

Faster to the loading dock: improving the movement of pallets with paper

Bachelor Thesis – Industrial Engineering and Management



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Preface

Dear reader,

This report presents the results of the bachelor thesis 'Faster to the loading dock: improving the movement of pallets with paper'. This thesis concludes my Bachelor Industrial Engineering and Management at the University of Twente.

I would like to thank several people that helped me to complete my thesis. First of all, I would like to thank Filip de Jonge for showing me all the operations at Solidus Solutions, answering my questions and introducing me to the right people at the warehouse. I would also like to thank Danny Groenheijde for giving me an assignment in the first place.

The past year, it has been difficult for me to stay motivated and I would like to thank my first supervisor Dennis Prak for being so patient with me. I would also like to thank him for always responding to my emails quickly, for giving me a lot of feedback and for pushing to improve my report. I would also like to thank Ipek Seyran Topan for helping me with the preparations in module 11 and for being my second supervisor.

Last, but certainly not least, I would like to thank my friends and family for their support. In particular I would like to thank Justin for always listening to me and helping me when I had questions and I would like to thank my father for helping me find this assignment.

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Management Summary

Solidus Solutions is a manufacturer and converter of recyclable board. This research will be conducted at their site in Bad Nieuweschans. At this location, recycled paper is transformed into new rolls and sheets of paper. The finished sheets are placed on pallets and transported to the warehouse across the street via an underground conveyer. From this warehouse they are transported to either internal or external clients of Solidus Solutions. The focus of this research will be on this warehouse. Customers order several pallets of sheets with the same specifications and a truck only travels to one customer.

The main issues that the company brought forward are the high labour costs of the employees in the warehouse, the fork lift drivers, and the high order collection time. After making a problem cluster, it turned out that the core problems are: no logical floorplan and little standardisation of actions to collect orders. To be able to validate whether this research was successful, the two initial problems are chosen as key performance indicators. The values of these KPIs before and after the research is conducted will validate whether a solution is successful.

The first step of the problem solving approach is to identify the current situation at the warehouse. When the orders enter the warehouse via the conveyer belt, a forklift driver takes the order to one of 25 storage areas. All of the 25 storage areas have different dimensions, so they have different capacities. Currently, the orders get assigned to a random location within the warehouse that has room for such an order. The pallets of papers can be stacked onto each other up to a maximum of three pallets. The orders are placed in storage until a truck comes to collect them. There is a system in place for transportation. If trucks are signed onto this system, the order will be transported to another location that is closer to the loading dock earlier, this location is the loading station. There is a total of four forklifts available for transporting the customer orders within the warehouse.

The second step of the problem solving approach is to research warehouse improvement theories. A few theories are highlighted in this research. The first one is placing larger orders more to the front of the warehouse to decrease the order collection time, this one is also tested later. The second one is to install racks, this would increase the maximum stacking level to four and it most likely makes it easier to handle the pallets, this is also tested. Another solution is to create diagonal aisles through the warehouse, this will decrease the traveling time of forklifts, which is also tested. Yet another solution is to stack the pallets differently to create stability. The last solution is to install an AGV system. These last two possible solutions were not tested.

The third step is to make a simulation of the current situation and to determine the current values of the KPIs labour hours and order collection time. A concept model is made for this basic simulation. It is also determined that of the two KPIs, labour hours is twice as important.

The fourth step is testing the solutions. Most of the solutions mentioned earlier are built into the simulation and tested. Another solution is added: filling up the front of warehouse first. It is also tested what the effects on the waiting time of the customer orders is if small improvements are made to standard time parameters, such as: loading pallets onto a forklift. Lastly, the effect of arranging the forklifts differently on the waiting time is tested.

When comparing the weighted outputs of the current situation with the weighted outputs of the solutions, it can be concluded that a floorplan with diagonal aisles and/or vertical racks should be introduced and that the front of the warehouse should be filled first. Another observation is that the waiting time can be reduced by arranging the forklifts differently in some situations and that the total waiting time decreases with 5% if some standard time measurement, such as the loading time of a forklift, goes down by 1s.

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1. Introduction

This chapter provides an introduction to the bachelor thesis. It introduces the company and its specific department that was researched. The action problems will be identified and a problem solving approach will be established based on the core problems that are found.

1.1. Solidus Solutions

This bachelor thesis will be executed at Solidus Solutions. Solidus Solutions is a manufacturer and converter of recyclable board. They have several locations across the Netherlands and the rest of Europe. This research will be conducted at their site in Bad Nieuweschans. At this location, recycled paper is transformed into new rolls and sheets of paper. These rolls and sheets can have all kinds of measurements and thicknesses depending on the customers' wishes. There are separate storage areas for the finished sheets and rolls. The rolls are stored next to the production hall, the sheets are placed on pallets and transported to the warehouse across the street via an underground conveyer. From these storage units they are transported to either internal or external clients of Solidus Solutions. Customers usually order several pallets of sheets with the same specifications and a truck only travels to a single customer.

1.2. Problem Context

The focus of this bachelor thesis will be on the paper sheet warehouse. The company is working hard to improve the operations concerning this warehouse. The first step was implementing a registration system for the collection of the finished goods. Whereas trucks used to come by to collect orders randomly, now they have to sign into a time slot. Now that their transport policy is improved, they want to make improvements to the warehouse where they store the paper sheets. In this warehouse, customer orders are stored on pallets that are stacked on top of each other and clustered together in different locations. Pathways for the forklifts are created between the different locations.

They have started improving the warehouse by implementing a system that tells the forklift drivers where to place the finished goods, but this system still has some limitations and is not living up to its full potential. The system selects a random location on the floorplan and checks if there is room left for the customer order that it is processing. If there is enough room, it assigns the order to this location. Further research into optimisation of the allocation warehouse system or other optimisation methods for the warehouse have not been conducted.

1.3. Problem identification

The main issues that the company brought forward are the high labour costs of the employees in the warehouse, the fork lift drivers, and the high order collection time. After some investigation into these initial problems (grey), more causal and consequential problems were found. An overview of all these problems can be found in the problem cluster in Figure 1.1.

There is a floorplan available but this is only designed to make navigation easier. The system that is available, places stock in a random location in the warehouse if there is space available. This random stock placement is one of the reasons why the employees make too many movements. This last problem has two other causes: there is little standardisation of the actions that the employees take to collect orders and the warehouse is crowded. Standardisation, in this case, means a certain way of working that is always applied either by employees or by automated systems. The warehouse is crowded because the stock spends too much time in the warehouse since the orders are produced too early.

Together with the lack of employees that handle the orders, the employees making too many movements causes the high order collection time, one of the starting problems. The lack of standardisation that was mentioned before also causes that the collection of a customer order only starts after a truck arrives. This last problem in combination with the high order collection time causes a high waiting time for truck drivers.

The excessive number of movements that the employees make also causes a high number of working hours per employee, which, in turn, causes the other initial problem, the high labour costs. These high labour costs make it difficult to hire new employees, which comes back to the lack of available employees to handle the orders.

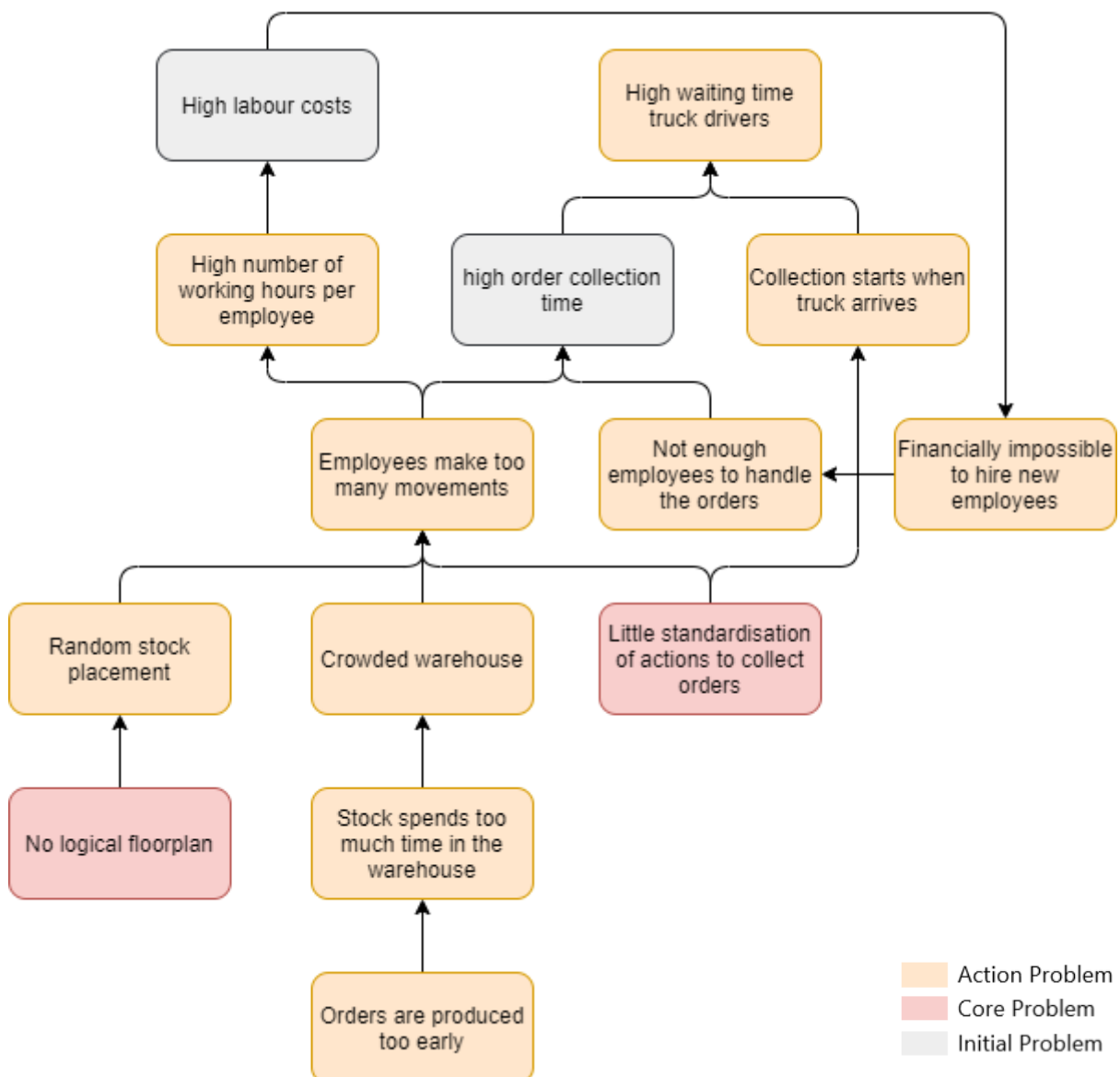


Figure 1.1 – Problem Cluster

In order to start a research, a core action problem needs to be chosen. A good core problem is at the beginning of a chain, so that the solution to the core problem influences most of the other problems in the problem cluster (Heerkens & van Winden, 2012). Only three core problems remain, one of which is not within the scope of this research as the production planning done in another department of the company. This means that 'orders are produced too early' will not be a core problem in this research. Both of the other potential core problems have an impact on both of the initial problems and seem to

be equally important. Although usually one core problem is chosen, these problems can be handled at the same time because they are both happening in the same place and can be simulated in one model.

So, the core problems (red) of this research are identified as:

‘No logical floorplan’ and ‘little standardisation of actions to collect orders’

1.4. Norm and Reality

To be able to validate if the problems were solved to the satisfaction of the company, a norm that has to be reached by the end of this research is set and a reality based on the same variable is established. Since the two initial problems are two key performance indicators (KPIs), labour costs and order collection time, these will be chosen as the validation indicators. The labour costs will be measured using the working hours, because this data is more accessible than actual salaries. When comparing the reality and the norm, the total number of working hours, including overtime hours and hours made by externals, should have decreased.

1.5. Problem Solving Approach

The scope of this research was to optimise the warehouse by finding solutions to the core problem. The end goal of the research is to help the company make improvements to their warehouse by suggesting solutions they can implement themselves. A problem solving approach is made to come to these solutions. In the different phases of this approach, knowledge questions will be answered that will help determine the right solutions for the problems at hand.

1.5.1. Current Situation

The first step of this research was to identify the current situation. In order to create the best solution, it is important to know the context of the problem. Several different knowledge questions were answered to find what the operations in the warehouse are, where this happens and the characteristics of the customer orders that are important to this research. These questions are:

- a) What happens to the customer orders in the warehouse?
- b) How many new customer orders come into the warehouse every day?
- c) How many customer orders leave the warehouse every day?
- d) What information does the warehouse system give the forklift drivers?
- e) How many employees and forklifts are available?
- f) Do different forklifts interfere with each other if multiple orders handled at the same time?
- g) How fast does a forklift drive?

To answer these questions, employees that are involved in the daily operations of the warehouse were interviewed, the daily operations were observed and data concerning the customer orders are analysed. A description of the current situation can be found in chapter 2.

1.5.2. Theoretical framework

The second step was to do research on improvement techniques in warehouses. This research helps to identify possible implementations that can improve the performance of the warehouse. The knowledge questions of the research were:

- a) What methods are used to optimise warehouse layout?
- b) What are standardisation techniques in a warehouse.

