

# Developing a new storage allocation method for Company X's order picking warehouse

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## Management summary

*The data used in the research is confidential. The company in this research will therefore be referred to as Company X.*

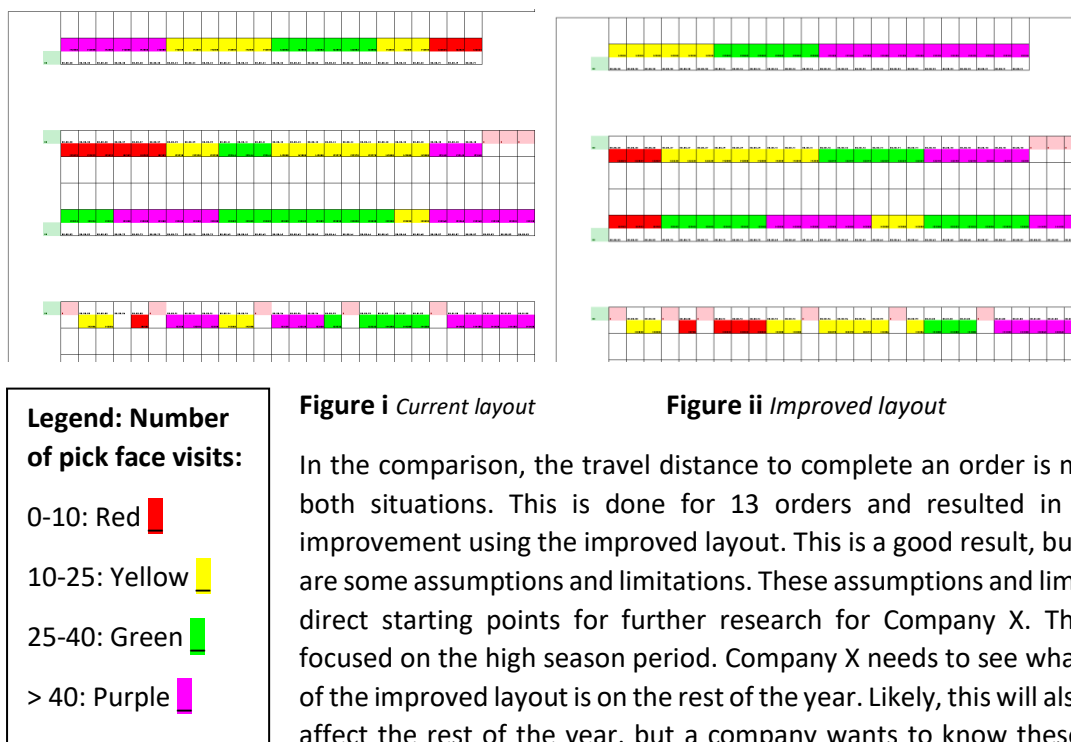
Company X is facing a problem with handling their large orders. This does not happen in the most efficient way and because of that other smaller orders will not be shipped on time. The company needs a person to investigate how this can be done. At this moment, Company X is implementing a new system that is used during their order picking process. That is the reason why the company thinks this is the perfect time to optimize their warehouse. This research is the first step for Company X to the optimization of their warehouse.

In this research, we are looking for the answer to the main research question:

*How can Company X handle large orders efficiently to make sure all orders can be shipped on time?*

To answer this question, research is done. First, we looked into literature that can be found on warehouse optimization. After selecting useful literature, we used the information that we found to start with the optimization of Company X's order picking warehouse. We did an order analysis during the high season to collect order and product characteristics. After that, the current situation is described. This was done by interviewing employees in the warehouse and going through the warehouse ourselves to understand how the current system works.

Based on the data found with the data analysis, an improved layout was created using a new allocation method for a small part of the warehouse. This improved layout was tested against the current layout. In figure i, the current layout is displayed and in figure ii, the improved layout can be found. The colors in these two layouts represent the amount of pick face visits per product. Pick face visits are the number of times a product is ordered in separate orders. In other words, for how many orders does the order picker need to go to that storage place. In the legend, the amount of pick face visits per color can be found.



sure. Another point is that for the products frequently ordered together only the large orders are taken into consideration. It may be interesting to see what products are ordered frequently together for all the orders. Also, the assumption is made that all products in the same zone are stackable. This can be tested in real life with the layout that is provided by this research. In this research, the focus is on one zone of the order-picking warehouse. The expectation is that it will also work for the other zones because the zone used is pretty generic. Still, this is not a certainty and should be investigated by Company X by using the allocation method for other zones as well.

