occupation is almost the same, as the usage of the racks is not different compared with the "Butter on quality" method. All other KPIs perform less, which can be explained by the fact that butter is not stored on quality, which offers a bigger improvement than only knowing the inbound orders.

5.4.3.2.2 Inbound and outbound

Combining the knowledge of the inbound pallets with the outbound pallets, leads to an improvement of all KPIs compared with only knowing the inbound pallets. Racks can be matched which leads to grouped storage of lot numbers, instead of storage scattered throughout the warehouse.

5.4.3.3 Inbound and outbound combined with butter storage

Not only using the knowledge of the inbound and outbound pallets but combining this with the butter storage based on quality, leads to even better KPIs. The percentage of unnecessary movements decreases to 2.09% which is a decrease of 88.2% compared with the current policies in place. The time to complete one outbound order is on average 16.19 minutes and scores the best of all evaluated policies.

5.4.3.4 No restrictions

When looking at the previous discussed policy, it stands out that there are still inefficiencies although the policies have been improved. Reason for this is that due to the lay-out limitations some levels are almost full while other levels have a lower occupation. This can be seen in Table 5-7, where the occupation is high for levels 1, 2, 3, and 7, which are used for mass and butter. The levels reserved for kibbled and cake have a way lower occupation, which means that more space is reserved than actually necessary. Therefore, we take a look at a policy where there are no lay-out restrictions.

Table 5-7 Occupation per level

Level	Occupation
1	0.94
2	0.93
3	0.93
4	0.56
5	0.75
6	0.54
7	0.88
8	0.59

Table 5-8 KPIs per productgroup

Product	Transport Time	Movements	Racks per order	Order Time
Butter	00:59	2,40%	2,70	16:39
Cake	01:14	0,27%	2,52	10:16
Kibbled	01:25	0,44%	2,53	11:36
Mass	01:15	2,61%	3,54	18:28

In case we use the same combination of policies and sensitivity analyses but disregard the lay-out restrictions, we approach the optimal solution. The number of unnecessary movements is 0.53% and all other KPIs outperform all other solutions. Due to the high occupation, it has peaks of about 85%, it is impossible to move all pallets only twice. This configuration is hard and maybe impossible to achieve but it shows the near-optimal scenario that could be achieved at Hoogtij 2. (section 1.5)

5.4.4 Influence of occupation on warehouse performance

The influence of the warehouse occupation on the warehouse performance is mentioned multiple times, to clarify these statements simulations with different occupations were used. As can be seen in Figure 5-2, with the current policies the percentage of unnecessary movements increases from 6.11% to 25.83% when the occupation increases from 40% to 90%. In case the "Improved + butter" policy is used, the percentage of unnecessary movements only increases to 9.2%. This figure supports the statement that a higher occupation leads to more unnecessary movements.

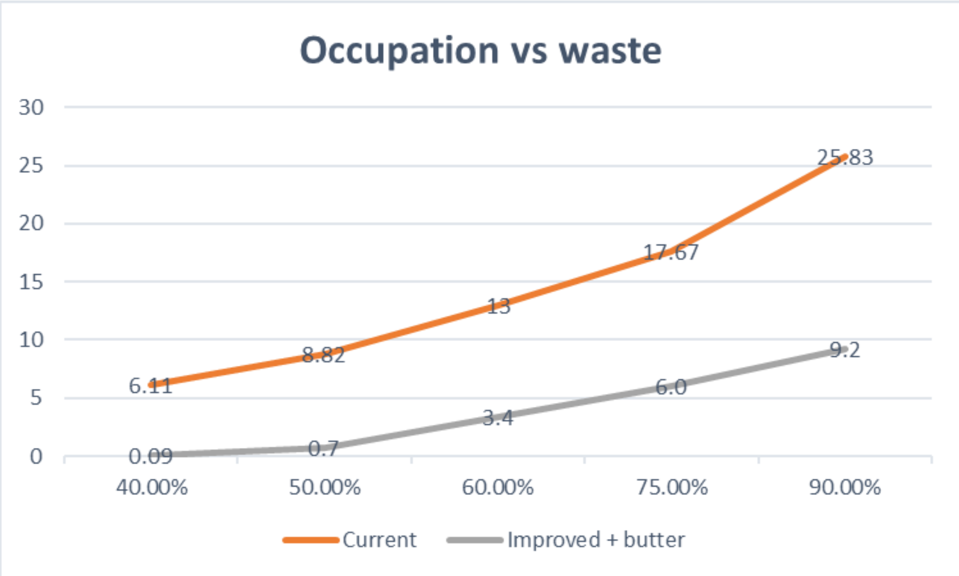

Figure 5-2 Warehouse occupation vs unnecessary movements (%)

5.4.5 Transport time per year

Table 5-9 shows the transport time per pallet for every policy that is evaluated. The differences follow the same pattern as most other KPIs, where "No restrictions" leads to the best results, with almost 900 hours less transport time than under the current policies. As this scenario is almost impossible to achieve, the best-found combination of policies is "Inbound + outbound + butter".

Table 5-9 Total transport time per policy per year

	Transport Time (hours)	Time saved (Hours)
Current 0.75	2324	
Improved 0.75	1900	424
Butter on quality	1480	844
Inbound known	1831	493
Inbound known + outbound known	1781	542
Inbound known + outbound known + butter on quality	1501	823
No restrictions	1439	885

5.5 Qualitative requirements

As 2 of the 4 requirements have been discussed, the qualitative requirements are mentioned and scored, to produce the best solution for Gam Bakker. The up-to-date output feature as well as the implementability requirement are qualitative and are therefore scored by making use of an expert opinion. The flexibility and up-to-date output feature of the proposed policies are scored by an expert opinion by the employees of Bolk Logistics as they have experience with implementing automation tools in practice. They are able to judge the consequences of a program based on the method used.

5.5.1 Implementability

It is important to mention that all proposed policies have some burdens before implementation can be successfully done, but there are differences. These differences are explained to grade the policies on this aspect.

5.5.1.1 Storage policy

In case the storage policy is based on lot number there is no change in working method for the employees except the working supervisor. He will not have to decide where the pallets should be stored, this is done by an algorithm which makes it easier for him. This proposal can be done with programs that are already in place, which does not lead to major problems. The interactivity with other programs is not a problem as well, as all databases are already connected with Power BI and therefore the calculations are possible. As all problems that can be foreseen can be dealt with in reasonable time, this policy should be possible to implement in reasonable time.

5.5.1.2 Improved picking policy

The picking policy entails a change in the method that is currently used by the employees in the warehouse. At this moment, the WMS selects appropriate pallets that match with the lot number requested. As the selection should take the sequence of pallets into account, another tool has to be created that selects the appropriate pallets. In practice this means that the employees get a list of pallets to pick, instead of the WMS appointing the pallets. This is not a problem, as long as it is clear how such a list should be interpreted and used to ensure the least movements possible. This policy is harder to implement as more employees are part of this process, but as the interactivity with other programs does not result into problems, this policy should be implementable only a bit more difficult than the storage policy based on lot number.