The theoretical framework can be found in chapter 3.

1.5.3. Simulation model

A simulation model was made to represent the warehouse with the simulation program Plant Simulation. The findings of the first step of the research will be used to make this model. Before the simulation was build, research was done on the requirements of a good simulation model and a conceptual model of the simulation was made. The current values of the KPIs are determined with the use of this simulation model. The specifications of the simulation model can be found in chapter 4.

1.5.4. Solution testing

In this step of the research, the findings of the second step are applied to the simulation made in the previous step to find the most efficient layout and the best standardisation solutions. The knowledge questions that are answered in this phase are:

- a) What new warehouse layout fit this situation best?
- b) What are the best alternatives to standardise the workshop?
 - What can be done with what is already there?
 - What investments can be made to standardise?

The simulation model was then altered to fit the possible solutions. If these changes have a positive effect on the KPIs, the solutions are a success. The successful solutions form a new layout for the warehouse and make more standardisation possible. Whether or not the solution testing was successful can be found in chapter 5.

1.6.Deliverables

The main deliverables are a new warehouse layout and suggestions for standardisation of the warehouse. These deliverables will help the company to decrease the time it takes to prepare orders and the labour costs by making the warehouse more efficient. These deliverables can be found in chapter 6.

Other deliverables will be a description of the simulation of their warehouse operations with and without implementations in chapters 4 and 5 respectively, and a validation of the solution by comparing the new system with the old system using the KPIs, labour hours and order collection time in chapter 6.

2. Current Situation

This chapter will describe the current situation in the paper sheet warehouse. A flow chart of the warehouse operations is introduced, the current layout is outlined and the specifications of the customer order that are important in the warehouse are described.

2.1. Warehouse Operations

The operations in the warehouse start when a customer order arrives in the warehouse via the underground conveyer. Based on the number and the measurements of the pallets, the warehouse system assigns the order to a random section of the warehouse that still has room for an order of that size. The order, that usually consists of more than one pallet is taken off the conveyer and transported to the right location by a manually controlled forklift. Most forklift drivers take two pallets at a time. The warehouse system also tells the forklift drivers how many pallets should be stacked on top of each other. Once the orders have been placed in their assigned spot, they remain untouched until the customer sends a truck to collect them. Customers can sign into a timeslot to collect their order for a small registration fee. If customers choose to sign in, their orders are transported from the warehouse to a special loading station close to the loading dock shortly before the truck arrives. When customers do not sign in, their order will only be collected after the truck arrives. Trucks that sign in always have priority over trucks that arrive randomly, which means that random trucks have to wait if the warehouse personnel is busy. After a truck arrives, the order is loaded onto the truck and leaves the warehouse. Figure 2.1 depicts the flow chart of the warehouse operations that are described above.

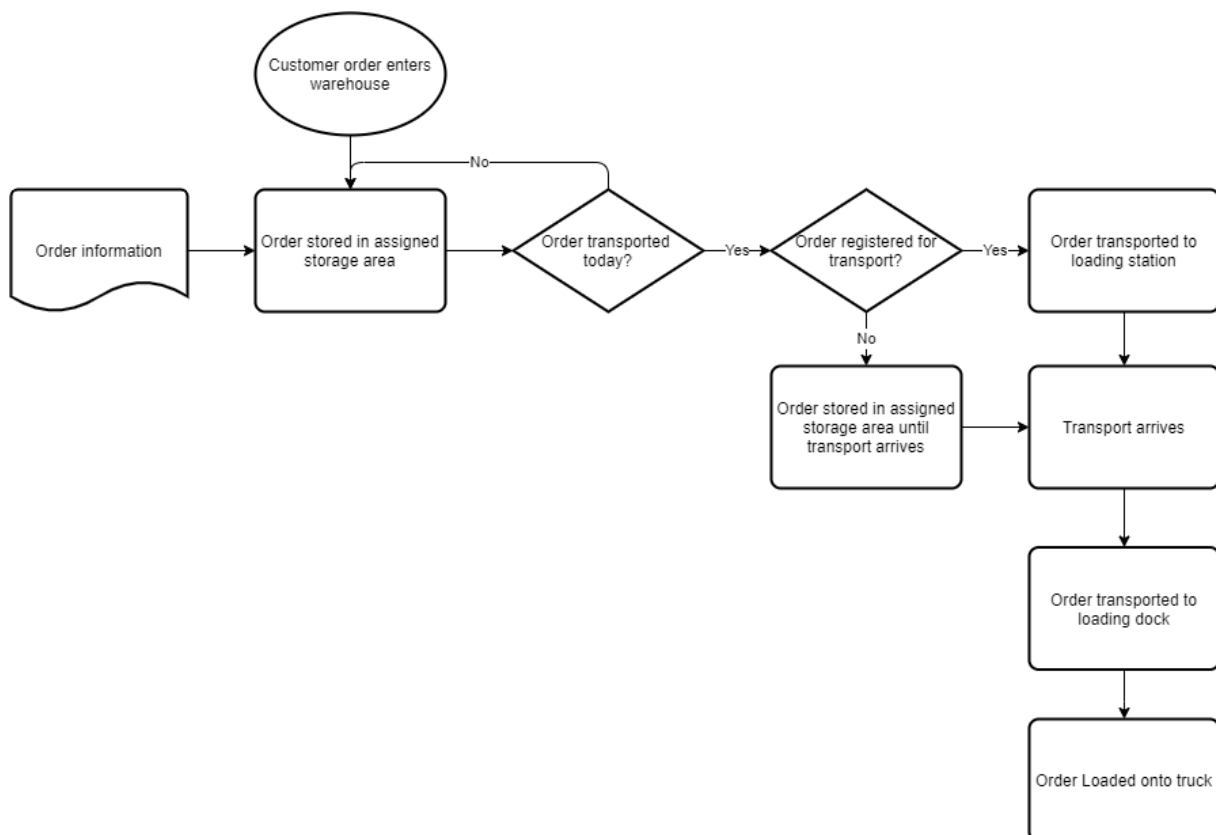


Figure 2.1 – Flowchart of Warehouse Operations

The number of orders that come into the warehouse each day differs a lot per day. On average, about 420 000 tons of paper come into the warehouse each day. Each week, an average of 85 orders leave the warehouse. The number of trucks coming to collect orders is very different every day. The limit to the number of shipments the warehouse can handle is 25 orders per day.

2.2. Warehouse Layout

The customer orders first enter the warehouse via the conveyer belt at the back of the warehouse. All of the pallets with goods on them have a tracking number that is scanned when they are at the end of the conveyer belt. A screen shows the location that the orders should be placed in, it also shows how the pallets should be stacked. Figure 2.2 depicts the conveyer belt, the pallets are scanned on the left of the belt and the information on the pallet is shown on the screen on the right.

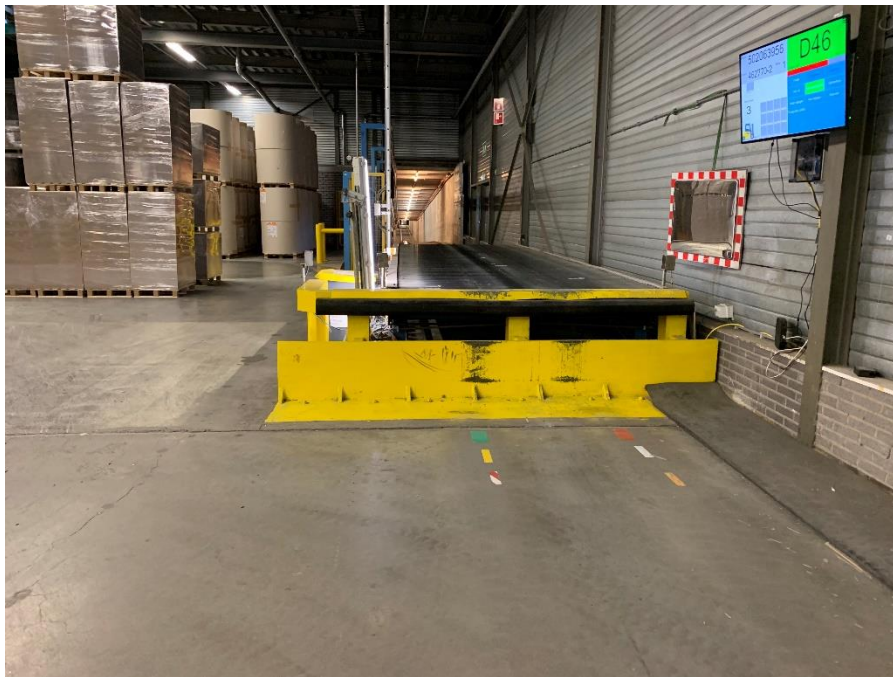


Figure 2.2 – Conveyor Belt

The warehouse has four forklifts that are parked at the front of the warehouse next to the office and the canteen. When an order comes in via the conveyer, the drivers are alerted by a screen that is in their canteen. All of the paths between the storage areas have a width of four meters. Because of the wide paths, forklifts can also pass each other in an aisle if necessary.

The warehouse is divided into 25 storage areas, which are subdivided into numbered rows with a width of two meters. The warehouse system knows the surface area of each of these rows and places an order in a row that fits the specific surface area of all of the pallets of a customer order. It also takes into account that pallets can be stacked on top of each other up to a maximum height of three pallets. These rows are indicated on the ground by two red dots with the number in between, this is also depicted in Figure 2.3.

The warehouse is much higher than the height of three pallets, but the construction will lose its stability if it is stacked higher than three. After an order is placed in a row, the system adjusts the available surface area in this row. At all times, the management can access an overview program that shows how much surface area is available in each row.



Figure 2.3 – Example of Row Indicator

The loading dock and the loading station are located at the front of the warehouse, close to the office. The loading station consists of four rows and pallets are not stacked in these rows, so the pallets can be handled more quickly. The warehouse managers in the office prepare when the orders have to be moved to the loading station. When a truck arrives, they make sure the right order is loaded onto the truck and that the truck drivers secure the pallets to avoid accidents.

A floorplan of the warehouse is depicted in Figure 2.4. The different coloured blocks are the storage areas as they are set by the warehouse management. The numbers in the storage areas indicate how many rows each area has and what the length of the rows is. The arrows in the storage areas indicate the direction in which pallets are stored, in other words, these arrows are drawn along the y dimension of the storage areas. The arrow in the conveyer belt illustrates that the pallets come into the warehouse in that direction. The arrows in the loading station and loading dock indicate that the forklifts drive 'into' these locations in that direction.

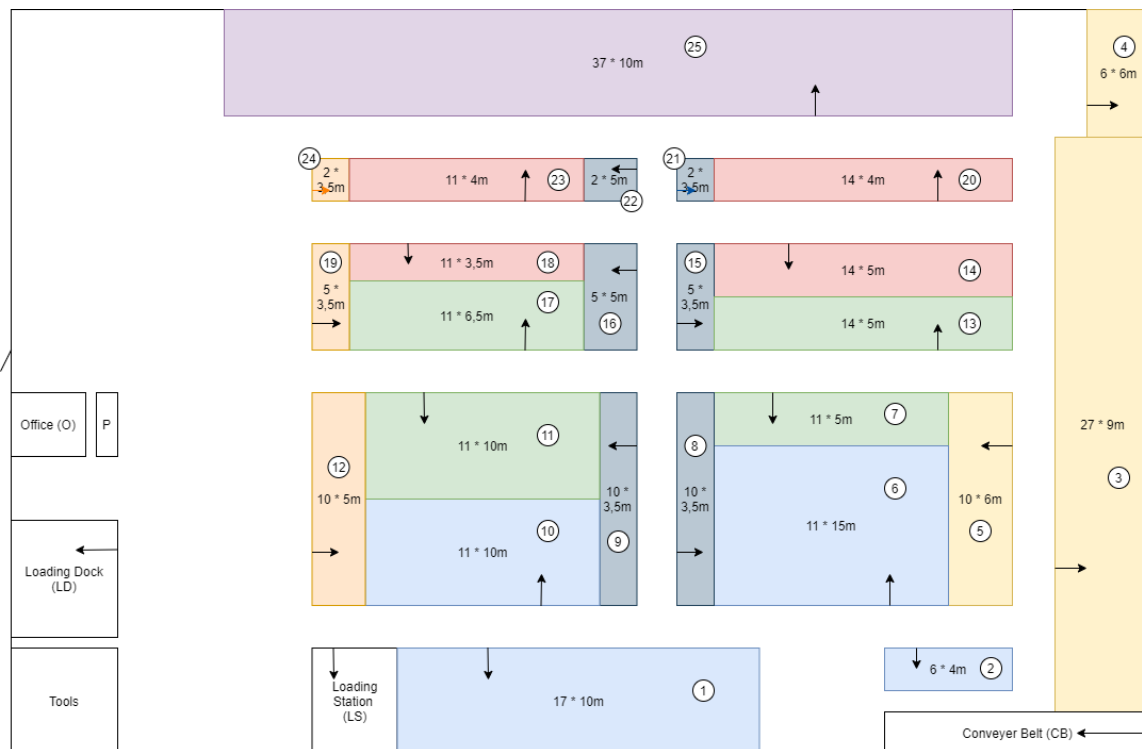


Figure 2.4 – Current Floorplan

2.3.Customer Orders

The customer orders are placed on pallets based on the size of the paper sheets. Instead of having a fixed size, all customer orders get pallets that fit the specific order. This means that there is no set pallet size. The length and width of the pallets can range between 0.5 and 2.1 m. The width of the rows in the warehouse is only 2 m, which means that the widest size pallets would take up two rows instead of one. The maximum height of the goods on the pallets is 1.8 m, so if there are three pallets with maximum height stacked on top of each other, that would be 5.4 m high. The weight of the finished goods on the pallets ranges between 100 and 1500 kg. If the production is 420 tons a day, that means that between 280 and 4200 pallets are filled on that day.