To do all these recommendations, Company X can consider multiple options. They can see if someone in the company itself can and wants to explore these things further. An advantage is that this person knows a lot about the company already, but maybe not so much about warehouse optimization.

A second option can be looking for another student that continues where this research stops. An advantage of this is that is almost cost-free. Such a student only needs a company supervisor that needs to put in a couple of hours a week. A disadvantage is that this student can find a lot of interesting things but will probably not have the time to complete the whole layout. The result is then a new list of recommendations. The same is happening with this research.

The last option can be to hire someone to do the whole project till the improved layout is completely tested and can be used in their warehouse. This option is probably the most expensive one but will get the best results if the company can find a suitable person. This person can fully focus on the project and does not have restrictions in time as a student has.

The main research question is unfortunately not answered completely. We did find a way of handling the large orders more efficiently, but we did not find out if because of that smaller orders are shipped on time. If the large orders take less time, there is more time for the small orders. In that way of thinking, it is reasonable to think that smaller orders will be shipped on time as well.

It is up to Company X what they want to choose and what to do with the results of this research. There is enough to investigate further and the options on how to continue are there. They need to decide on what they think will get the results they want taking into consideration the costs that come with that choice. This research has shown that there is potential with this way of assigning the products. Company X had trouble with convincing the order pickers that the layout could be improved. This research can help with showing the order pickers that the layout improved and their work can be made easier. The following part consists of a roadmap (see table i) to show what steps need to be taken to go from the result of this research to the implementation of the improved layout.

**Table i** Roadmap

|               | <b>6 weeks</b>                                                | <b>12 weeks</b>                                       | <b>18 weeks</b>                                                                                                | <b>24 weeks</b> |
|---------------|---------------------------------------------------------------|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------|
| <b>Zones</b>  | <i>Test one other zone</i>                                    | <i>Test half of the warehouse</i>                     | <i>Test whole warehouse, using the two scripts for dividing the trips and measuring the distances per trip</i> | -               |
| <b>Period</b> | <i>Investigate one other timeframe outside of the already</i> | <i>Investigate the months from February till July</i> | -                                                                                                              | -               |

|                                    |                                                                             |                                                                                    |                                                                                            |                                                       |
|------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------|
|                                    | <i>researched four weeks</i>                                                |                                                                                    |                                                                                            |                                                       |
| <b>Assumptions and limitations</b> | <i>See if the stackable assumption holds with testing this in real life</i> | <i>Investigate products that are ordered frequently together for normal orders</i> | -                                                                                          | -                                                     |
| <b>Division of the trips</b>       | <i>Write a VBA script to divide the trips, used in testing zones</i>        | <i>Write a VBA script to measure the distances per trip</i>                        | -                                                                                          | -                                                     |
| <b>Implementation</b>              | -                                                                           | -                                                                                  | <i>Investigate how the improved layout can be implemented with the new scanning system</i> | <i>Implement the improved layout in the warehouse</i> |

## Preface

Within all subjects of Industrial Engineering, my interest is the most in everything that is happening in a warehouse. I find it interesting to see how everything works and how it can work even better. This assignment was exactly what I think is the most interesting and that is why I am very happy I got the opportunity to do this.

I want to thank some people that helped me with my bachelor's research. My UT supervisor, Peter Schuur, and Company supervisor, Alexander Dalenoort. Both supervisors helped with the whole process. Peter made a lot of time for me and we always had good meetings and conversations. Unfortunately, all the meetings with Peter were via Skype. In-person would have been nicer and more personal, but with the corona crisis, this was not possible. Furthermore, I am very happy that during this corona crisis, Alexander has let me free in whether I wanted to come to the company or that I wanted to work from home. Also, providing me with every sort of data that I needed. This result was not possible without all that.

Have fun reading my thesis!

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# Chapter 1: Introduction

In the framework of completing my bachelor studies Industrial Engineering and Management at the University of Twente I performed research at Company X into optimizing their order picking warehouse by developing a new allocation method.

## 1.1: Motivation

Company X has a big warehouse where order picking is one of the main activities. This warehouse is divided into a bulk warehouse and an order-picking warehouse. Order picking is one of the most important activities because the faster the orders are picked the sooner the products are in shops to be sold to customers. Company X uses a single order picking strategy where every order is picked separately. Company X is convinced that this order picking process can be improved, but they do not have an idea where or how this can be improved.