5.5.1.3 Butter quality

The storage and retrieval of butter based on quality is not different compared with other policies if we look at the interactivity with other programs. The difference lays in the fact that at this moment Company X does not allow Gam Bakker to make the pallet selection themselves. As the choices to crate the selection of pallets is more difficult than the selection of cake, Company X was hesitant to let Gam Bakker make this selection. Due to several reasons Company X is open for the fact that Gam Bakker does the selection. Different to the cake procedure, Gam Bakker should do the calculation for which qualities of butter are necessary. So instead of receiving an order that mentions 20 pallets of 12% and 4 of 20%, it results in an order that requests 24 pallets with an average of 13.3%. This is more complicated but can be dealt with by creating an automated program that manages these requests. The rest of this policy is the same as the cake procedure, which means that only a small part of the policy is harder to implement. Therefore, this policy is valued slightly harder to implement than the others.

5.5.1.4 Knowledge about inbound pallets

Exactly knowing which containers arrive at the terminal is dependent on CTVrede. Currently, the list made by the warehouse supervisor (section 2.3.3) is correct for most containers. Due to inconsistencies in the working method of CTVrede there are some containers that were either not on the list or that were on the list but did not arrive at the warehouse. As this method demands a change in the working method at a third party it is way harder to implement than the other policies.

5.5.1.5 Knowledge about outbound pallets

The knowledge about all outbound pallets at Hoogtij 2 is not present at the moment. For approximately 40% of the orders is exactly known which pallets will be picked, the other orders are or not known or the orders are not linked to pallets. To get a complete overview of which pallets will depart from the warehouse, Gam Bakker should get insight in the production process of Company X as well as from which warehouse they will order which products. As Company X does not have a regular production cycle, they do not know this for all the products. Overall, this policy is hard to implement as multiple parties have to develop their internal processes before a cooperation can be started.

5.5.2 Up-to-date output

The up-to-date output feature of all policies is evaluated at once, as all policies have the same refresh and up-to-date possibilities. The problems that may occur in all scenarios is that the warehouse situation in reality differs from the warehouse situation in the tool, as not all movements and decisions are directly linked to the system.

All other policies are implemented using Power BI and the WMS as source of data. In case that the location of a pallet changes, a new storage or picking proposal is automatically created if requested. The only problem that may arise is the fact the fact that the systems are dependent on the scans of the pallets and not only on the decisions. In other words, it may happen that it is decided that a pallet should be moved to a certain rack, but it is not already scanned at that rack. The systems show that the rack is empty and therefore advice the next pallet to go to the same rack. In practice, this means that pallets may be directed to already filled racks. The same applies for the ordering/picking method, where a pallet can be selected for two different orders.

This problem can be dealt with by making use of reservations, which should be done in a different table. As the solution is the same for all three policies, there is no major difference when looking at the real time feature. It will take some time, but it is possible to deal with this problem.

5.6 Scores of all policies

All policies have been evaluated based on the defined criteria and therefore we can compare the scores, to select the best solution possible. The final scores have been calculated by the MCA explained in section 4.3 and can be found in Table 5-10.

Table 5-10 Final scores of all policies

	Warehouse Efficiency (0.3)	Flexibility (0.3)	Up to date (0.2)	Implementability (0.2)	Final Score
Current 0.75	0.0	0.0	8.0	10.0	**3.6**
Improved 0.75	2.9	3.7	7.5	7.0	**4.9**
Butter on quality	7.7	8.4	7.5	6.5	**7.6**
Inbound known	7.3	8.1	7.5	4.0	**6.9**
Inbound known + outbound known	8.0	8.4	7.5	3.5	**7.1**
Inbound known + outbound known + butter on quality	9.2	8.2	7.5	3.5	**7.4**
No restrictions	10.0	9.1	7.5	0.0	**7.2**

The first thing that needs to be mentioned, is that all policies other than the "improved 0.75" fulfil the minimum improvements set in section 4.3.3 except for the implementability part. "Butter on quality" is the only policy that fulfils all targets set.

When looking at the final scores, the "Butter on quality" policy performs best when looking at all requirements. Reason for this is the fact that the performance on the warehouse is better than most policies. While the policies that have a better warehouse performance score worse on the implementability requirement. In the scenario where there are no restrictions the warehouse performance is way better than all other policies, but as it is almost impossible to implement, this policy scores worse than two other policies.

"Inbound known + outbound known + butter on quality" is the best performing policy that takes restrictions into account. It scores better than all other realistic policies on warehouse performance, but due to implementability burdens it does not suit Gam Bakker best.

When looking at the requirements, it stands out that the current policy scores worst on the KPIs but best on the qualitative requirements. Reason for this is that it leads to unnecessary movements and higher KPIs, but as it does not make use of any program it is already implemented and can be done in real time. The only reason up-to-date output does not score a 10 is the fact that if the working foreman is not present, the process cannot be executed or at least performs in a different way than intended.

5.7 Conclusion

A simulation study has been used to evaluate the different proposed combination of policies to choose the best policies possible for Gam Bakker. The policy with storage based on lot number for kibbled and mass, storage based on quality for butter and cake, and picking based on sequence suits Gam Bakker best.

The proposed policies have been scored based on 4 KPIs, the method used to score these policies are between brackets:

- Warehouse efficiency (simulation)
- Flexibility (simulation)
- Up-to-date output (expert opinion)
- Implementability (expert opinion)

The combination of the storage policy based on lot number and picking based on sequence of pallets scored best of the initial policies. The percentage of unnecessary movements decreased from 17.67% to 13.17% and the time to complete one outbound order decreased to approximately 38 minutes.

Although this policy is an improvement compared with the current policies, sensitivity analyses have been conducted to measure the influence of storage based on butter quality and the influence of more information on the warehouse logistics. The storage based on butter quality outperforms al other policies on all KPIs. The number of unnecessary movements decreases for all products as a more efficient storage of one product influences the other products.

The last policy, exactly knowing which containers will arrive and which pallets will depart from the warehouse, outperforms all policies on warehouse performance except the simulation where there are no restrictions. As it is currently almost impossible to implement the "no restrictions" policy, this policy is disregarded when looking for the policy that suits Gam Bakker best.

Although a warehouse lay-out without any limitations is hard to achieve at Hoogtij 2, the lay-out still can have great influence on the performance of the warehouse. Therefore, follow-up research is advised as it is more complex than only changing the product groups per level. An improvement for one product group can lead to a setback for another product group. This follow-up research should take that into account and look at different types of lay-out.