Before the orders are produced, someone overseeing the production decides how the sheets are distributed over the pallets that are available for this order. It is not possible to make the warehouse system aware of this, which can cause problems when stacking the orders. Now, the pallets have to be stacked one-on-one, like Figure 2.5, because their height is not registered in the system. If the system could determine what their height should be, one-on-two stacking, like in Figure 2.6, could be possible. One-on-two stacking would highly increase the stability.

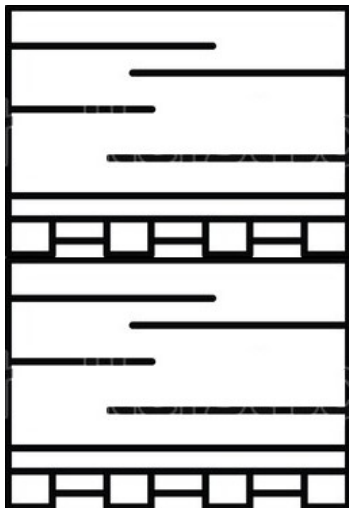


Figure 2.5 – One-on-One Stacking

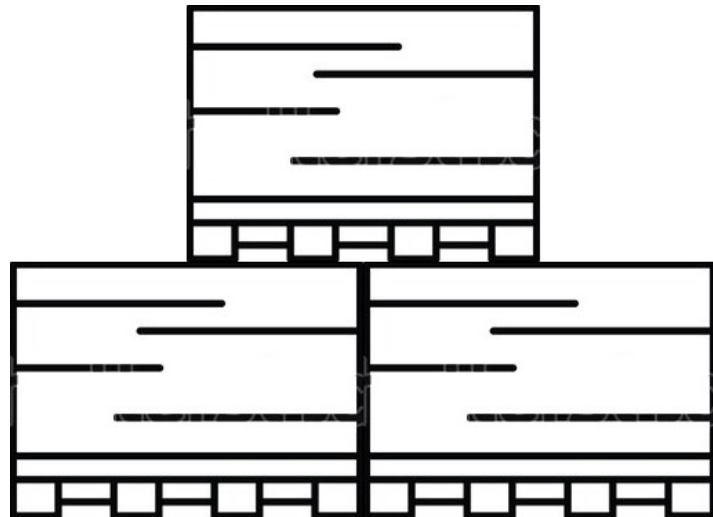


Figure 2.6 – One-on-Two Stacking

3. Theoretical Framework

In this chapter, different approaches to the optimisation of warehouse layout and standardisation techniques will be discussed. The potential answers that are found should be applicable to a distribution warehouse where customer orders of several pallets are stored in the same place. The warehouse already has a system that tells employees where to store customer orders randomly. This system can later tell the employee collecting the order for transport where to find it. The theory that is found will be applied to a simulation of the current situation to see if it benefits this situation.

3.1. Warehouse Layout

There are several methods that can be used for storage allocation: Random Storage, Dedicated Storage and Classed Based Storage (Tambunan & Tambunan, 2020). Currently the company to be researched uses Random Storage, where items can be placed in every available location with the same probability. Dedicated Storage suggests items should have a standard location. This storage method cannot be used in this situation because there are no identical customer orders. In a Class Based Storage system, the warehouse is divided into different parts based on a certain characteristic or criterium. Such a storage policy can also be called ABC zoning (Muharni, Kulsum, & Khoirunnisa, 2019). In case of the company to be researched, the different classes could be divided by weight or number of pallets. More weight might lead to slower trips and more pallets leads to more trips. Placing the bigger and heavier customer orders closer to the loading dock could decrease the overall distance travelled and order collection time.

Currently, the warehouse has no racks in place, pallets are stored on top of each other. There is a limit to how many pallets can be stored on top of each other because at each level, the structure becomes more unstable. Placing racks in the warehouse could be beneficial because they are more stable, which means more pallets can be stacked on top of each other. It will also make material handling for forklift drivers easier, since all the pallets are completely horizontal. A problem of such racks can be the slot size, material on pallets have different heights and if all the racks have the same slot size, the space is not utilised completely (Cardona & Gue, 2018). To improve the utilisation of the pallet racks, there should be several slot sizes. To implement these different slot sizes, pallets get a few set heights and the racks are adapted to those heights. Cardona and Gue (2018) concluded that the use of different slot sizes has huge benefits to warehouse with a larger variety in pallet heights, if the pallet heights do not differ that much, making these different slots is not that beneficial.

Conventional warehouses have a longitudinal layout, which means they have straight and parallel aisles. The warehouse to be researched is similar in a way that the paths all have a 90° angle to each other. For an optimal utilisation of the warehouse, a layout with diagonal aisles can be introduced (Facchini, et al., 2018; Zhou, et al., 2019). These layout shapes are called fishbone and V-shaped, a fishbone layout is depicted in Figure 3.1 and a V-shaped layout is depicted in Figure 3.2. The diagonal aisles create a faster route through the warehouse, which means such aisles reduce the travel time. Such a fishbone or V-shapes aisle could also be created in the warehouse of this research for this purpose.

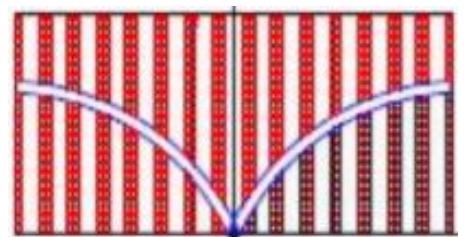


Figure 3.1 – Fishbone layout

To conclude, to optimise the warehouse layout, a Class Based storage policy can be used based on the size of the orders, racks with set slot sizes can be put in place and diagonal aisles can be created. These three options will decrease the movements of employees and with it, decrease the labour costs and the order collection costs.

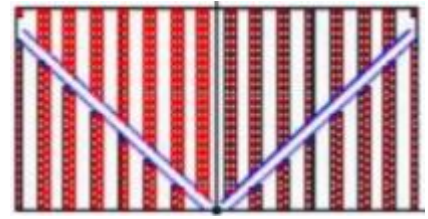


Figure 3.2 – V-Shaped Layout

3.2. Standardisation

In this review, standardisation will be defined as: a certain, easy way of working that is always applied either by employees or automated systems. A structured way towards a standardised working environment is by identifying all the operations that happen when handling inventory and then eliminating the irrelevant actions. Eliminating these actions leaves an effective way of working that will decrease labour costs and order collection time. The principle of identifying the process and then eliminating waste can also be called Value Stream Mapping (VSM) (Baby, N, & Jebadurai, 2018). As a starting point a value stream map should be made. To do this, all operations should be mapped together and the time that it takes to finish them should be determined. By determining which tasks take longest, the bottlenecks in the process can be identified. When the value stream map is created, a list of wasteful actions and their location should be made. These wasteful actions should be eliminated and a future state VSM should be made. This future state VSM will reveal an optimal sequence of operations in the warehouse.

Coming back to the point that was made about setting standard heights for pallets so they fit into racks, this is of course also a form of standardisation. The standardisation of pallet heights is not only useful when the pallets are stored on racks. Implementing a standard pallet height in the current warehouse system would mean that one-on-two stacking is possible. The difference between one-on-one and one-on-two stacking is explained in chapter 2.3. The benefit of one-on-two stacking is more stability, which will decrease the time it takes to load and unload pallet onto and off the forklift.

Another part of standardisation is automation, replacing actions of humans by machines. In a warehouse, a typical automation option is to replace the forklift trucks with Automatic Guided Vehicles (AGV). 'The main purpose of AGV is to more easily send goods from one location to another' (Xu, Cao, Gao, & Cao, 2020). When thinking about implementing an AGV system, it is important to know what design alternatives are available. Different classifications to consider are: guideway or navigation determination, vehicle capacity and vehicle addressing mechanism.

Generally, there are two AGV navigation methods, predetermined and unscheduled path navigation (Xu, Cao, Gao, & Cao, 2020). Since a set layout will be in place during this research, a predetermined path navigation will probably be easier to implement. Predetermined path navigation can be subdivided into unidirectional and bidirectional navigation, which indicate in how many directions an AGV can travel in the same lane (Peters, Smith, & Venkatesh, 1996). To move the pallets around as quickly as possible, bidirectional would be the better option. However, with the current floorplan, a unidirectional navigation could also be used. To navigate an AGV, markers that can be detected by the vehicle should be put in place. This can be done using magnetic nails guidance, optical guidance, tape guidance etc. In order for the AGV to detect sites and what has to be done at this site, landmark magnetic stripe identification or radio frequency identification technology is used (Xu, Cao, Gao, & Cao, 2020).

The vehicle capacity of an AGV can be classified as single load or multiple load (Peters, Smith, & Venkatesh, 1996). Right now, the forklifts take two pallets at a time, so to be just as efficient a multiple load vehicle should be used.

An AGVs addressing mechanism can be either direct or indirect (Peters, Smith, & Venkatesh, 1996). When the vehicle is addressed indirectly, it has a set route where it can pick up orders. In direct addressing, the vehicle can travel to every location in the warehouse to pick up orders. A direct addressing mechanism would work better in this situation, again because the vehicles only need to collect pallets and do not have to collect several items when they are travelling through the warehouse.

In conclusion, to identify a standardised way of working, VSM should be used. Other standardisations that can be implemented are: a standard pallet height and AGVs can be used to automate the operations and thereby standardising the operations.

4. Simulation

In order to validate if the implementations mentioned in chapter 3 improve the current situation, a simulation model is built. A basic scenario is made to indicate what the current order collection time and labour costs are. The basic scenario will be altered to fit the possible improvements. The results of the implementation of possible solutions will be discussed in the next chapters. This chapter will focus on the theory behind a good simulation model and on how this model is built with the use of a concept model. The current values of the KPIs: labour hours and order collection time, are also determined in this chapter.

4.1.Theory behind simulation models

A simulation model is made to generate results in a simplified computer model, these results are used to improve the real world system that the simulation is based on (Robinson, 2014). The first step to making a good simulation model is to make a conceptual model of the real world system. The different components of such a model are: objectives inputs, assumptions, simplifications and outputs (Robinson, 2014). The inputs can be further specified as the structural and operational elements in Table 4.1 (Septiani, Divia, & Adisuwiry, 2020). A flow chart and current layout model are also requirements for a good conceptual model (Geetha, Kulkarni, Kulkarni, Gaitonde, & Kotturshettar, 2020). In chapter 2, a flow chart of the warehouse was already introduced. To make a current layout model, crucial details will be added to the floorplan from chapter 2.

Structural Elements	
Element	Definition
Entities	The moving objects in simulation model
Locations	The places in the simulation model that the entities move through
Resources	The means of transportation of the entities through the simulation model
Path networks	The routes that the resource travels to move the entities through the simulation model
Operational Elements	
Element	Definition
Arrivals	How entities enter the simulation model
Processing	How entities move through the simulation model

Table 4.1 – Structural and Operational Elements

4.2.Model Classification

Simulation models and their structural and operational elements can be classified in three different ways (Banks, Carson, Nelson, & Nicol, 2005). First of all, a static model simulates a particular point in time, while a dynamic model represents the change of a system over time. Second, models can have deterministic or stochastic elements. Deterministic elements are predetermined and will not change when running the simulation. Opposite to deterministic elements, stochastic elements are random and are usually determined with a probability distribution. The last classification is whether a model is discrete or continuous. A discrete model only runs events, events are defined as the movement of entities through the system, while continuous models run constantly, even if nothing is happening.

The simulation model in this study is dynamic, because it simulates the real-time system over a period of time. The model will entail deterministic but also stochastic elements. Some elements, like the distances between the locations in the simulations, will not change during a single run of the simulation and are deterministic. Other elements, like the characteristics of the customer orders, are stochastic, while the customer orders also have different characteristics in the real world system. Lastly, the model is discrete, while the simulation program that is used, Plant Simulation, uses this type of simulation. In conclusion, the simulation model that is used for this research is dynamic, stochastic and discrete.

To make sure the simulation resembles the real system, the warehouse should never be empty. How long the orders are in the warehouse is not important for this study, because there are no working hours devoted to them until they have to be moved to the loading station or the loading dock. However, to make it more realistic the warehouse should never be empty. There should always be orders in the warehouse to make sure that all of the different storage areas are used. So, to ensure there is a warm-up period the order dates of all of the orders that are produced on the same day will be within the same working day five days later. This way, there will not be any orders shipped out of the warehouse the first few days.

The number of orders that are produced and come into the warehouse each day has differed a lot lately. That is why the choice was made to experiment with this number. Different values for the number of customer orders will be used in different runs of the basic simulation. These values will range between 10 and 20. Afterwards it can be determined what the relationship between the number of orders and the KPIs is.