At this moment, the layout of the warehouse is based on gut feeling and experience. Furthermore, Company X has never really thought about how order pickers walk through their warehouse. This way of order picking has worked for many years, but they want to know where they can improve.

The orders for Company X come in on Monday and need to be shipped before Thursday to have them in stores before the weekend. The weekend is when most of the products of Company X are sold. This means that Monday, Tuesday, and Wednesday are the busiest days in the Warehouse. In this period, the order pickers can benefit from an efficient process. Ensuring that all orders are shipped on time to be at the shops before the weekend. This is essential because if this is not the case Company X misses revenue.

Company X is implementing a new scanning system in their order picking process. That is a reason why Company X wants to take a closer look at how their order picking process is performing and where the process can be improved.

## 1.2: Problem description

This research starts with looking into all the problems related to the orders being late at the shops. First creating a problem cluster to get an idea about what could be the reason for the orders being late. Company X thinks that a lot can be done with the layout of the warehouse. That has been taking into consideration, but own investigation within the company to find the core problem must be done as well.

Company X has problems dealing with the large orders that come in. When a big order comes in, all the order pickers help with picking that order to make sure that it can be sent to the shop on time. These big orders are from important customers. These need to be on time; hence every order picker helps with those orders. Other orders get less attention and will be shipped too late.

Company X sells seasonal products, so this problem only occurs during the high season. During the rest of the year, this is not a problem, because then fewer orders come in. For the rest of this project plan, the problems discussed are all related to the period of the high season. This is around the end of spring and the beginning of summer.



**Figure 1.1** Problem cluster

With creating a problem cluster (see Figure 1.1), a closer look can be taken in identifying the core problem. Starting at what the problem is within the warehouse. The problem for Company X starts with the fact orders sometimes arrive too late at the shops. A cause for this is that the workload for the order pickers is too high and they are not able to complete the picking process for certain orders to get them on time. That this process takes too long could have multiple reasons. Maybe, they simply need more pickers to be able to complete these orders. Another reason can be that the products are not efficiently located in the warehouse. This can result in a larger travel distance for an order picker and this results in that it takes longer to complete an order. When a large order comes in, all the order pickers help with that order to pick it in time. This large order leads to other orders being late because every order picker needs to help with these kinds of orders.

From the problem cluster, the following core problem follows: Orders with a large number of order lines are being handled inefficiently. A variable is the amount of workforce that is needed to complete such a big order. The indicator for this variable is then the number of order pickers. This makes the variable workforce measurable. Another variable is the workload from a big order. An indicator for this variable is the number of lines in an order. In other words, how many different products does an order picker need to pick.

Furthermore, a variable that is used to see how the warehouse is performing is the travel distance of an order picker. The indicator for this variable is the number of storage blocks an order picker needs to go by to completely pick an order.

The core problem needs to be explained with a norm and a reality. Reality is where that process stands before this research and the norm is where Company X wants to be after this research. Company X has 5% orders being shipped too late during the high season and they want to have 0% orders too late working with the same amount of order pickers. They want to see if it is possible to get all the orders on time without hiring more order pickers.

### 1.3: Research questions

Within this research, multiple research questions are answered. The main research question is:

*How can Company X handle large orders efficiently to make sure all orders can be shipped on time?*

To answer this main research question, a couple of sub-questions are answered. These sub-questions are linked to the steps that are taken to solve the core problem. Some sub-questions have sub-questions as well. As mentioned, these questions are linked to the problem-solving approach. The first question is about getting to know and understand the current situation. The second question is about creating the new storage allocation method. Combining the answers to these questions helps us to answer the main research question.

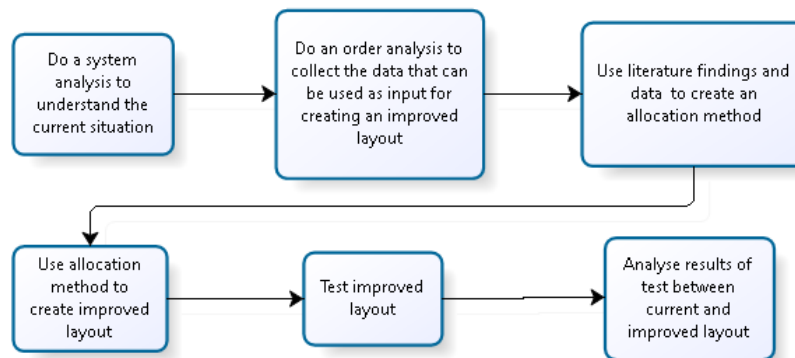
- Sub-question 1: What is the current situation in Company X's order picking warehouse?
  - How is Company X handling large orders in the current situation?
  - What is the structure of the large orders coming in?
  - What is the current layout of the warehouse?