Looking at the time saved per year for each policy, the already mentioned storage method based on quality for butter scores best. It can save up to 844 hours per year, which can be used for other activities or an increase of throughput. Overall, this combination of policies performs better than all other policies and is therefore chosen is the best solution for Gam Bakker.

6 Implementation of the proposed solution

The results of this thesis are in prefer a storage policy based on lot number or quality and a picking policy that takes the sequence of pallets into account. This chapter gives an overview of the most important aspects for implementing this solution.

6.1 Storage policy

The implementation of the storage policy has same critical aspects that need to be considered. These are mentioned and a method to deal with these aspects are explained.

6.1.1 Data gathering and validation

All data that is necessary as input for the proposed storage policy is already available at Gam Bakker. However, this data should be combined and put into one or two tables that would fit the policy best. The first table should be a correct overview of the occupation of all racks in combination with which lot number or quality is present. This table can be used to allocate pallets to the racks. The second table should consist of all pallets that need to be allocated, namely the pallets on the terminal.

As the data in the WMS is not always correct, for example 18 pallets are present in the WMS at a rack with a capacity of 12, data validation should be continuously executed. A list should be created of inconsistencies in the data, after which a check should be carried out what causes these inconsistencies.

6.1.2 Computation time

The average number of containers present at the terminal has increased to approximately 200. This means that there are 4000 pallets present on the terminal. In case we would let a program calculate the best option for every rack, it would be too time-consuming. The program that should calculate these preferred racks took 30 minutes, after which it gave memory errors. Therefore, a selection should be made of all containers that are likely to arrive on a day. This list should consist of all containers that can arrive. In case the preferred container cannot be picked another container is picked by CTVrede (section 4.1.2). This deviating container should also be in the container list that is used as input for the tool.

6.1.3 Accessibility

As the employees in the warehouse cannot be bothered with ambiguous storage advice, the tool should be clear and easily accessible. The proposal per rack should be clear within one action, this can be a scan of the container or clicking the container in a program. A tool that prints the proposal when the container is selected results in the best results.

6.1.4 Back-up

Recently, it occurred that containers arrived that were not on the terminal. This happened due to unforeseen circumstances that are likely to occur again. The tool should be able to support the warehouse supervisor in making decisions even if the container is not known. An overview of the warehouse should be present within the tool, which offers the employee to search where the products with the same lot number or quality are in the warehouse. This prevents the employees from making wrong decisions in case the container is not known by the tool.

6.2 Picking policy

The steps necessary to smoothen the implementation process of the picking policy is explained in the following section.

6.2.1 Data gathering and validation

The same WMS data used for the storage policy can be used as input for the picking policy. The table used for the picking policy should consist of information about all pallets (Figure 6-1). Based on this information the sequence of the pallets can be calculated. Using the combination of the previous mentioned data, the picking policy can be carried out as mentioned in section 4.4.2.2.

	Pallet Code	productcode	zone code	bin code	lot no_ on pallet	External Lot Number	ColorCode	Entry_Date	Storing_Date	Storing_Time
1	P-487491	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:40:49.703
2	P-487493	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:44:19.477
3	P-487492	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:46:12.987
4	P-487494	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:47:23.967
5	P-487495	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:48:14.757
6	P-487496	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:49:02.687
7	P-487497	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:49:27.647
8	P-487498	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:51:52.473
9	P-487499	TPPPNT25B4000	HAL 2B	2BA0101	33305	72139705	NULL	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:53:24.250
10	P-487500	TPPPNT25B4000	HAL 2B	2BA0101	33306	72139705	QA92	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 08:53:54.097
11	P-487508	TPPPNT25B4000	HAL 2B	2BA0101	33306	72139705	QA92	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 09:14:18.897
12	P-487507	TPPPNT25B4000	HAL 2B	2BA0101	33306	72139705	QA92	2021-11-11 00:00:00.000	2021-11-11 00:00:00.000	1754-01-01 09:14:24.233

Figure 6-1 Information current stock

6.2.2 Improve cake selection process

The employees of Gam Bakker currently manually do the selection of cake pallets. This results in waiting time between the order of Company X and the actual proposal of Gam Bakker. Improving/automating this process leads to a higher throughput time, which offers possibilities for the ordering of butter based on quality.

6.2.3 Butter selection

As butter is the biggest product group at this moment, the order and transport process should be as fast as possible. By proving that the cake selection process can be carried out faster, Company X will be more interested in implementing the ordering of butter based on quality. As the selection process of butter pallets is harder than the cake process (section 5.5.1.3), a project group should be formed to smoothen this process.

As already mentioned, the biggest improvement can be gained by implementing the storage and picking of butter based on quality. To smoothen up the selection of cake pallets, a tool should be created that calculates the different qualities necessary to fulfil the order of Company X. This process is done manually, but as the one responsible from Company X is retiring and Company X wants to outsource this process to Gam Bakker, Gam Bakker should be able to propose pallets within minutes. By using a tool instead of doing it manually, it speeds up the process and the employees of Gam Bakker can use their time, which is already scarce, for other activities.

6.3 Conclusion

In order to implement the picking and storage policies as discussed in Chapter 5, various aspects should be considered to make sure this process is as smooth as possible.
The subjects that desire most attention for the storage policy are:

- Data gathering and validation
- Computing time
- Accessibility
- Back-up if container was not on the terminal

All aspects desire a different approach to solve the foreseeable problems. However, all capabilities necessary to deal with these aspects are present at Gam Bakker and these foreseeable problems should be dealt with in reasonable time.

The picking policy has other points of attention, except for the first one:

- Data gathering and validation
- Improve cake selection process
- Butter selection

The data gathering and the cake selection process are both internal process and should therefore be dealt with solely by Gam Bakker, Company X is not involved in this process. The butter selection process demands that Company X is actively involved in changing the current working method. In case the foreseen problems are solved, the implementation of this process can lead to a better performance of the warehouse of Gam Bakker.

7 Conclusion and recommendations

As the possible burdens for implementation have been discussed, conclusions are given in section 7.1. The limitations that may have altered the research are discussed in section 7.2. Section 7.3 discusses the scientific relevance of this research. Finally, practical recommendations for Gam Bakker are given in section 7.4.

7.1 Conclusions

The motivation behind this research was the (literal) growth of Gam Bakker in combination with the lack of development in the warehouse operation. This resulted in the following research question, as mentioned in section 1.6:

"How to improve the storage and picking policy, to decrease waste and increase the throughput of the warehouse?"