The length, width and height of the pallets of a customer order are used to determine the production time of the customer order. The length and width can range between 0.5 and 2.1 m, the height of a pallet can range between 0.5 and 1.8 m. It is calculated that it takes 71s to produce one cubic meter. So, to determine the production times of orders the amount of cubic meters an order entails is multiplied by 71s.

In the basic scenario all customer orders get assigned a random number that belongs to a store to simulate the random allocation of a customer order to a storage area.

To make a distinction between the orders that are first transported to the loading station before going to the loading dock and the orders that are directly transported to the loading dock, an attribute is added to the entity customer order. This attribute is called 'LoadingStation' and the variable type is Boolean. There is a 72 percent chance of the attribute to be true, in the real world system this would mean that the order is moved to the loading station first. If the attribute is false, the order will only move to the loading dock once the order date is reached in the real world system. In the simulation, the customer orders that have the value 'true' will be handled before the orders that are 'false'.

To summarise, the attributes of a customer order that will be used are: number of pallets, length, width, height, random allocation, order date and loading station.

Locations

Production Hall

In the production hall the customer orders are made that will later enter the warehouse. All of the pallets of a customer order leave the production hall at the same time.

Conveyer Belt (CB)

The conveyer is the location where the customer orders enter the warehouse. From here they are transported to their assigned storage space. The pallets have to be taken off the conveyer belt one by one. If an order arrives before the previous one has been moved to a storage area, a queue is formed.

Parking (P)

The forklifts always start and end a job at the parking space.

Stores (1-25)

The stores are the locations where the customer orders are stored. In the basic scenario there are 25 stores that all have different sizes. Each store is divided into rows that are 2 meters wide. Table 4.2 contains the number of rows every store has and the length of these rows in meters. Once an order is placed in a row, the warehouse system will first put one order in all the other rows before it places a second order in that row.

Store	Xdim #rows	Ydim Length in m	Store	Xdim #rows	Ydim Length in m	Store	Xdim #rows	Ydim Length in m
1	17	10	10	11	10	18	11	3,5
2	6	4	11	11	10	19	5	3,5
3	27	9	12	10	5	20	14	4
4	6	6	13	14	5	21	2	3,5
5	10	6	14	14	5	22	2	5
6	11	15	15	5	3,5	23	11	4
7	11	5	16	5	5	24	2	3,5
8	10	3,5	17	11	6,5	25	37	10
9	10	3,5						

Table 4.2 – Storage Area Dimensions

Loading Station (LS) and Loading Dock (LD)

If a customer signed into a timeslot, the order will be moved to the loading station before being moved to the loading dock. This happens 72% of the time. When a truck arrives to get an order at the order date, it is moved to the loading dock.

In the simulation, two customer orders can be moved to the loading dock at the same time. Orders are moved to a queue before moving to the loading dock. When more than two orders move to the queue, the orders that should be moved to the loading station have priority over those that do not have to be moved to the loading station.

When the attribute LoadingStation is 'true', the time it takes to get to the queue in the simulation is the time it takes to get from the storage area to the loading station in the real world system. The time it takes to get from the queue to the loading dock in the simulation is the time it takes to get from the loading station to the loading dock in the real world system.

When the attribute LoadingStation is 'false', the time it takes to get to the queue in the simulation is zero and the time it takes to get from the queue to the loading dock in the simulation is the time it takes to get from the storage area to the loading dock in the real world system.

Transport

From the loading dock, the customer orders are loaded onto trucks that bring them to the customer.

Resource

Forklift

The resource used to move the customer orders around is a manually driven forklift. The system has four forklifts available. As the forklifts have to be divided before running the simulation, two will transport the orders from the conveyor belt to the storage areas and two will transport the orders from the storage areas to the loading dock.

Path Network

Within the warehouse, the forklifts that transport the customer orders can move around between locations, these movements are:

- Between the parking space and the conveyer belt
- Between the conveyer belt and the assigned storage area
- Between the parking space and the assigned storage area
- Between the assigned storage area and the loading station
- Between the assigned storage area and the loading dock
- Between the loading station and the loading dock

The distance between the parking space and the conveyer belt is 101 meters and the distance between the loading station and the loading dock is 24 meters. The distance to the storage area will decrease or increase depending on which row the customer order is assigned to.

4.3.4. Arrivals

All of the pallets of a customer order arrive at the same time. They are put on the conveyer belt in the production hall and moved to the warehouse. To determine the interarrival time of the customer orders a general set-up time of the machine of 10 minutes and the transporting time within the production hall of 6 minutes is added to the production time of a customer order.

Interarrival time

$$= \text{set up time} + (\text{length} * \text{width} * \text{height} * \text{\#pallets} * 71\text{s}) + \text{transport time}$$

4.3.5. Assumption

Some assumptions were made about the real world system to make the simulation less complex. These assumptions are:

Forklift

- It is assumed that it takes 21 seconds to get out of the office, onto the forklift and start the forklift.
- It is assumed that it takes 15 seconds to turn off the forklift and go to the office.
- It is assumed that a forklift drives 11 km/h.
- It is assumed that forklift drivers always take the shortest route to any location in the system.
- It is assumed that all forklift drivers take 2 pallets at a time.

Production

- It is assumed that the set-up time between orders is 10 minutes.
- It is assumed that the production time per 1 m³ is 1 minute and 11 seconds.
- It is assumed that the transport time in the production hall is 6 minutes.
- It is assumed that there is constant planning.

4.3.6. Simplifications

Some concepts of the real world system were simplified, also for the purpose of a less complex simulation. These simplifications are:

- In the simulation, every customer order is a single entity that moves all the pallets at once visually. The number of pallets in a customer order is used in the calculation of the handling times.
- The whole production line is simplified to one buffer that creates a number of entities at the start of each day.
- The loading station is not added to the simulation model as a location where entities can travel through. Instead, the queue is created. For the customer orders that have to move to the loading station, this queue acts as the loading station.

4.3.7. Processing

How the customer orders move through a simulation of the warehouse is depicted in Figure 4.2.

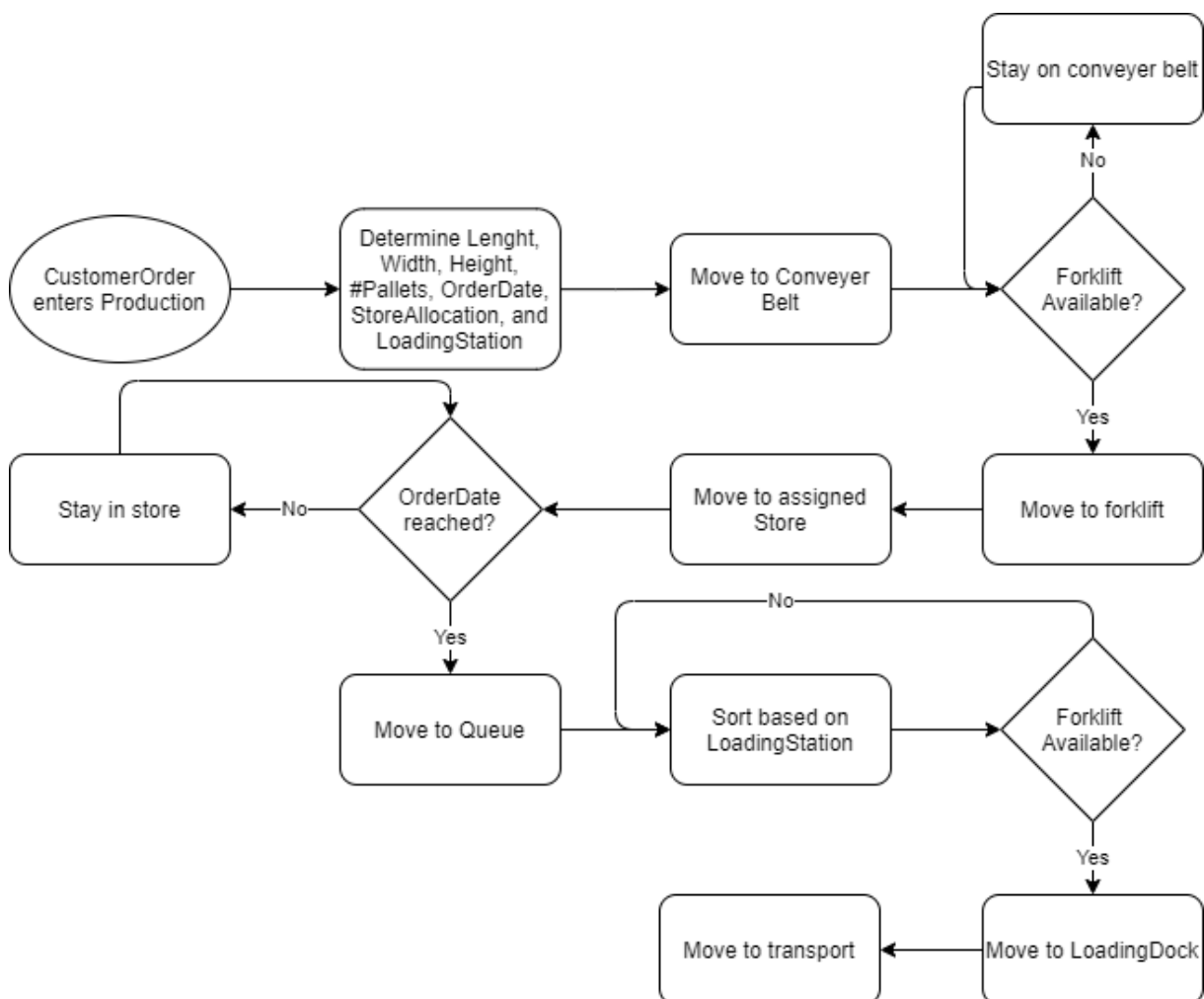


Figure 4.2 – Flowchart Concept Model

4.3.8. Output

The simulation eventually gives an estimation of the two KPIs that are discussed in the chapter norm and reality, labour hours and the order collection time. These two variables will be the most important output of the model.

Labour Hours

The labour hours consist of all the time the forklift drivers spend on customer orders, from getting informed about a task and walking to the forklift, to the moment that they park their forklift after they have completed a task. The events the forklift drivers perform are:

1. Picking orders up at the conveyer and transporting them to their storage location
2. Taking orders from their storage location to the loading station
3. Taking orders from the loading station to the loading dock
4. Taking orders from their storage location to the loading dock

Making the formula for the labour hours:

$$\begin{aligned} \text{Labour hours} &= \text{Transport from Conveyer} \\ &+ \text{Transport to Loading Station from Storage Area} \\ &+ \text{Transport to Loading Dock from Loading Station} \\ &+ \text{Transport to Loading Dock from Storage Area} \end{aligned}$$

A more detailed calculation for the labour hours can be found in appendix A1.1.

Order Collection Time

The order collection time is the waiting time of the truck drivers that come to collect customer orders. A big influence on the order collection time is whether the truck was registered in advance. If a truck is registered in advance, the order is moved to the loading station before the truck arrives and the order only has to be moved from the loading station to the loading dock. If the truck is not registered in advance, the order has to be collected from the assigned store space. This means the order collection time can be defined as one of these two events in the simulation:

1. Taking orders from the loading station to the loading dock
2. Taking orders from their storage location to the loading dock

Making the formula for the order collection time:

$$\begin{aligned} \text{Order Collection Time} \\ &= \text{Transport to Loading Dock from Loading Station} \\ &+ \text{Transport to Loading Dock from Storage Area} \end{aligned}$$

A more detailed calculation for the order collection time can be found in appendix A1.2.

Optimal outputs

To come to the optimal outputs, the best solution for both KPIs should be determined. If both KPIs have a different optimal solution, a compromise between the two KPIs should be determined. It can occur that the labour hours decrease while the order collection time increases or the other way around. To find the optimal outputs, the importance of both problems should be determined. The problem cluster that is presented in Figure 1.1 in chapter 1 shows that both KPIs are caused by both initial problems, so in that sense they are both equally important. However, the KPI labour costs influences more problems in the cluster than order collection time, so it can be concluded that labour hours is the more important KPI. This is taken into account by giving weights to the two KPIs. Labour hours gets a weight of 2 and order collection time gets a weight of 1. This makes the formula for the total weighted outputs:

$$\text{Weighted outputs} = \sum \text{Labour hours} * 2 + \sum \text{Order collection time}$$

The optimal solution is the situation where the outcome of this formula is at its lowest

4.4.Interface

The interface of the simulation model contains all the components that are mentioned above.