- Sub-question 2: How can a new storage allocation method be made to increase the order picking efficiency?
- Sub-question 3: What criteria need to be used when assigning the products to a storage location?
- Sub-question 4: How can we compare the new method with the current situation?

In the next section, the problem-solving approach is described and the sub-questions are linked to the research methods used.

#### 1.4: Problem-solving approach

In this section, the research method and problem-solving approach are described and explained. As mentioned before, we want to answer the main research question. The aim is to create a new way of assigning products to storage locations by analyzing the structure of these large orders and thereby increase the overall efficiency by minimizing the travel distance of the order pickers. In figure 1.2, an overview of the problem-solving approach is shown and after that, the problem-solving approach is explained in more detail.



**Figure 1.2** Overview of the problem-solving approach

To be able to understand the current situation in the warehouse of Company X, some research is done. This part is related to sub-question 1 mentioned in Section 1.3. We investigated who is related to this problem and who will be helping us solve the problem. Second, we understood how Company X is handling these large orders. We collected data from the high season from the last couple of years to analyze what type of orders are coming in precisely. The results of this analysis include the following characteristics: the dimensions and weight of the product, pick-face visits per SKU, and identification of items that are frequently together in these large orders. With this information, we identified the products that need to be either put together or close to the I/O-point.

The large orders that Company X receives in the high season, are being split into smaller separate orders already. From the meetings with Company X, it was not clear where this splitting is based on. In the meeting with the order pickers, we gathered information on how the orders are split and how Company X is currently handling these orders. Next to that, the current layout of the warehouse is determined. This has already been done for a large part, but still, the precise locations of the products are determined. In Chapter 3, the current situation is described in such a way that we can use this to compare it to the improved layout.

The last part of the approach is linked to sub-question 2 and 3 mentioned in Section 1.3. As mentioned, a new method for Company X to be able to handle the large orders that are coming in during the high

season is developed. This method is based on literature findings. In the literature, storage policies are found. These policies provided us with criteria to use when making the new method. This resulted in a method that consists of multiple steps. These steps are described in Chapter 4. With this allocation method, an improved layout is created and this layout is shown in Chapter 5.

This part is related to sub-question 4. To test whether the new method increases the efficiency for a warehouse like Company X's warehouse, this research includes a comparison between the current situation and a situation wherein the new method is applied. Doing this for the entire layout in the warehouse will be too big and too complicated. The comparison is done with a small part of Company X's warehouse to see if the method itself works. For simplicity of the comparison, a return routing policy is used for both situations to keep it from being a factor that influences the results.

### **1.5: Scope and Deliverables**

To make sure that this research is not too broad, the scope of this research is not on the whole warehouse. As mentioned in section 1.4, the research is focusing on a smaller part to create a method of assigning the products. If this works, Company X can consider exploring the method further and investigate what it can do for the whole warehouse. This research wants to provide Company X with a method to assign products to a storage location with as goal to increase the efficiency in handling the large orders to make sure smaller orders are shipped on time.

## Chapter 2: Theoretical background

In the theory section, first a research question is answered with the use of a systematic literature review, and further theory about warehouse optimization is explained. After that, a theoretical perspective is selected and explained. We want to address that Company X's order picking warehouse is a manual order picking warehouse. Therefore, the literature in this theory section is all related to manual order picking. In the end, we have chosen an approach used during this research.

### 2.1: Overview of relevant literature

Being able to pick orders efficiently is influenced by multiple factors. As Petersen & Schmenner (1999) assess in their paper there are main two policies that influence these operations within a warehouse. These are storage policies and routing policies. A storage policy assigns an item to a storage location. Routing policies determine the route of a picker for a picking tour and specify the sequence in which items are picked. Petersen et al. (1999) show in their research that the choice of certain routing and storage policies can result in increased picking efficiency. The goal of these policies is to reduce the total order picking time of an order. Total order picking time roughly consist of walking time to locations, time for picking the actual item, and time for remaining activities (K. J. Roodbergen & Koster, 2001). Tompkins et al. (1996) have shown that within a manual order picking operation, the travel time is the largest component of the total order picking time. To increase the efficiency of a warehouse, these storage and routing policies are used to minimize this travel time.