The analysis of the current situation at Hoogtij 2 has shown that the choice of using shuttle racks without adapting the storage and picking policy has led to inefficient warehouse operations. The storage policy is based on the moment of arrival, after which the pallets are placed at the nearest available rack. The picking policy does not take the storage sequence of the pallets into account and Company X determines which pallets are picked. These policies lead to the following conclusions of the analysis:

- 12.2% of the movements is unnecessary, a pallet is moved without being ordered
- Multiple lot numbers are stored in the same rack
- There are no data available for the warehouse employees, they make decisions on experience or incorrect indications

Literature showed that only the operational decisions can be altered, as the (semi-) long term decisions have already been made at Hoogtij 2. Using a fast-pick area to improve the warehouse logistics is not possible due to a misfit with the limitations of the shuttle racks. To conclude, there is not one operational policy that suits all the requirements for Hoogtij 2, hence the policies are created based on practical rules within the limitations of the warehouse.

For improvement of the storage policy, the pallets should be put away based on lot number instead of moment of arrival. In case the lot number is present in the warehouse, the pallets should be placed in the same rack or at least close (first above, thereafter next to each other). In case the lot number is not present, the pallets should be placed in the hall with least occupation. Furthermore, pallets that are moved from one rack to another should be placed in racks with same lot number.

The picking policy at Hoogtij 2 should take the sequence of pallets into account. Pallets that are at the front of the rack have a higher priority of being picked than pallets that are behind other pallets. This decreases the chances of sorting pallets to fulfil orders. The selection of butter orders should be done by Gam Bakker instead of by Company X. This means that pallets can be picked based on product code and quality instead of lot number. The process for butter will then be the same as the selection of cake orders.

These policies have been evaluated by using a simulation study. In this study it was found that, with the future occupation of at least 75%, the following improvements can be gained by implementing the new policies instead of the current policies:

- The number of unnecessary movements decreases with 66%
- The average time to complete an order decreases from 46:25 to 20:45 minutes
- The average transport time per pallet decreases with 37%

These results confirm that the improvement of policies can minimize waste and maximize the throughput of the warehouse.

Coming back to the research question, the following adaptions for the storage and picking policy have been found:

- Storage based on lot number
- Taking the sequence of pallets into account when picking
- Select butter orders based on quality instead of lot number

7.2 Limitations

This research has some limitations. The biggest limitation is the lack of available data. Hoogtij 2 was opened in October 2021, which means that all relevant data is gathered over a period of only 8 months. Data gathered before this period can lead to false conclusions as the warehouse capacity has increased with Hoogtij 2 and different type of products are stored. This limitation means that the used data has been obtained over a brief period and data can give a misleading indication due to start-up problems.

The simulation is also subject to various limitations. First, only direct pallet movements have been considered while the employees of Gam Bakker also perform other activities, for example labelling pallets. The time a pallet is on the shuttle is not part of the transport time per pallet and therefore the actual transport time can differ from the simulation. Second, the simulation assumed that the chosen policies were used from the moment the warehouse was opened. In reality however, the warehouse is already filled with pallets when the new policy is implemented. These pallets are stored according to the current policy and will thus not be placed at the ideal location according to the new policy. This can lead to a worse performance than calculated with the simulation. Pallets are not stored as desired and the picking policy can choose the wrong pallets, which leads to even more transport time and pallet movements.

7.3 Scientific relevance

This research is strongly focussed on the warehouse situation at Gam Bakker, which means that the direct scientific relevance is limited. However, due to the lack of literature about operational decisions concerning a shuttle rack system, we add something new to the literature:

- A method to base operational decisions on for a shuttle rack system
- Focus point for storage and picking policies in a shuttle rack system

These subjects have been thoroughly analysed and used for the improvements of the warehouse operation of Hoogtij 2. The same approach could be used for other situations, as the FIFO-policy limits the options for improving the warehouse efficiency regarding shuttle racks. The analysis of the current situation and the use of Discrete Event Simulation is not new and can already be found in literature.

7.4 Recommendations for Gam Bakker

First, we recommend Gam Bakker to implement the storage policy that allocates pallets based on either lot number or product code and quality. This change in policy does not require high investment costs.

The storage policy has proven to be an improvement compared with the current policy. Regarding this policy we have the following recommendations:

- The policy should be implemented in such a way that the employees can access and understand the necessary information. A Power-BI tool has been created to do so, which can be seen in Appendix D.
- The warehouse employees should actively validate the tool. In case decisions, based on the same information, by the tool structurally differ from the decisions of the employees, the tool must be checked for incorrect outputs.

The current picking policy should change to a policy where the storage sequence of pallets is taken into account. This requires a change in the working method as currently the WMS decides which pallets should be picked. This method could be implemented in the same way the current cake selection is imported into the WMS.

Gam Bakker should convince Company X to implement the butter selection based on quality. By sharing the results of this research in combination with the current inefficiencies, Company X will be encouraged to help improve the whole process. With this method, the pallets can be stored and picked based on quality, which results in a major improvement of the warehouse operation. As this is a time-consuming project, a project group should be created to make sure this process fits both companies well.

A second point of cooperation with Company X, should be a better insight in the outbound orders placed by Company X. As shown in multiple sensitivity analyses, more information leads to an even better performance of the warehouse. As Gam Bakker needs information that Company X is not able to gather and share with Gam Bakker, a project group could implement a better information platform that can be used by both companies.

Furthermore, Gam Bakker should try to improve the partnership with CTVrede. Gam Bakker is dependent on the terminal process of CTVrede and currently this process lacks information. Improving the information flow could lead to other improvement possibilities for the warehouse. In case more information is present about either the location or the sequence of pallets, the dock selection at Hoogtij 2 could improve. As no research has been done on this influence, further research is necessary for the partnership with CTVrede.

Finally, in case Gam Bakker has implemented all recommendations of this report, it should look into the possibility to change the warehouse lay-out. It has been proven that in case there are no height restrictions the warehouse process will improve even more. This can be part of a follow-up research as not only the product groups per level should change, but a different type of lay-out could even lead to a better performance.

References

Altinkaya, M., & Zontul, M. (2013). Urban bus arrival time prediction: A review of computational models. *International Journal of Recent Technology and Engineering*.

Ballestín, F., Perez, A., & Quintanilla, S. (2020). A multistage heuristic for storage and retrieval problems in a warehouse with random storage. *International Transactions in Operational Research*, 1699-1728.

Bartholdi, J., & Hackman, S. (2008). Allocating space in a forward pick area of a distribution. 1046-1053.

Carla, A., Carvalho, M., & Pereira, G. (2008). *A Warehouse Design Decision Model - Case Study.* Estoril, Portugal: IEEE.

Chow, H., Choy, K., Lee, W., & Lau, K. (2006). Design of a RFID case-based resource management system for warehouse operations. *Expert Systems with Applications*, 561-576.

Curry, R. (2013). A Duration-of-Stay Storage Policy in the Physical Internet. *Industrial Engineering Undergraduate Honors Theses*.

Deen, S. (2021). *Onderzoek naar het optimaliseren van de interne logistiek.* Bachelor Scriptie, Hogeschool Inholland Haarlem.