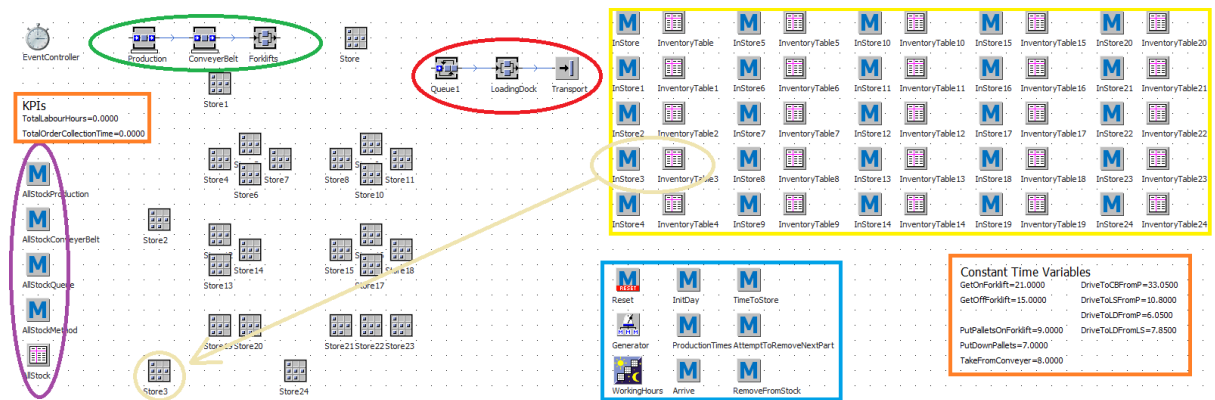


Figure 4.3 – Simulation Interface

The simulation interface is divided into different sections.

The green section is the starting point of the simulation. Every morning, a number of entities is created at the first location, production. All attribute values are determined here. When the production time of the first entity has passed, it moves on to the conveyer belt. When the entity is the first in line at the conveyer belt and a forklift is available, it moves to the next location. Here, the time it takes to take the entire order to the assigned storage area is calculated. When enough time has passed to take the order to the storage area, the entity moves to the assigned store.

The yellow section monitors what happens in the storage areas. When a customer order moves to a store, it also appears in the assigned table and, based on how many customer orders are already in the store, the labour hours and the order collection time are predetermined. When the order date of an order in a store is reached, the entity moves to the queue and the information is cut from the table.

The red section is where the entities move to be transported. First, they go to a queue. When several orders move to the queue at the same time or when the forklifts are still busy with the previous order, they stay in the queue. In the queue, the orders that have to move to the loading station get priority, which means these orders will move out of the queue first. When there is room for an entity at the loading dock, the first entity in the queue moves to the loading dock, from where it moves to transport and leaves the system.

The orange sections contain information that is important for the calculation of the KPIs that will determine whether or not possible solutions are successful. How the KPIs are calculated can be found in appendix A1.1 and A1.2.

The blue section contains the controls of the different locations, like the working hours of the locations and the calculations of the attributes

The purple section helps to further identify if improvements are successful. The table contains information on how long the entities stayed in each location. Later, this information can be used to see if, for example, entities spend less time in queues and more time in the store or if they spend less time in the system in general.

4.5. Reality

To determine the reality, the basic simulation that is described above is used. Different runs are performed with customer orders (CO) per day ranging between 10 and 20. Using the Event Controller that is built into the simulation program, the length of the runs is set to a year by asking the program to simulate 365 days. The values of the two key performance indicators, total labour hours (TLH) and total order collection time (TOCT) are calculated during the runs and the results at the end of the runs are written down in Table 4.3. The average labour hours and order collection time per order are also calculated, so the relationship between the customer orders per day and the KPIs can be analysed. The last column contains the weighted outputs, these numbers have been calculated according to the formula that was previously discussed in section 4.3.8.

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2543106,39	696,74	684715,46	187,59	5770928,24
11	4015	2807295,79	699,20	750659,3	186,96	6365250,88
12	4380	3058932,34	698,39	822494,74	187,78	6940359,42
13	4745	3313621,38	698,34	886122,14	186,75	7513364,9
14	5110	3575140,34	699,64	966935,72	189,22	8117216,4
15	5475	3828594,32	699,29	1038376,04	189,66	8695564,68
16	5840	4094755,36	701,16	1097157,53	187,87	9286668,25
17	6205	4348980,95	700,88	1178987,59	190,01	9876949,49
18	6570	4615010,36	702,44	1241671,1	188,99	10471691,82
19	6935	4880714,6	703,78	1309927,71	188,89	11071356,91
20	7300	5140986,1	704,24	1383002,53	189,45	11664974,73

Table 4.3 – Reality Values

The results for the average labour hours and the average order collection time reveal that the labour hours increase slightly when the number of customer orders per day go up. The biggest storage areas are area 3 and 25, those two are also the furthest from the different handling stations. When the number of customer orders increases, smaller storage areas could get full, in which case there is a bigger chance that these customer orders are moved to the bigger storage areas, that have larger travel times.

4.5.1. Variability

The average labour hours and order collection time do not increase consistently, sometimes the averages even decrease. Most likely, the reason for this is the high variability in customer orders. Some orders could have twice as much pallets as others and the variability in the distance to the storage areas is even bigger, the distance can range between 10 and 130 meters. As the number of pallets and the storage areas are chosen randomly, it is possible that adding extra customer orders decreases the KPIs when the number of pallets is low or if the distance from the working stations is small.

5. Solution Testing

The theory that is presented in chapter 3 will now be used to implement possible solutions into the basic simulation model. The following solutions are implemented based on the theory and on observations made when running the basic simulation:

1. Placing the bigger orders in the front of the warehouse
2. Placing racks that make it possible to store up to 4 pallets high instead of 3
3. Creating diagonal aisles through the warehouse
4. Filling the front warehouses first

For each of these solutions, the changes that were made to the basic model and their outcomes will be discussed. The implementation of the four solutions is judged as successful if they decrease the weighted outputs formula that is set in section 4.3.8.

Other solutions that are mentioned are assumed to influence the standard times set in the last chapter. These solutions are:

5. Implementing a standard pallet height
6. Stacking one-on-two instead of one-on-one

The effect of decreasing the standard times in the simulation is that the values of the KPIs decrease. Since it is not that interesting to evaluate the new values of the KPIs, the effect of decreasing the standard times on the waiting times of the customer orders will be evaluated. There are two moments at which orders can experience waiting times, when they enter the warehouse and there is no forklift available at the conveyer belt and when they have to be moved to the loading station or loading dock and there is no forklift available.

Another way of shortening the waiting time, might be to arrange the forklifts differently, so maybe it would be better to have three forklifts at the conveyer and one at the loading area, or to have one forklift at the conveyer and three forklifts at the loading area. This will also be discussed in this chapter.

5.1.Order classification

Placing orders that require more movements closer to the loading dock, will decrease average the order collection time.

5.1.1. Changes to the basic model

The classification of the orders is done when the orders are created at the beginning of a day. In the basic simulation, this is done randomly. In this simulation, the orders will be classified based on the number of pallets they contain. The orders with the most pallets will then be assigned to the stores that are closest to the loading dock. The storage areas are divided into four groups, where group 1 is closest to the loading dock. The number of pallets an order can have is also divided into four groups. The first group of storage areas will be filled with the group with the highest number of pallets. The division of the groups can be found in Table 5.1. After determining in what group of stores the order should be placed, a random store from that group is assigned to that order.

Group number	Storage areas	#Pallets
1	1, 10, 11, 12, 17, 19	>9
2	8, 9, 15, 16, 18, 23, 24	7-9
3	2, 5, 6, 7, 13, 22	4-6
4	3, 4,14, 20, 21, 25	<4

Table 5.1 – Storage Classification

5.1.2. Output

Again, runs were performed with the customer orders per day ranging between 10 and 20 and the running time was set at 365 days. The values of the two key performance indicators, total labour hours and total order collection time are written down in Table 5.2, as well as the average labour hours and order collection time per customer order. The weighted outputs of this solution are in the last column of the table.

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2597690,59	711,70	682736,69	187,05	5878117,87
11	4015	2864818,93	713,53	744082,36	185,33	6473720,22
12	4380	3132099,37	715,09	819445,68	187,09	7083644,42
13	4745	3393489,24	715,17	881808,05	185,84	7668786,53
14	5110	3659466,56	716,14	962399,32	188,34	8281332,44
15	5475	3920280,77	716,03	1030948,47	188,30	8871510,01
16	5840	4192281,34	717,86	1096302,02	187,72	9480864,7
17	6205	4448931,86	716,99	1173385,85	189,10	10071249,57
18	6570	4719240,13	718,30	1238947,45	188,58	10677427,71
19	6935	4978908,02	717,94	1296695,35	186,98	11254511,39
20	7300	5243710,22	718,32	1369847,74	187,65	11857268,18

Table 5.2 – Output Solution 1

When comparing this table to the reality values in Table 4.3, it can be concluded that order classification does not decrease the KPIs significantly, it even increases some values. Although the average order collection time does decrease a little, the average labour hours increase too much, making this implementation unsuccessful. That this option is unsuccessful indicates that the distance between the storage areas and the conveyer belt has a great influence on the labour hours and that maybe placing the bigger orders closest to the conveyer belt would have a better outcome. However, this was not included in this research. Again, the variability seems to have an influence on the results because the averages sometimes decrease when the number of customer orders per day goes up.

5.2. Racks instalment

Installing racks in the warehouse will increase the number of pallets that can be placed on top, or above, of each other. The racks are also accessible from two sides, which will most likely decrease the traveling distance of the forklifts. It will also be easier for forklift drivers to place and remove pallets from the racks because they are situated on a more stable surface, this will have a positive influence on the standard times. This last advantage will not be tested with this implementation as it cannot be determined how much time this would save. However, what happens to the KPIs when the standard times are decreased will be investigated in section 5.5.

5.2.1. Changes to basic model

A few changes need to be made to the simulation to represent a warehouse of the same size but with racks installed. The most important one is that the floorplan needs to be altered, the current locations do not allow for racks as they are not the same size. In the new floorplan that represents this possible solution, all of the racks have the same size. Figure 5.1 and Figure 5.2 are the floorplans that was made for this situation. The racks have different lengths and all of them have a depth of 5 m. There is still a 4 m wide path for the forklifts everywhere. The racks are still divided into rows of 2 m, these rows can be accessed from both sides of the racks with the exception of the rows in storage area 1, 2 and 3 in Figure 5.1 and storage area 1 and 2 in Figure 5.2 as these are put against the wall.

The total surface area of the storage areas in the old floorplan was 3,860 m², the surface area of the new floorplan in Figure 5.1 is smaller, 2,910 m². However, in the basic situation only three pallets can be stacked on top of each other, making the surface area for the three stacking levels 11,580 m², while the new situation has four levels, making that surface area 11,640 m². The surface area of the storage areas in Figure 5.2 is 2,760 m², making the surface area for the four levels of this floorplan 11,040 m², which is only 4,7% less than the original floorplan.