A warehouse first needs a storage policy before it is possible to determine a routing policy. That is why in this research, first a closer look is taken into the possible storage policies. Answering the following research question: What kind of storage policies are used within order picking warehouses? This question is answered by performing a systematic literature review.

Within this systematic literature review, multiple storage policies and strategies are found. The most widely used storage policies, but also some lesser-known policies. The first observation that can be made is the difference between random storage policies and dedicated storage policies. Dedicated storage policies can be divided into multiple policies. These are turnover-based, cube-per-order index, duration-of-stay, correlation-based policies (Bahrami et al., 2019). In between random storage policies and dedicated storage policies, there lie class-based storage policies. This is a combination where the items are divided by different classes and within these classes, the products are located randomly. Random storage policies and Class-based storage policies are the most used storage policies that can be found in the literature about warehouse optimization (Reyes et al., 2019). The reason for this is because they set a good comparison standard. Reyes et al. (2019) also show in their literature review that COI storage policies and correlation-based policies are evaluated in multiple papers, but not as much as class-based and random policies.

As mentioned before, in the literature review of Bahrami et al. (2019) more common-known storage policies that are used are summarized and explained. These are the random storage policies, dedicated storage policies, and Class-based policies.

A random storage policy is when items are placed according to the availability of a storage location. The replenisher puts away the SKUs (Stock Keeping Units) however is convenient at that moment. This is a popular policy, because of its simplicity and advantages including space utilization, simple implementation, immunity to demand and assortment fluctuations, and uniform usage of aisles that lead to lower congestion. However, a tracking system is required because the policy can lead to a difficult and confusing positioning of items (Bahrami et al., 2019).

With dedicated storage policies, a storage location is reserved for specific SKUs. Turnover-based policy (also known as full-turnover or volume-based) is when the assignment is based on the turnover or demand of the products. The most demanded products are placed in the most easily accessible storage locations. These locations are normally close to the I/O point (input/output- point).

Cube per order index policy (COI-based policy) is when the assignment of the items is based on the ratio of the number of locations occupied by this SKU and the pick frequency of this SKU. This policy was first introduced by Heskett (1963). The products with a lower ratio are placed in the convenient places closer to the I/O-point and the items with a higher ratio are placed further from the I/O-point. COI policy can work very well for single command retrieval, but Schuur (2015) shows in his paper that when a single command strategy is used for a multi command situation, there is no performance guarantee.

In the literature review of Bahrami et al. (2019), the policy duration of stay (DOS) was found. In other articles, nothing was found about this policy. With this policy, products with a shorter DOS have a location closer to the I/O-point, and products with a longer DOS are placed further away from the I/O-point. The DOS approach needs the most data in comparison to other storage policies (Goetschalckx & Ratliff, 1990). This is not a commonly used policy and does not come back as a comparison policy when articles are creating a new method for storing items in a warehouse.

With correlated storage policy, products from for example the same products sort are placed together. The strategy needs a suitable index to estimate the correlation between products in the warehouse. The lack of data to calculate the index is a reason that this is a policy that is complex to use, but with the advances of big data and such it may be possible to start using this policy more (Bahrami et al., 2019).

Petersen & Aase (2004) show with their simulation experiment that within-aisle volume-based and class-based storage require significantly less picker travel than random storage. However, random storage uses the entire picking area in a better way, such that there is less worker congestion. Furthermore, they show that additional savings from volume-based storage over class-based storage with three storage classes is less than 1%. This is important for managers because it is shown that simple class-based policies can significantly reduce total fulfillment time as much as complicated volume-based policies (Petersen & Aase, 2004).

Lee et al. (2020) propose a new assignment strategy to resolve the conflict between travel time and picking delays. The correlated and traffic balanced storage assignment (C&TBSA) consists of two stages: clustering and assignment. Clustering is based on travel efficiency and traffic flow balance. The assignment is based on the grouped SKUs. The highly demanded clusters should then be in more accessible locations to minimize the travel time. C&TBSA can be most effective for warehouses where congestion frequently occurs or where a lot of order pickers work at the same time. Furthermore, warehouses, where highly correlated SKUs are handled, can consider using C&TBSA as a potential storage assignment method to increase their efficiency (Lee et al., 2020).