Ekren, B., Sari, Z., & Lerher, T. (2015). Warehouse Design under Class-Based Storage Policy of Shuttle-Based Storage and Retrieval System. *IFAC-Papersonline*, 1152-1154.

ERIM. (2022). *Storage Strategies*. Retrieved from Material Handling Forum: https://www.erim.eur.nl/material-handling-forum/research-education/tools/calc-order-picking-time/what-to-do/storage-strategies/

Gu, J., Goetschalckx, M., & McGinnis, l. (2006). Research on warehouse operation: A comprehensive review. *European Journal of Operation Research*, 1-21.

Gu, J., Goetschalckx, M., & McGinnis, l. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*, 543-549.

Heragu, S., Mantel, R., & Schuur, P. (2005). Mathematical model for warehouse design and product allocation. *International Journal of Production Research*, 432-440.

IBM, S. W. (2021, 4 16). *Retrieval Algorithm*. Retrieved from IBM: https://www.ibm.com/docs/en/warehouse-management/9.5.0?topic=retrieval-algorithm

Janssen, R. (2001). On the Use of Multi-Criteria Analysis in Environmental Impact Assessment in The Netherlands. *Journal of multi-criteria decision analysis*, 101-109.

Jeong, R. (2004). *The prediction of bus arrival time using automatic vehicle location systems data.*

Kong, C., & Masel, D. (2007). A high-throughput pick line for split-case order picking. *Proceedings of the 2007 Industrial Engineering Research Conference*, 860-865.

Kong, C., & Masel, D. (2008). Methods for Design and Management of a Fast-Pick Area in a Warehouse. *Proceedings of the 2008 Industrial Engineering Research Conference*.

Law, A., & Kelton, W. (1991). *Simulation Modelling and Analysis.* New York: McGraw-Hill.

Mahajan, P. S., & Ingalls, R. (2004). Evaluation of Methods Used to Detect Warm-Up Period in Steady State Simulation. *Proceedings of the 2004 Winter Simulation Conference*, 671.

Mes, M. (2021). *Simulation Modelling using Practical Examples: A Plant Simulation Tutorial.* University of Twente.

Petersen, C., Aase, G., & Heiser, D. (2004). Improving order-picking performance through the implementation of class-based storage. *Operations Management and Information Systems*, 534-544.

Petersen, S. G. (1999). The impact of routing and storage policies on warehouse efficiency . *International Journal of Operations & Production Management*, 1053-1064.

Richards, G. (2014). *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern.*

Rouwenhorst, B., Reuter, B., Stockrahm, V., Van Houtom, G., Mantel, R., & Zijm, W. (2000). Warehouse design and control: Framework and literature review. *European Journal of Operational Research*, 515-533.

Schuur, P. (2021). Lecture 7_Design Of A Fastpick Area _The Fluid Model_2021. Enschede, Overijssel.

Verhoeven, R. (2018). *Halfautomatisch compact opslagsysteem met een hoog rendement.* Retrieved from docplayer.nl: https://docplayer.nl/106957373-Pallet-shuttle-halfautomatisch-compact-opslagsysteem-met-een-hoog-rendement.html

Williams, B., & Hoel, A. (2003). Modeling and Forecasting Verhicular Traffic Flow as a Seasonal ARIMA Process: Theoretical Basis and Emperical Results. *Journal of Transportation Engineering*, 664-672.

Zhao, X., Zhang, R., Zhang, N., Wang, Y., Jin, M., & Mou, S. (2020). Analysis of the Shuttle-Based Storage and Retrieval System. *IEEE*, 146154-146165.

A. Appendix introduction

Time planning

As already mentioned, this report consists of multiple sub questions to answer the research question. To make sure every sub question is handled correctly in a timely manner, a time management schedule has been created. This schedule can be found in Figure A-1, where an indication is given for the processing time per sub question.