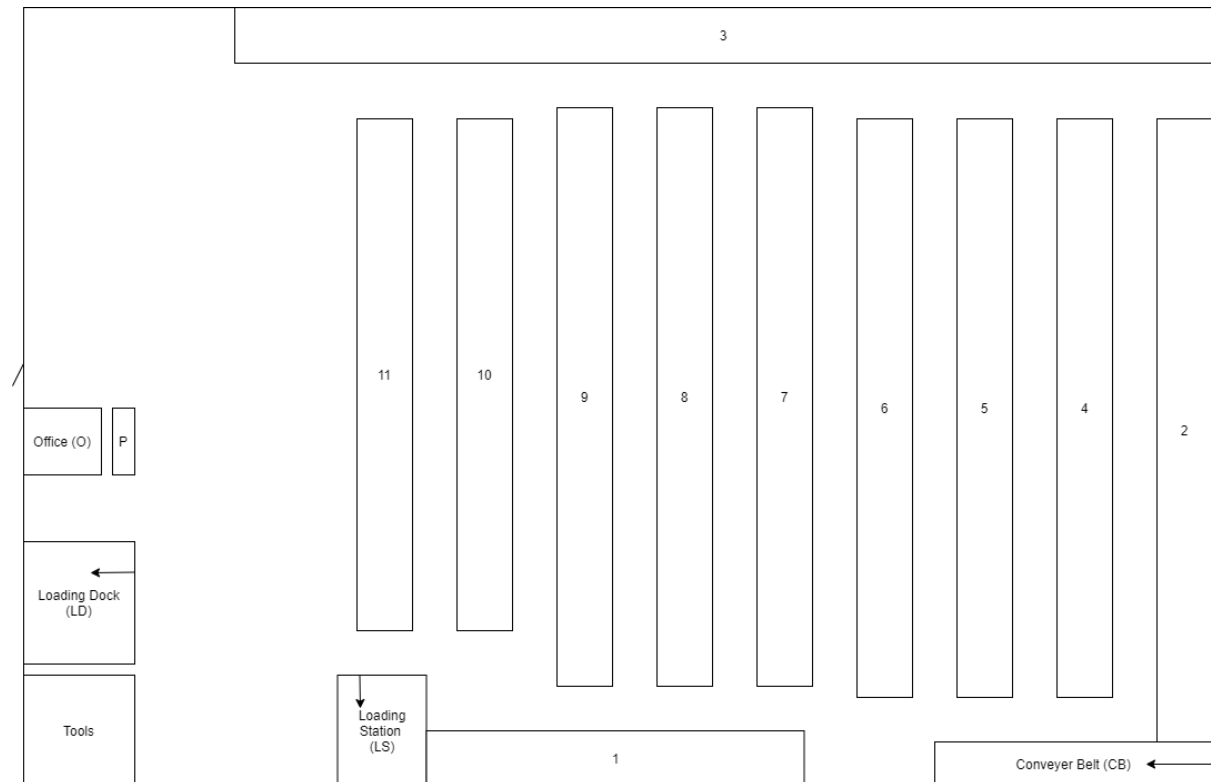


Figure 5.1 – Floorplan 2.1

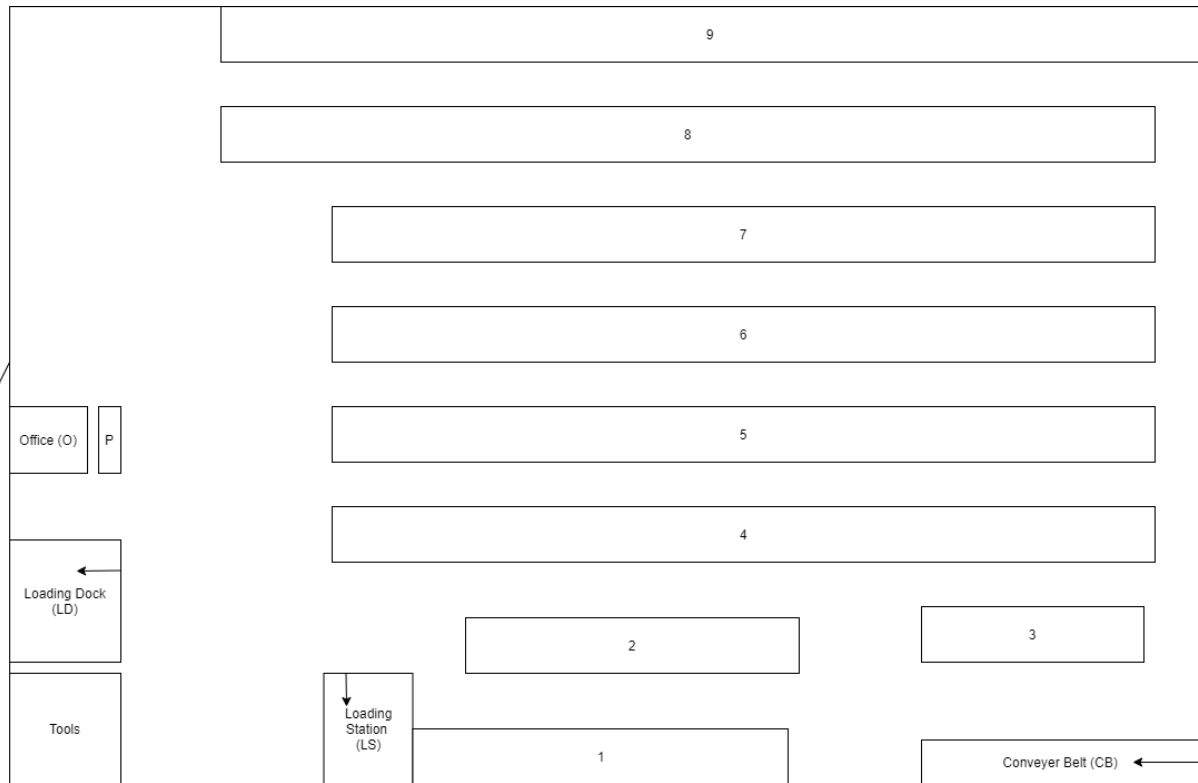


Figure 5.2 – Floorplan 2.2

5.2.2. Output

Different simulations are made for both floorplans and runs with customer orders per day ranging between 10 and 20 are performed with a running time of 365 days. The values of the two key performance indicators, total labour hours and total order collection time, of the first floorplan are written down in Table 5.3, as well as the average labour hours and order collection time per customer order. The same is done for the second floorplan in Table 5.4. The weighted outputs of this solutions are in the last column of both tables.

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2347834,81	643,24	684173,98	187,44	5379843,6
11	4015	2599562,45	647,46	748154,52	186,34	5947279,42
12	4380	2848882,92	650,43	819730,08	187,15	6517495,92
13	4745	3099270,56	653,17	888138,67	187,17	7086679,79
14	5110	3354580,81	656,47	971784,39	190,17	7680946,01
15	5475	3607298,98	658,87	1042559,69	190,42	8257157,65
16	5840	3872455,02	663,09	1103433,38	188,94	8848343,42
17	6205	4128177,29	665,30	1186283,31	191,18	9442637,89
18	6570	4399389,32	669,62	1256973,08	191,32	10055751,72
19	6935	4664939,55	672,67	1320621,12	190,43	10650500,22
20	7300	4932519,04	675,69	1397585,09	191,45	11262623,17

Table 5.3 – Output Solution 2.1

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2662642,35	729,49	709965,21	194,51	6035249,91
11	4015	2935607,40	731,16	777050,4	193,54	6648265,2
12	4380	3183850,19	726,91	849188,45	193,88	7216888,83
13	4745	3436166,23	724,17	907765,47	191,31	7780097,93
14	5110	3683659,65	720,87	981190,95	192,01	8348510,25
15	5475	3940039,19	719,64	1049973,69	191,78	8930052,07
16	5840	4202652,58	719,63	1112074,32	190,42	9517379,48
17	6205	4455113,39	717,99	1182662,93	190,60	10092889,71
18	6570	4726280,31	719,37	1249919,36	190,25	10702479,98
19	6935	4988936,77	719,39	1307735,11	188,57	11285608,65
20	7300	5263151,93	720,98	1375805,01	188,47	11902108,87

Table 5.4 – Output Solution 2.2

When comparing these two tables to the reality values in Table 4.3, it can be concluded that placing racks in the width of the warehouse as is done in Figure 5.1 is successful and that placing the racks in the length of the warehouse as is done in Figure 5.2 is unsuccessful. Introducing the first floorplan makes it easier to reach all storage areas from the conveyor belt and the loading station, which has a positive effect on the KPIs. The second floorplan is probably unsuccessful because it makes travelling to the storage areas from the conveyor belt more difficult.

The averages of the KPIs seem to increase more consistently in Table 5.3, which means that having a smaller range of distances to storage areas, creates a more predictable pattern when the number of customer orders per day goes up. Table 5.4 again shows that the variability has a big influence.

5.3.Diagonal aisles

Creating diagonal aisles will make traveling through the warehouse easier. It does, however, cost more aisle space.

5.3.1. Changes to basic model

For this possible solution, the biggest change will also be the floorplan. Just creating diagonal aisles in the existing floorplan would take away too much storage space, so two new floorplans were made. These floorplans are presented in Figure 5.5 and Figure 5.6. In the floorplan in Figure 5.5, a diagonal aisle is created to make it easier to travel to and from the loading dock and loading station and another diagonal aisle makes it easier to travel to the conveyor belt. To make sure there is still enough storage space in the this floorplan, a storage area was placed in the middle, too much space would be lost without this storage area. The other floorplan makes it easier to travel to conveyor belt and the storage areas in the back of the warehouse from the parking area. Like the original floorplan they has storage areas with different measurements. All of the storage areas have rows of 2 m that can only be accessed on one side.

The total surface area of the storage areas in the first floorplan is 3,654 m², which is only 5,5% less than the 3,860 m² of the basic floorplan. The total surface are of the storage areas in the second floorplan is 3,670 m², which is only 4,9% less than the basic floorplan.

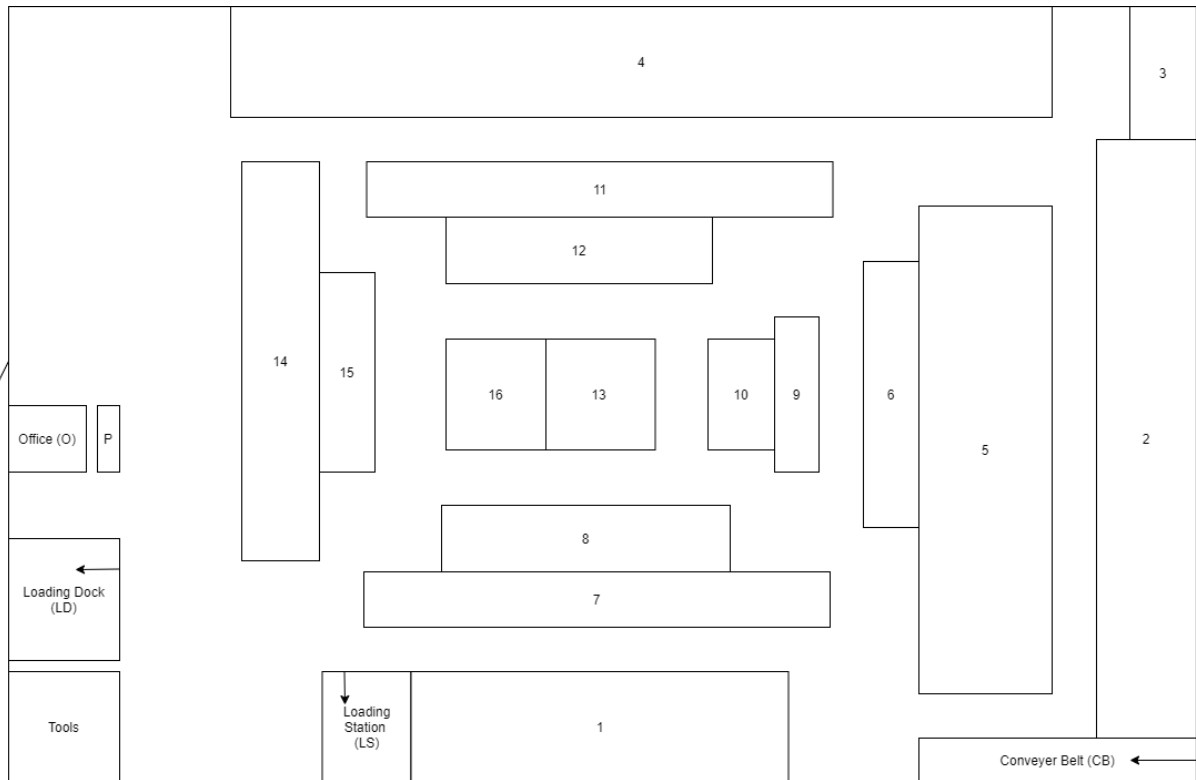


Figure 5.5 – Floorplan 3.1

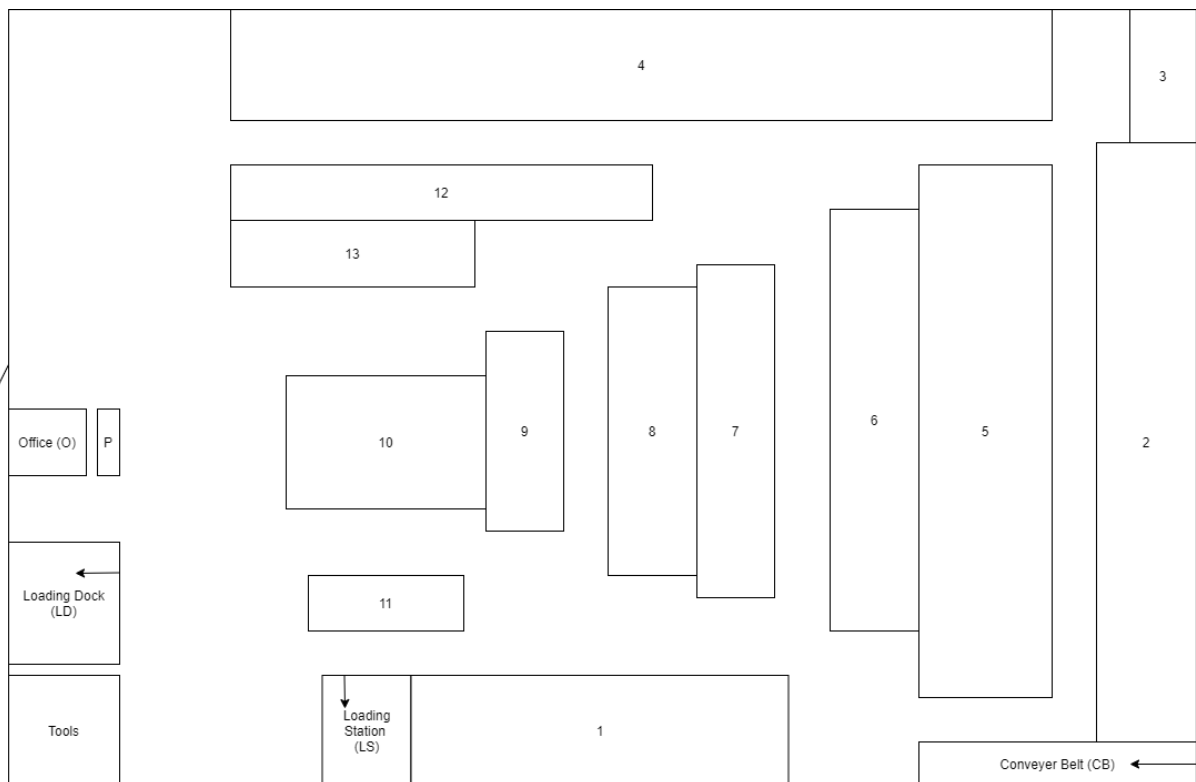


Figure 5.6 – Floorplan 3.2

5.3.2. Outputs

Different simulations are made for both floorplans and runs with customer orders per day ranging between 10 and 20 are performed with a running time of 365 days. The values of the two key performance indicators, total labour hours and total order collection time of the first floorplan are written down in Table 5.5, as well as the average labour hours and order collection time per customer order. The same is done for the second floorplan in Table 5.6. The weighted outputs of this solutions are in the last column of both tables.