Guo et al. (2016) also evaluate three different types of policies. These policies are random, class-based, and full turnover storage policies. They find that the average travel distance for a random policy is not constant but decreases with the increase in the skewness of the demand curve. The random storage policy performs better with more skewed demand curves, as the warehouse can become smaller. Furthermore, they conclude that ranking items according to their turnover reduces average travel distance by increasing the system efficiency. This average on the other hand also increases because

of the need for expanded storage space. This policy concludes that balancing the tradeoff, a class-based policy with a small number of classes is optimal (Guo et al., 2016).

Dukić & Oluić (2019) conclude that the performance of the routing and storage policies discussed in the paper, heavily depends on the situation, regarding the size and the shape of the warehouse and the size of the picklists. These policies are volume-based and the COI policies. All Volume-based storage methods reduce travel distances for order pickers, although the chosen routing policy still can make a big difference on the resulted performance. That is why choosing the right combination of routing and storage policy is a crucial task by improving the order picking efficiency (Dukić & Oluić, 2004). Also van Gils et al. (2018) show in their study that warehouses can benefit by considering storage, batching, zone picking, and routing policy simultaneously. Battini et al. (2015) present in their paper a new storage assignment method called the storage assignment and travel distance estimation joint method. This is a new approach to design and evaluate a manual picker-to-parts picking system. This method can be an interesting guide for designs that consider the effect storage and routing policy simultaneously (Battini et al., 2015). From these different papers, routing and storage policy are very dependent on each other.

Zhang et al. (2019) aim at improving the order-picking frequency by assigning storage locations to items, where the correlation among items is considered. They introduce the demand correlation pattern (DCP) to describe item correlation and formulate the storage location assignment problem as an integer programming model. Two algorithms are developed: minimum increment heuristic (MIH) and simulated annealing (SA). MIH is especially useful for situations in which items are weakly correlated and order size varies. SA is advised for when items have a strong correlation. Furthermore, Zhang et al. (2019) conclude that it is more effective to apply correlation-based storage strategies to warehouses with more storage locations per aisle.

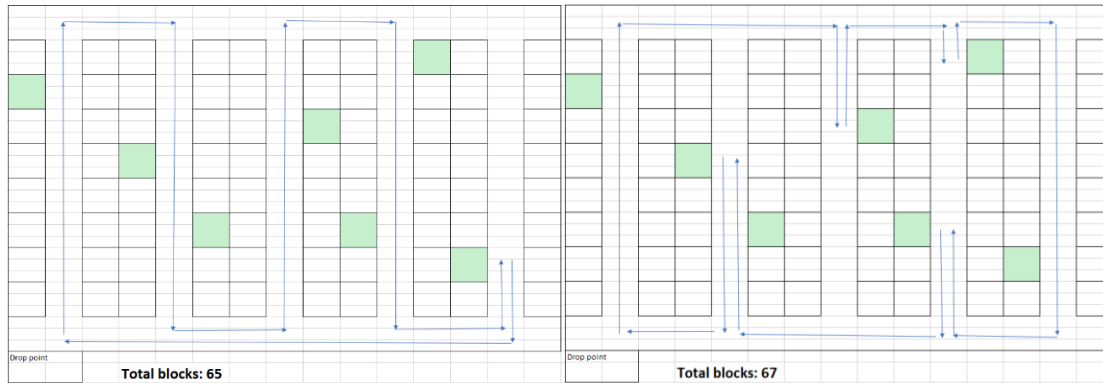
Žulj et al. (2018) aim to develop a strategy that considers the weight of the products from one single customer order, to make sure that after everything is picked, no sorting is needed. It is possible to construct an optimal route in such a way that no sorting is needed, where heavy items are picked before the light products (Žulj et al., 2018).

Mantel et al. (2007) show in their paper that for single order picking without batching, a slotting strategy based on the order can outperform the widely used COI slotting strategy. This by minimizing the total traveling time of all tours. This is done by logically assigning SKUs that are ordered frequently together. Order Oriented Slotting (OOS) strategy allocates items, given a routing policy and given a set of orders, in such a way that total travel distance is minimal (Mantel et al., 2007).