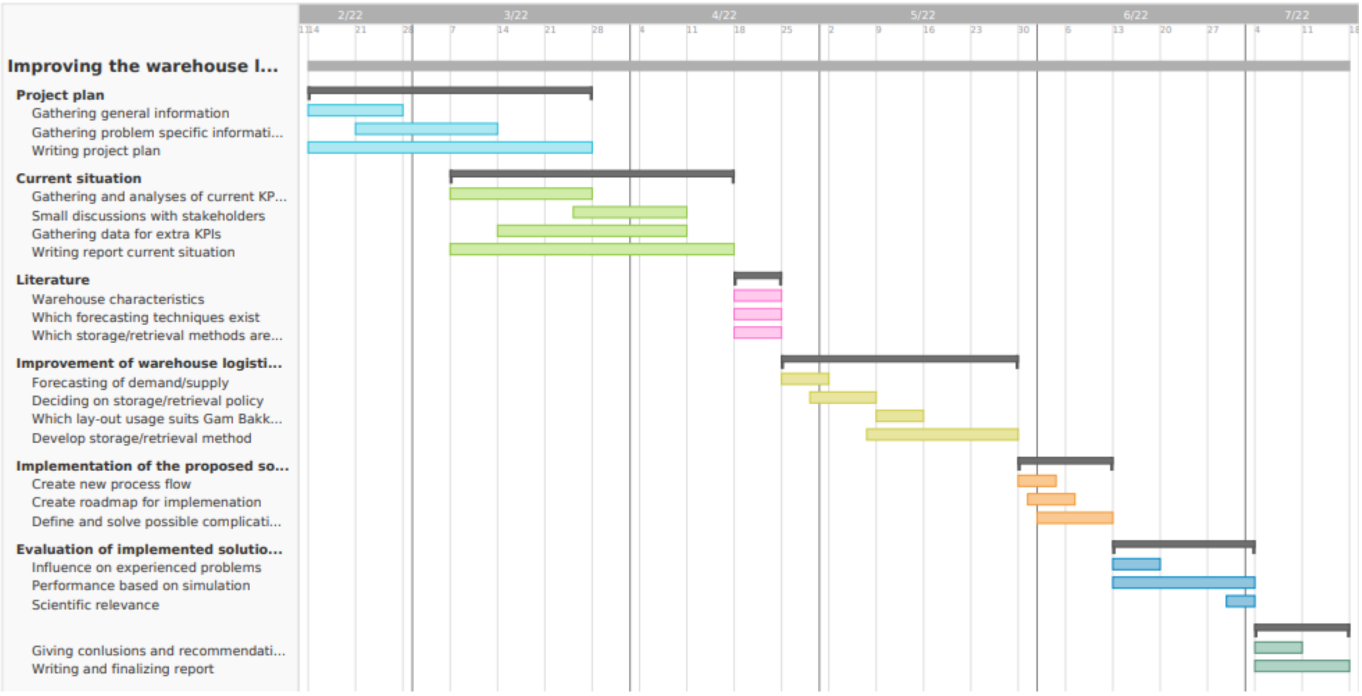

Figure A-1 Time Planning

B. Appendix current situation

Pallet allocation

592
2246
3900

	Hal 2B			Hal 2C			Hal 2D			Hal 2E	
						2DA40		2DB40	2EA40		2EB40
						2DA39		2DB39	2EA39		2EB39
			2CA38		2CB38	2DA38		2DB38	2EA38		2EB38
			2CA37		2CB37	2DA37		2DB37	2EA37		2EB37
			2CA36		2CB36	2DA36		2DB36	2EA36		2EB36
2BA35		2BB35	2CA35		2CB35	2DA35		2DB35	2EA35		2EB35
2BA34		2BB34	2CA34		2CB34	2DA34		2DB34	2EA34		2EB34
2BA33		2BB33	2CA33		2CB33	2DA33		2DB33	2EA33		2EB33
2BA32		2BB32	2CA32		2CB32	2DA32		2DB32	2EA32		2EB32
2BA31		2BB31	2CA31		2CB31	2DA31		2DB31	2EA31		2EB31
2BA30		2BB30	2CA30		2CB30	2DA30		2DB30	2EA30		2EB30
2BA29		2BB29	2CA29		2CB29	2DA29		2DB29	2EA29		2EB29
2BA28		2BB28	2CA28		2CB28	2DA28		2DB28	2EA28		2EB28
2BA27		2BB27	2CA27		2CB27	2DA27		2DB27	2EA27		2EB27
2BA26		2BB26	2CA26		2CB26	2DA26		2DB26	2EA26		2EB26
2BA25		2BB25	2CA25		2CB25	2DA25		2DB25	2EA25		2EB25
2BA24		2BB24	2CA24		2CB24	2DA24		2DB24	2EA24		2EB24
2BA23		2BB23	2CA23		2CB23	2DA23		2DB23	2EA23		2EB23
2BA22		2BB22	2CA22		2CB22	2DA22		2DB22	2EA22		2EB22
2BA21		2BB21	2CA21		2CB21	2DA21		2DB21	2EA21		2EB21
2BA20		2BB20	2CA20		2CB20	2DA20		2DB20	2EA20		2EB20
2BA19		2BB19	2CA19		2CB19	2DA19		2DB19	2EA19		2EB19
2BA18		2BB18	2CA18		2CB18	2DA18		2DB18	2EA18		2EB18
2BA17		2BB17	2CA17		2CB17	2DA17		2DB17	2EA17		2EB17
2BA16		2BB16	2CA16		2CB16	2DA16		2DB16	2EA16		2EB16
2BA15		2BB15	2CA15		2CB15	2DA15		2DB15	2EA15		2EB15
2BA14		2BB14	2CA14		2CB14	2DA14		2DB14	2EA14		2EB14
2BA13		2BB13	2CA13		2CB13	2DA13		2DB13	2EA13		2EB13
2BA12		2BB12	2CA12		2CB12	2DA12		2DB12	2EA12		2EB12
2BA11		2BB11	2CA11		2CB11	2DA11		2DB11	2EA11		2EB11
2BA10		2BB10	2CA10		2CB10	2DA10		2DB10	2EA10		2EB10
2BA09		2BB09	2CA09		2CB09	2DA09		2DB09	2EA09		2EB09
2BA08		2BB08	2CA08		2CB08	2DA08		2DB08	2EA08		2EB08
2BA07		2BB07	2CA07		2CB07	2DA07		2DB07	2EA07		2EB07
2BA06		2BB06	2CA06		2CB06	2DA06		2DB06	2EA06		2EB06
2BA05		2BB05	2CA05		2CB05	2DA05		2DB05	2EA05		2EB05
2BA04		2BB04	2CA04		2CB04	2DA04		2DB04	2EA04		2EB04
2BA03		2BB03	2CA03		2CB03	2DA03		2DB03	2EA03		2EB03
2BA02		2BB02	2CA02		2CB02	2DA02		2DB02	2EA02		2EB02
2BA01		2BB01	2CA01		2CB01	2DA01		2DB01	2EA01		2EB01

Figure B-1 Time per pallet per rack past 6 months

2B	2C	2D	2E
1358.4	0	672	0
1730.9	0	2040.2	1536
473.7	841.8	936.1	852.2
1119.8	1287.8	732.2	1093.1
688.7	1120.9	1736.4	704.9
1630	1712.6	1218.2	1341.5
1399.5	2347.4	1494.4	1397.9
1667.9	1617.8	1231.3	1044.5

2347.4
1173.7
0

Figure B-2 Time per pallet per height past 6 months

C. Appendix simulation

Simulation model

As previously mentioned, the model is built in Siemens Plant Simulation, a discrete event simulation program. The model is explained from top to bottom, starting with an overview of the warehouse, following a hall and last a rack. The methods are not in the figures as it does not give a better understanding of the model and will make things more complicated.

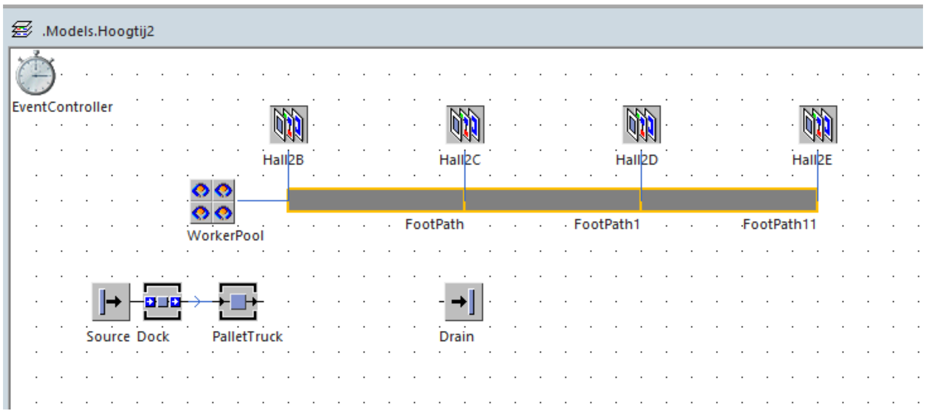

Figure C-1 Simulation Model: Warehouse

As can be seen in Figure C-1, the warehouse self is built out of 4 halls (2A is the powder hall and thus not built). The halls are connected with footpath which enables the employees to travel between the different halls. A product is created at the source after which it is immediately sent to the docks. At the docks, the best rack possible is chosen considering the policy in place. Thereafter, the product is transported to the chosen rack which can be seen in Figure C-2. A hall consists of all racks that are in place, for example hall 2B has 2 times 35 racks, which means that there 70 racks in total.