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2442021,46	669,05	674779,98	184,87	5558822,9
11	4015	2704151,97	673,51	739364,02	184,15	6147667,96
12	4380	2954823,01	674,62	810008,7	184,93	6719654,72
13	4745	3200117,51	674,42	876795,05	184,78	7277030,07
14	5110	3453764,11	675,88	958659,33	187,60	7866187,55
15	5475	3708757,26	677,40	1027819,31	187,73	8445333,83
16	5840	3980040,61	681,51	1085451,3	185,86	9045532,52
17	6205	4231511,74	681,95	1167166,81	188,10	9630190,29
18	6570	4501965,62	685,23	1235419,57	188,04	10239350,81
19	6935	4766474,86	687,31	1299079,32	187,32	10832029,04
20	7300	5017920,89	687,39	1368674,83	187,49	11404516,61

Table 5.5 – Output Solution 3.1

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2400480,49	657,67	669538,75	183,44	5470499,73
11	4015	2652035,91	660,53	732258,17	182,38	6036329,99
12	4380	2900778,08	662,28	798036,21	182,20	6599592,37
13	4745	3149149,82	663,68	864134,59	182,11	7162434,23
14	5110	3400388,33	665,44	943668,12	184,67	7744444,78
15	5475	3650215,59	666,71	1014096,9	185,22	8314528,08
16	5840	3911475,46	669,77	1073058,34	183,74	8896009,26
17	6205	4159919,31	670,41	1149621	185,27	9469459,62
18	6570	4422689,76	673,16	1217978,82	185,38	10063358,34
19	6935	4680916,93	674,97	1278607,28	184,37	10640441,14
20	7300	4990440,19	683,62	1362826,74	186,69	11343707,12

Table 5.6 – Output Solution 3.2

When comparing these two tables to the reality values in Table 4.3, it can be concluded that creating diagonal aisles is a successful solution. The values in both tables are lower than the values in the reality table. The floorplan in Figure 5.6 is the more successful one, as it has the lowest values. This floorplan makes for the lowest distances to all the storage areas from the standard locations.

The averages of the KPIs also seem to increase more consistently in both tables, which adds to the theory that a smaller range of distances to storage areas, creates a more predictable pattern when the number of customer order per day goes up.

5.4. Filling the front storage areas first

During the simulation of the concept model, it was obvious that the warehouse was not completely filled yet. An example of this is depicted in Figure 5.7, this is the end result of a run with 18 customer orders per day. Filling up the front of the warehouse first instead of filling it up randomly could decrease the values of the KPIs.

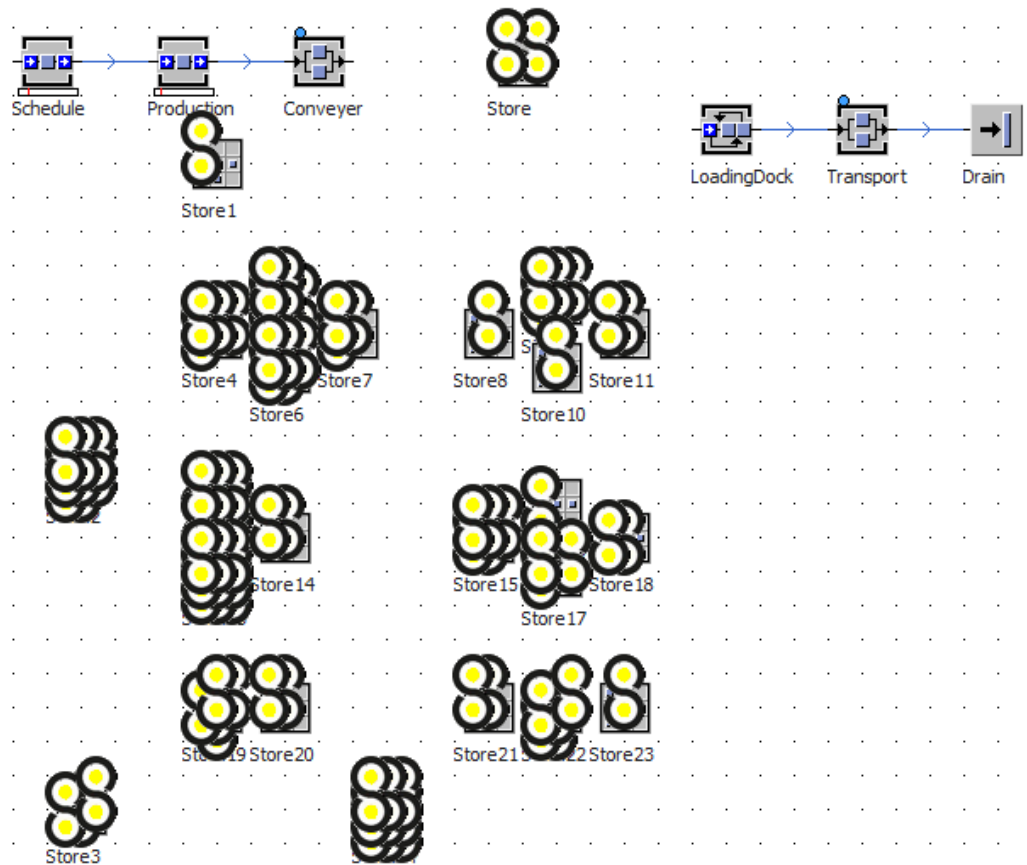


Figure 5.7 – End Result 18 Customer Order Per Day

5.4.1. Changes to basic model

For the implementation of this solution, the table that was created for the first solution, which is discussed in section 5.1.1, is used. When the customer orders enter the warehouse, they are first assigned to one of the stores in the top two rows of the table. Only if these warehouses are full, the customer orders will be assigned to storage areas in the bottom two rows.

5.4.2. Outputs

Runs were performed with the customer orders per day ranging between 10 and 20 and the running time was set at 365 days. The values of the two key performance indicators, total labour hours and total order collection time are written down in Table 5.7, as well as the average labour hours and order collection time per customer order. The weighted outputs of this solutions are in the last column of the table.

CO/day	CO total	TLH in seconds	Average LH in seconds	TOCT in seconds	Average OCT in seconds	Weighted outputs in seconds
10	3650	2418221,89	662,53	637349,02	174,62	5473792,8
11	4015	2677222,06	666,80	704441,4	175,45	6058885,52
12	4380	2924943,44	667,80	770380,52	175,89	6620267,4
13	4745	3171955,9	668,48	834420,28	175,85	7178332,08
14	5110	3421095,82	669,49	901755,72	176,47	7743947,36
15	5475	3670693,52	670,45	971133,55	177,38	8312520,59
16	5840	3934015,49	673,63	1034153,45	177,08	8902184,43
17	6205	4181778,96	673,94	1103933,2	177,91	9467491,12
18	6570	4447959,88	677,01	1172142,07	178,41	10068061,83
19	6935	4710491,2	679,23	1239567,15	178,74	10660549,55
20	7300	4968901,34	680,67	1310231,88	179,48	11248034,56

Table 5.7 – Output Solution 4

When comparing this table to the reality values in Table 4.3, it can be concluded that filling the front of the warehouse first is a successful way to reduce the KPIs. From these results, it can also be concluded with certainty that the inconsistent values of the average labour hours and the average order collection time were caused by the large variety in travelling distances. By making the range smaller the variability decreases and the values rise in a more predictable pattern.

5.5. Influencing waiting time

In this section, the effect of changing the standard time and changing the number of forklifts at the different stages on the waiting time of the customer orders will be analysed. First, the waiting time of the orders in the basic simulation is determined. There are two different stations at which orders wait for available forklifts, the conveyer belt and the queue. Waiting at the queue in the simulation is the same as an order waiting to be picked up from the store when a truck comes to collect it or when it has to be moved to the loading station, but all of the forklifts are busy. Table 5.8 contains information on the total waiting time at the conveyer for all of the customer orders combined and on the total waiting time at the queue for all of the customer orders combined. The table also shows the total waiting time of the two stations combined.

CO/day	Total waiting time in seconds – conveyer	Total waiting time in seconds - queue	Total waiting time in seconds
10	85059,32	41753,76	126813,08
11	82269,82	41908,95	124178,77
12	82872,84	54564,73	137437,57
13	133327,5	61522,37	194849,87
14	750356,6	69058,18	819414,78
15	1201005,74	71409,7	1272415,44
16	1343373,83	72778,82	1416152,65
17	1325750,65	80578,93	1406329,58
18	1338637,42	91047,98	1429685,4
19	1372062,21	104753,1	1476815,31
20	1368142,34	88616,5	1456758,84

Table 5.8 – Waiting Time Basic Simulation

From the table, it can be concluded that the waiting time at the conveyer increases a lot when the number of customer orders per day goes above 12. At that point, the forklifts are getting a lot busier and the production moves faster than the warehouse. The total waiting time at the queue goes up

slowly as the number of customer orders go up, which is to be expected, more orders in the warehouse results to a smaller window between order collections. At 20 customer hours per day, both values go down, which is very strange and might also be due to the variability.

5.5.1. Decreasing standard time

In order to show what would be the effect of lowering the standard times of putting down pallets and picking them up on the waiting time, the only change to the basic model is to change their values in the simulation. The standard times are:

- Get on forklift
- Get off forklift
- Put pallets on forklift
- Put down pallets
- Take pallets form conveyer

Two different experiments are done, one where one of the last three standard parameters that were just mentioned is decreased with 1 second and one where two of the last three standard parameters are decreased by 1 second. The results of the first experiment are in Table 5.9 and the results of the second experiment are in Table 5.10.

CO/day	Total waiting time in seconds – conveyer	Total waiting time in seconds - queue	Total waiting time in seconds
10	76744,82	41146,51	117891,33
11	69001,72	41285,74	110287,46
12	77948,81	53798,24	131747,05
13	104348,1	63747,53	168095,63
14	636661,8	68472,27	705134,07
15	1144155,36	73017,86	1217173,22
16	1342399,33	74435,2	1416834,53
17	1324622,575	80371,29	1404993,87
18	1335338,7	87391,71	1422730,41
19	1370999,56	107753,28	1478752,84
20	1367285,67	88099,09	1455384,76

Table 5.9 – Waiting Time, Standard Time Decreased 1s

CO/day	Total waiting time in seconds – conveyer	Total waiting time in seconds - queue	Total waiting time in seconds
10	76120,44	42057,17	118177,61
11	67291,7	40663,74	107955,44
12	78074,29	52941,42	131015,71
13	92851,58	62915,87	155767,45
14	495078,1	67904,63	562982,73
15	1081491,22	74607,11	1156098,3
16	1307431	73568,19	1380999,2
17	1314657,04	79588,8	1394245,8
18	132655,01	89636,34	1222291,35
19	1325769,39	106124,5	1431893,9
20	1309850,53	86094,38	1395944,9

Table 5.10 – Waiting Time, Standard Time Decreased 2s

When comparing these tables to the values in Table 5.8 and with each other, it is obvious that the values do go down, but the change is not that drastic. The difference is especially small between the values when the standard time decreases with 1 and 2 seconds and the number of customer orders per day is low. When the number of customer orders per day goes up, the change gets a little bigger. However, to really decrease the total waiting time, a lot more time should be taken off the standard times.

5.5.2. Arranging the forklifts differently

In the basic simulation, both of the stations that use forklifts have two forklifts at their disposal. If both of them are occupied, the rows form that cause these waiting times. The total waiting time could possibly change if the forklifts are arranged differently. Again, two experiments are conducted, in the first experiment the conveyer belt gets three forklifts and the loading area gets one forklift. In the second experiment the conveyer belt gets one forklift and the loading area gets three forklifts. The results of the first experiment are in Table 5.11 and the results of the second experiment are in Table 5.12.

CO/day	Total waiting time in seconds – conveyer	Total waiting time in seconds - queue	Total waiting time in seconds
10	85059,32	353838,18	438897,50
11	82269,82	335908,26	418178,08
12	82872,84	421437,81	504310,65
13	133327,52	442138,86	575466,38
14	750356,55	406368,89	1156725,44
15	1188223,06	419888,93	1608111,99
16	1279059,45	469736,25	1748795,7
17	1256074,19	516087,96	1772162,15
18	1269069,77	510676	1779745,77
19	1303476,48	522698,89	1826175,37
20	1298215,36	461909,92	1760125,28

Table 5.11 – Waiting Time, Forklifts 3-1

CO/day	Total waiting time in seconds – conveyer	Total waiting time in seconds - queue	Total waiting time in seconds
10	103593,18	10975,21	114568,39
11	102589,58	11233,81	113823,39
12	102749,13	13273,55	116022,68
13	151533,37	19729,57	171262,94
14	788281,57	32020,25	820301,82
15	1337590,59	39661,87	1377252,46
16	1610463,09	34481,72	1644944,81
17	1639360,22	39459,85	1678820,07
18	1659100,48	53700,85	1712801,33
19	1687583,8	65101,96	1752685,76
20	1692933,78	53387,4	1746321,18

Table 5.12 – Waiting Time, Forklifts 1-3

When comparing these tables to the values in Table 5.8, the new values are a lot higher than the original values most of the time. Only when the number of customer orders per day is low, assigning one forklifts to the conveyer belt and three to the loading locations reduces the waiting time. However,

this changes when the number of customer orders is 14 or higher, in that case the original division of forklifts is better. So, in general is better to arrange the forklifts in the original configuration.