With the literature that was found, it became clear that there are some more standard storage policies and that in the last decade's different adjustments on those longer existing policies are made for specific warehouse settings. As mentioned in multiple of these papers, the strategy used in different settings heavily depends on the size and the shape of the warehouse and the size of the picklists. This is probably also the reason why a lot of new methods are being developed for all these different kinds of situations.

Next to storage policies, the efficiency of a warehouse is also influenced by routing policies. In this part of the theory, multiple of these routing policies are mentioned and explained. Two widely used routing policies within warehouses are the S-shaped policy and the largest-gap policy (Hall, 1993). In the research of Roodbergen & Vis (2006) both of these policies are described. With the S-shaped policy, an order pick walks through a whole aisle containing at least one item. If an aisle does not contain an item, then the order pick will not walk through that aisle. After picking the last item, the order pick goes back to the front aisle. With the largest gap policy, the order pick will walk through

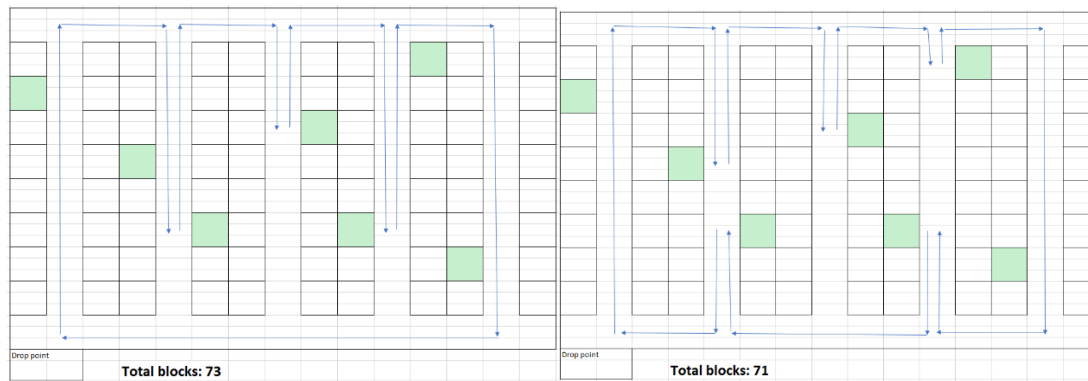
the first aisle to the back of the warehouse. Each aisle after that is entered up to the largest gap and left from the same side the order picker walked in. This gap is the distance between any two adjacent items or the distance between a cross-aisle and the nearest item. The last aisle will then be crossed entirely again, and the order picker will return to the I/O point. With the largest gap policy, the part of an aisle that is not walked by an order picker needs to be as large as possible (Roodbergen & Vis, 2006). In figure 2.1 and figure 2.2, the S-shaped and Largest gap policies are depicted. (These examples are not based on the layout of Company X's warehouse; total blocks are the total number of storage blocks passed by the order picker.)



**Figure 2.1** *S-Shaped policy*

**Figure 2.2** *Largest Gap Policy*

Within the literature, two other policies also came by multiple times. These are the return policy and the midpoint policy. The return policy is when each picker enters and leaves through the same end of aisles containing pick items. In the midpoint policy, the order picker never crosses the middle of the aisle and returns to the side where they entered from (See figures 2.3 and 2.4).



**Figure 2.3** *Return Policy*

**Figure 2.4** *Midpoint policy*

These routing policies are chosen based on different problem characteristics such as the shape of the warehouse, the number of aisles and cross aisles, picklist size, and the storage and batching policies (Silva et al., 2020).

As mentioned before, a lot of the more standard policies, both storage, and routing, are being used to develop more specific methods for more specific situations in warehouses. Company X also has a specific kind of situation in their warehouse. As mentioned in the introduction, the problem Company X is facing in their warehouse, is handling the orders with a large number of order lines. Within the warehouse optimization literature, not much can be found on methods for splitting large orders into smaller orders to increase the efficiency of handling these types of orders. Within this research, we want to create a heuristic/method that uses the structure of the large orders to determine an

assignment for the products to increase the efficiency of picking these orders. Such kind of method does not yet exist and we want to investigate and test if such a method can be beneficial for a company such as Company X.