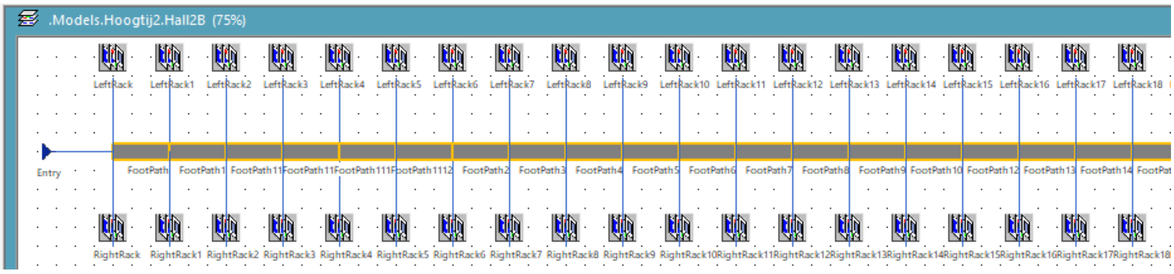

Figure C-2 Simulation Model: Hall

In case a product has been transported to the rack, it is placed in “storingbuffer” (Figure C-3). If an employee is available the product is sent to “Storing” where it will take an employee the total time of transportation and storing before a product is stored in its final destination, which is one of the 8 levels. In case the product is ordered, the pallet is placed on “pickingbuffer” and transported to the drain where it will leave the warehouse.

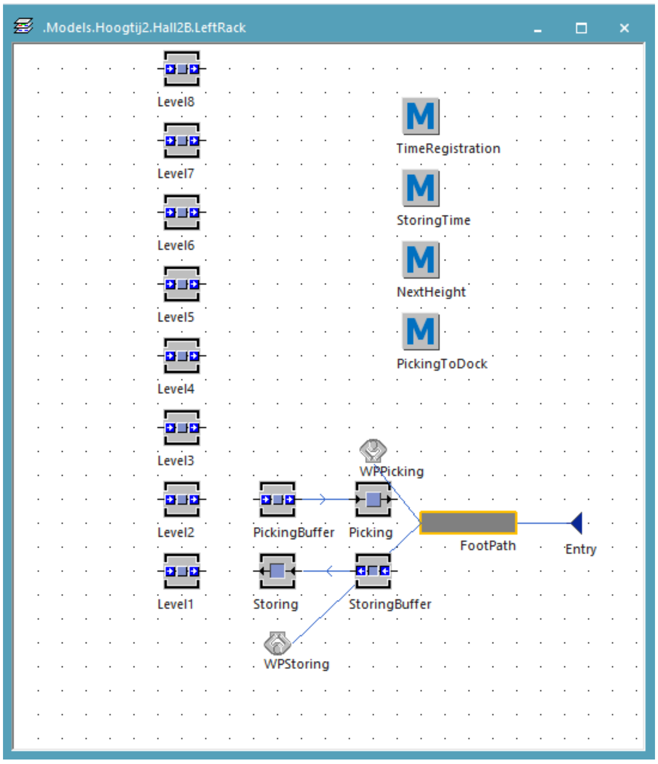

Figure C-3 Simulation Model: Rack

Distribution

The distribution used at the source of the simulation should be the same as the one that occurs in reality. Therefore, the actual time between arrivals from containers, that ware transported from the terminal to the warehouse, is used to validate the distribution that is used. When looking at the actual data, it follows the same pattern a Poisson distribution follows and therefore a test was conducted whether it is statistically correct to assume that the actual distribution is also a Poisson distribution. Figure C-4 shows the actual measured frequency of time between arrivals and the expected frequency of time between arrivals if it is a Poisson distribution. The frequency is on the y-axis, while the bin numbers (bin 1 is 24 – 25.1, bin is 25.1 – 26.2) are on the x-axis.

A chi-square test is used to validate whether this distribution indeed follows a Poisson distribution. The hypothesis is that this is a Poisson distribution and in case the total error is less than 66.4 we cannot reject this hypothesis and therefore assume that it is indeed a Poisson distribution. After conducting a chi-square test, we get a total error of 64.7 which is lower than the maximum of 66.4. Which means that we can assume that the arrivals of the containers indeed follow a Poisson distribution.

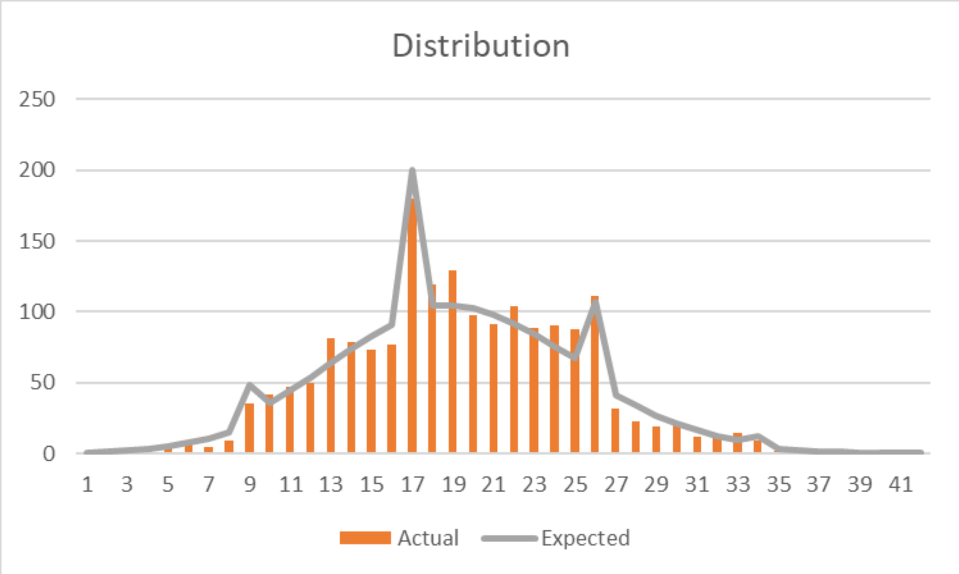

Figure C-4 Actual distribution vs Poisson Distribution

Warm-up period

The warm-up period is based on Welch's graphical method, where all calculations are done over a period of 113 days and simulation runs. Two different KPIs have been used to make sure the warm-up period is determined correct.

The first KPI used is the average number of movements a pallet experiences before leaving the warehouse. As can be seen in Figure C-5, the number of movements increases from 2 to 2.2 within 5 days, whereafter the line becomes constant. Unfortunately, after 45 days there is a slight increase, which means that the simulation is in a steady state after 50 days.