6. Conclusion

This chapter will conclude and reflect upon this research. The successful solutions will be discussed, recommendations will be done based on these findings and further research into the reduction of the KPIs of this research will be discussed.

6.1. Successful solutions

To create a simple overview of which of the first four solutions are successful, all of the weighted output of the solutions are expressed as a percentage of the weighted output of the basic simulation. These percentages can be found in Table 6.1. The first four possible solutions were:

1. Order classification
2. Racks instalment
 - 2.1. Racks in the width of warehouse
 - 2.2. Racks in the length of the warehouse
3. Diagonal aisles
 - 3.1. Aisles from the loading locations and from the conveyer belt
 - 3.2. Aisles from the parking area and from the conveyer belt
4. Filling the front storage areas first

CO per day	Solution 1	Solution 2.1	Solution 2.2	Solution 3.1	Solution 3.2	Solution 4
10	101,86%	93,22%	104,58%	96,32%	94,79%	94,85%
11	101,70%	93,43%	104,45%	96,58%	94,83%	95,19%
12	102,06%	93,91%	103,98%	96,82%	95,09%	95,39%
13	102,07%	94,32%	103,55%	96,85%	95,33%	95,54%
14	102,02%	94,63%	102,85%	96,91%	95,41%	95,40%
15	102,02%	94,96%	102,70%	97,12%	95,62%	95,59%
16	102,09%	95,28%	102,48%	97,40%	95,79%	95,86%
17	101,97%	95,60%	102,19%	97,50%	95,87%	95,85%
18	101,96%	96,03%	102,20%	97,78%	96,10%	96,15%
19	101,65%	96,20%	101,94%	97,84%	96,11%	96,29%
20	101,65%	96,55%	102,03%	97,77%	97,25%	96,43%
Average	101,92%	94,92%	103,00%	97,17%	95,65%	95,69%

Table 6.1 – Weighted Output in %

From this table, it is concluded that solutions 2.1, 3.1, 3.2 and 4 are successful. Placing bigger orders more to the front of the warehouse, as solution 1 suggested was not successful. Placing racks that can be accessed from both sides is successful for one of the floorplans. In this floorplan the racks are placed in the width of the warehouse, which makes it easier to drive all locations from the conveyer belt. The floorplan that is not successful has racks in the length of the warehouse, in this floorplan it takes longer to travel to all of the locations in the warehouse from the conveyer belt. Both of the floorplans of the third solution are successful, so creating diagonal aisles in the warehouse is a good way to reduce the travel times of the forklifts. Creating diagonal aisles from the parking area to the back of the warehouse decreases the KPIs the most. The fourth solution is also successful, so filling up the storage areas that are more to the front of the warehouse first works to reduce the values of the KPIs.

All of the solutions that are successful only decrease the KPIs by a maximum of approximately 6.75%. Although this is an improvement, it is not enough to justify changing the warehouse drastically. This

suggests that the warehouse is already pretty efficient. A combination of the different solutions will be more successful and such an option might be worth considering, this will be further discussed in section 6.2.

To create a simple overview of how waiting time is influenced by changing the standard times and arranging the forklifts differently, the total waiting times of the simulation after these changes are made are expressed as a percentage of the total waiting time of the basic simulation. These percentages can be found in Table 6.2.

CO/day	Standard time - 1s	Standard time - 2s	Forklifts 3-1	Forklifts 1-3
10	92,96%	93,19%	346,10%	90,34%
11	88,81%	86,94%	336,75%	91,66%
12	95,86%	95,33%	366,94%	84,42%
13	86,27%	79,94%	295,34%	87,89%
14	86,05%	68,71%	141,16%	100,11%
15	95,66%	90,86%	126,38%	108,24%
16	100,05%	97,52%	123,49%	116,16%
17	99,91%	99,14%	126,01%	119,38%
18	99,51%	85,49%	124,49%	119,80%
19	100,13%	96,96%	123,66%	118,68%
20	99,91%	95,83%	120,82%	119,88%
Average	95,01%	89,99%	202,83%	105,14%

Table 6.2 – Waiting Time in %

From this table, it can be concluded that the waiting time almost decreases in a linear manner on average, taking 1 second off the standard times will result in an average reduction of 5% of the total waiting time of both of the stations combined. When the number of customer orders per day is 16 or higher, a 2 second time reduction has to be realised in order to see an improvement in the waiting times. So, experimenting with a permanent reduction of the standard time by, for example, stacking differently is worth it if the number of customer orders per day is low and if a 5% reduction per second is acceptable. Another conclusion that can be drawn from the table is that it is never profitable to have three forklifts at the conveyer belt and only one at the loading station. It is especially a bad idea when the number of customer orders coming into the warehouse per day is low. However, when the number of customer orders is low, it is a good idea to only have forklift at the conveyer belt and three forklifts at the loading area. Until the number of customer order reaches 14, implementing this change causes an average decrease in waiting time of 10%.

6.2.Recommendations

To conclude the last section, the reduction of the KPIs labour hours and order collection time are not significantly high. However, even if it only decreases a little, it is worth it to change the way in which orders are assigned to a location, as this is not a big change. Rather than assigning them to a random storage area, they should be assigned to the storage area that is closest to the loading areas and that still has room for an order.

When the company does decide to also change the layout of the warehouse to reduce the labour hours and the order collection time or for any other reason, a floorplan with diagonal aisles and/or vertical racks should be introduced. An example of how the floorplan could look if both of the solutions are combined is depicted in Figure 6.1.

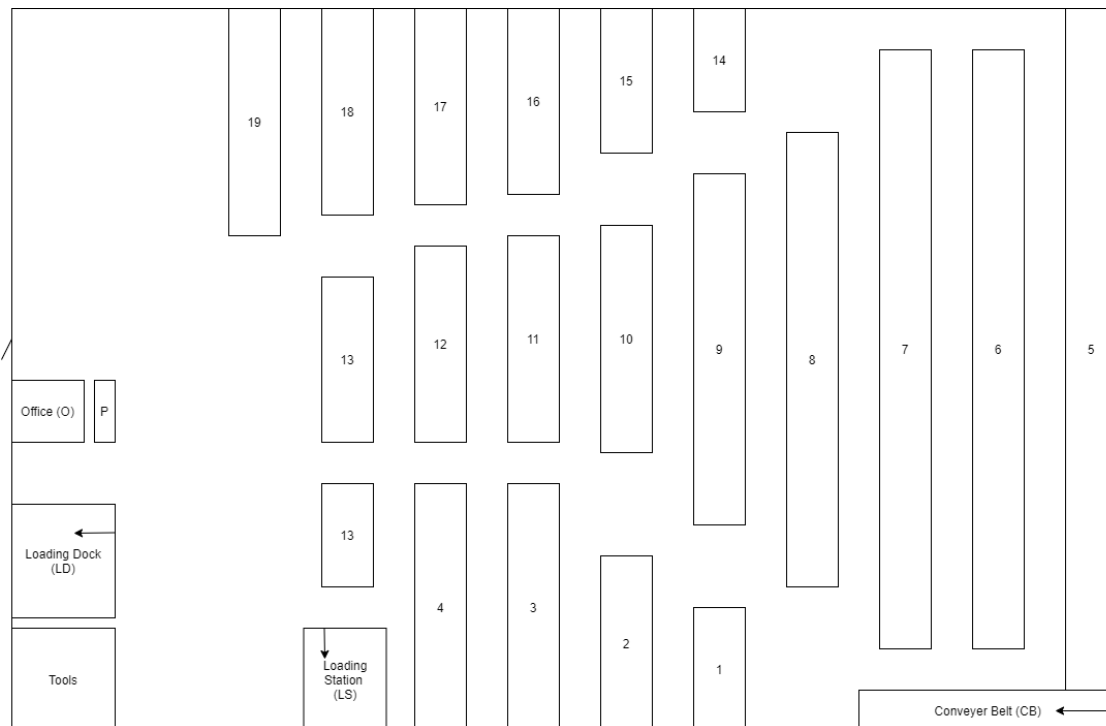


Figure 6.1

If the number of customer orders is low, it is much easier to reduce the waiting time of the customer orders at the conveyor and before they can be moved to the loading area. This can be done by arranging the forklifts differently or by reducing the standard times, such as the time it takes to pick up orders with a forklift. Reducing the waiting time when the number of customer orders per day is high can also be done, but it more difficult as it can only be done by reducing the standard time by at least 2 seconds. Reducing the standard times can, for example, be done by installing the racks or by stacking the pallets one-on-two instead of one-on-one.

6.3.Further research

To reduce the labour hours, the order collection time and the waiting time even more, further research can be done. A view of the options are presented below.

First of all, the current simulation model can be improved to a more stochastic model that has more variables that can be changed. For example, the production planning is now constant, but making it more random could give more insights into the waiting times. Another changeable variable could be the time slot in which trucks arrive. Making the model more stochastic will help to understand where the bottlenecks are.

Right now the simulation also does not have an option where the forklifts can be used for both the conveyor belt and the loading locations. Putting flexible forklifts into the simulation will probably also have a positive effect on the waiting time.

The floorplan in Figure 6.1, has not been tested yet, so to see if it actually reduces the weighted output more than the floorplans that have already been tested, it should also be put into the basic simulation model.

From this research, it has become obvious what the reduction of the standard times does to the labour hours and the order collection time, but how to reduce these standard times requires further research. Some suggestions are given, stacking one-on-two instead of one-on-one or setting a standard pallet height, but whether these suggestions work has not been tested.

The production planning also has an effect on the warehouse. When orders are produced earlier and spend more time in the warehouse, it can get crowded. Placing orders in the front of the warehouse first has the biggest effect on the labour hours and the order collection time when the warehouse is not crowded.

Another standardisation option that was discussed in the theoretical framework was the implementation of an AGV. It was generally described what the technical specifications of such a system would be, but there was not enough information to make an educated estimation of what the implementation of an AGV on this warehouse would be. To find out if the implementation of an AGV system is more beneficial than the use of forklifts with the simulation, it is necessary to find, for one, out what the impact is on the standard times. An AGV will most likely have a lower average speed than a manually handled forklift, but it has other benefits, such as the loading and unloading times. It is also important to add human error into the simulation. Right now, there is no human error factored in, but a huge advantage of an AGV system is that it takes away the human error. Lastly, it is important to calculate the financial side of it, what is the return on investment for example.

In conclusion, to do further research on the reduction of the labour hours and the order collection time, the simulation can be improved with stochastic variables, a better forklift configuration or the floorplan in figure 6.1. Other research that does not include the simulation, is testing how to reduce the standard times or reducing the number of customer orders in the warehouse by changing the production planning. Lastly, an AGV system should be researched further to see if it would benefit the company.

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Appendix

A.1. Calculations

A1.1 Labour Hours

```
Labour hours := PutAwayTime + CollectionTime

PutAwayTime :=
    GetOnForklift +
    DriveToCBFromP +
    TakeFromConveyer * Pallets +
    PutPalletsOnForklift * (Pallets / 2) +
    DriveToCBFromS * (Pallets - 1) +
    PutDownPallets * (Pallets / 2) +
    DriveToPFromS +
    GetOffForklift

if LoadingStation = true
    CollectionTime :=
        GetOnForklift +
        DriveToLSFromP +
        PutPalletsOnForklift * (Pallets / 2) +
        DriveToLDFromLS * (Pallets - 1) +
        PutDownPallets * (Pallets / 2) +
        DriveToLDFromP +
        GetOffForklift

    TimeToLS :=
        GetOnForklift +
        DriveToPFromS +
        PutPalletsOnForklift * (Pallets / 2) +
        DriveToLSFromS * (Pallets - 1) +
        PutDownPallets * (Pallets / 2) +
        DriveToLSFromP +
        GetOffForklift

elseif LoadingStation = false
    CollectionTime :=
        GetOnForklift +
        DriveToPFromS +
        PutPalletsOnForklift * (Pallets / 2) +
        DriveToLDFromS * (Pallets - 1) +
        PutDownPallets * (@.Pallets / 2)
```

```

                DriveToLDFromP                +
                GetOffForklift
    TimeToLS :=          0
End

```

A1.2 Order Collection Time

```

if LoadingStation =      true
    OrderCollectionTime := GetOnForklift      +
        DriveToLSFromP                +
        PutPalletsOnForklift * (@.Pallets / 2)  +
        DriveToLDFromLS * (@.Pallets - 1)      +
        PutDownPallets * (@.Pallets / 2)      +
        DriveToLDFromP                +
        GetOffForklift

elseif LoadingStation = false
    OrderCollectionTime := GetOnForklift      +
        DriveToPFromS                +
        PutPalletsOnForklift * (Pallets / 2)    +
        DriveToLDFromS * (Pallets - 1)          +
        PutDownPallets * (@.Pallets / 2)      +
        DriveToLDFromP                +
        GetOffForklift
end

```