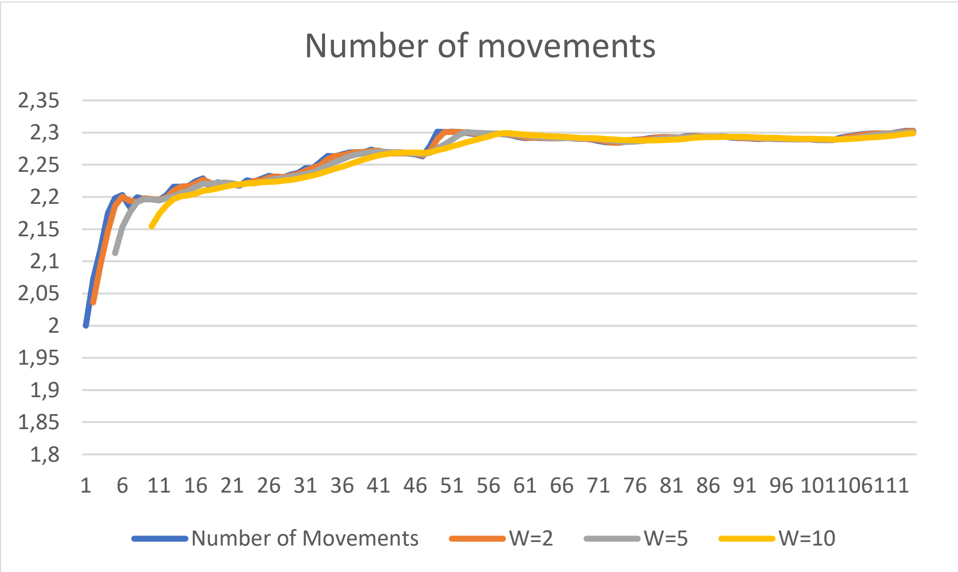

Figure C-5 Average number of movements

The same approach is used for another KPI, namely the transport time per pallet. Figure C-6 clearly shows that the transport time is not steady in the first 50 days. After 50 days, the line flattens out and the simulations ends in a steady-state. Therefore, the warm-up period is 50 days.

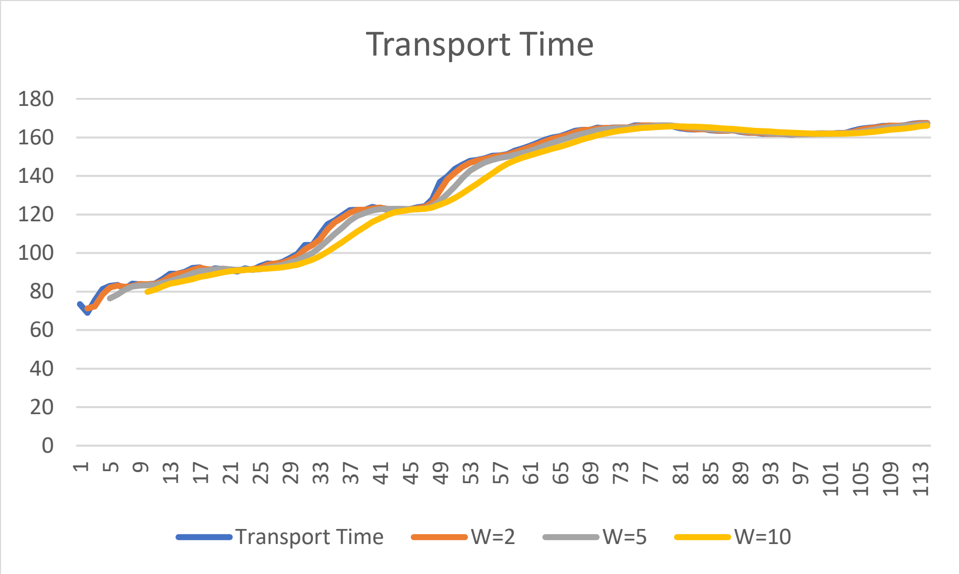

Figure C-6 Average transport time

Number of replications

Before the number of replications is explained, it is important to note that all these measurements have been conducted using the calculated warm-up period, simulation length and an average occupation of 70 percent.

Table C-1 Sequential Procedure for average movements

N	KPI (#)	Average	Var	T-value	CIHW	Delta	Check
1	1.162832						
2	1.176429	1.169631	9.2433E-05	12.7062	0.08638	0.073853	NOT OK
3	1.174539	1.175484	5.4246E-05	4.302653	0.018296	0.015565	OK
4	1.155973	1.16898	9.4641E-05	3.182446	0.01548	0.013242	OK
5	1.166804	1.168436	7.1062E-05	2.776445	0.010467	0.008958	OK

On the second column of Table C-1 can the achieved unnecessary movement per necessary movement be seen. The variation between the different independent runs is low, which results in the fact that after three simulation runs, we can state that the results are statistically significant. The width of the confidence-interval is between 1.158 and 1.179.

Table C-2 Sequential Procedure for average transport time

N	KPI (s)	Average	Var	T-value	CIHW	Delta	Check
1	97.26717						
2	100.8054	99.0363	6.25960180	12.7062	22.47886	0.226976	NOT OK
3	100.6172	99.56327	3.96289748	4.302653	4.94518	0.049669	OK

4	96.19695	98.72169	5.47495777	3.182446	3.723244	0.037715	OK
5	98.46119	98.66959	4.11979004	2.776445	2.520238	0.025542	OK

The same method is used for the data in Table C-2, which results in the same number of necessary replications. The transport time is represented as the time a pallet is actively transported, which is measured in seconds. The width of the confidence-interval is between 96.15 and 101.19.

Table C-3 Sequential Procedure for Number of racks per order

N	KPI (#)	Average	Var	T-value	CIHW	Delta	Check
1	4.920253						
2	4.994595	4.957424	0.00276338	12.7062	0.472304	0.095272	NOT OK
3	5.009215	4.974688	0.00227579	4.302653	0.118507	0.023822	OK
4	4.946293	4.967589	0.00171876	3.182446	0.065969	0.01328	OK
5	4.93487	4.961045	0.00150318	2.776445	0.04814	0.009704	OK

Lastly, the number of replications is calculated by using the number of different racks per order. As there is little variety between the measured number of racks, the number of replications is again 3 Table C-3. Which means that the overall needed number of replications is 3. The width of the confidence-interval is between 4.913 and 5.009. As the minimum number of necessary replications is 5, 5 replications per configuration are used in this research.

D. Appendix recommendation

Storage policy tool

INBOUND SUPPORT

Container Number

ACLU9808961

BUTTER	CAKE	KIBBLED	MASS	TOTAL
50	53	12	82	197

Container	External Pallet Code	Product	Article Code	Article Description	External Lot Number	Quality	Rack
ACLU9808961	62213332-10	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-13	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-15	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-17	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-18	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-19	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-20	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-5	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-6	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-7	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-8	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-9	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BA0104
ACLU9808961	62213332-21	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-38	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-39	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-40	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-41	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-42	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB0104
ACLU9808961	62213332-2	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB2106
ACLU9808961	62213332-3	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB2106
ACLU9808961	62213332-4	CAKE	11DB400KBB120001	10-12% DB400 COCOA CAKE	62213332	Red	2BB2106