Identifying and articulating a theoretical perspective support the knowledge claims in one's research findings and helps by effectively communicating the claims to the reader (Jawitz & Case, 2009). In the paper of Jawitz & Case (2009), one of the discussed theoretical perspectives is positivism. This is when the research aims to establish facts and laws, the research is guided by testing hypotheses, and the role of the researcher is to be an objective observer. As mentioned, within this research the aim is to develop a new method for Company X's storage allocation and test this to see if the efficiency can be improved. This collides with wanting to establish facts and laws. The method needs to be compared to the current situation to see if it improves the efficiency of Company X's order picking warehouse. These comparisons between the current situation and the situation using this new method need to be looked at objectively. This collides with the fact that the researcher needs to be an objective observer.

## 2.2: Approach chosen

From all the possible ways of increasing the efficiency in a warehouse, we use two storage policies and one routing policy. The storage policies used in Chapter 4 with the allocation method are COI-based policy and OOS. The routing policy used for the comparison is the return policy. The storage policies are not used directly how they are described in the literature, but the way of assigning the products is based on those policies. The COI-based policy is chosen because Company X's order picking warehouse has not considered the pick frequency and this can already increase efficiency easily. Taking into consideration the number of pallet places needed, when assigning the locations based on the number of pick face visits. OOS-like way of assigning is then used to logically assign products that are ordered frequently together. As Mantel et al. (2007) show in their paper this method is effective with single order picking without batching, which is the case for Company X's order picking process. The combinations of the two storage policies are tested against the current layout. Below both of these strategies are explained and described in more detail.

With the COI-based strategy, two criteria are needed. These are product size and demand. Based on these two criteria an improved layout can be determined. In this research, we used the number of pallet places as product size and we used pick face visits as demand. The higher the amount of pick face visits, the closer the products lay to the I/O-point. After creating a base for the improved layout, the layout is finished by putting products that are frequently ordered together. This is based on how the OOS strategy does this. In the article, there are some complicated formulas, but here we show only the four steps that are mentioned by Mantel et al. (2007). Each step is one heuristic. These steps are:

- Step 1: Use random heuristic: *This allocates products randomly to storage locations.*
- Step 2: Use popularity heuristic: *This step ranks the products based on their popularity. The most popular product closest to the I/O-point and the least popular product furthest away from the I/O-point.*
- Step 3: Use Interaction frequency heuristic
- Step 4: Use Interaction frequency-based quadratic assignment heuristic

In this research, we did not exactly execute the last two steps. With these steps, they use some complicated formulas that put the products that are ordered together frequently close to each other. We collected the data on what products were ordered together and just put these products together in the improved layout. Not strictly following these heuristics, but the way of assigning is based on how it happens with OOS. First, ranking on popularity and then putting products that are ordered

frequently together close to each other. The complete procedure on how we used the strategies from the literature in this research to create an improved layout can be found in Chapter 4. In the next chapter, we describe the current system and the current way of working.

## Chapter 3: Current system analysis

In this chapter, the current system is analyzed and described. Starting with an order and product characteristic analysis. After that, the current layout of the warehouse is created, implementing data of the order analysis in the current layout. This is done to get an overview of what kind of products lay where. In the last section of this chapter, the current way of handling large orders is described.

### 3.1: Order Analysis

As mentioned in Chapter 1, with the order analysis a couple of order and product characteristics must be determined. In this research, we need the following characteristics: the dimensions and weight of the product, pick-face visits per product, and identification of items that are frequently together in these large orders. With the use of Excel and VBA, these characteristics were found. All these results will not be displayed here, because there are a lot of different products and orders. When one of the characteristics is used during the rest of this research, it is explicitly mentioned. Also, in this part, small parts of the total results and code are displayed. In the Excel files that are attached with this research, all the results and data can be found, for the interested person. In the appendix, an explanation of these files is given. For the analysis, Company X provided us with order lists from multiple years where we have derived 13 large orders from. The analyses were mostly done using those 13 orders. For the pick face visits per product, we used all the orders in the provided order lists.

#### 3.1.1: Pick face visits per product

Pick face visits mean the number of times the order picker needed to go to a certain location. To put it in other words, it is the number of times a product appears in different orders. It is not about the total quantity of the product, but about how many different orders the products are in. As stated above, we used VBA in Excel to gather this data. We looked at the orders in the high season. Not only the large orders but every order. And again, we looked at the high season in 2018, 2019, and 2020 and took the average of the three years to use for the new layout.

**Table 3.1** *Example of the orders in Excel*

| Ordernumber | Productnumber |
|-------------|---------------|
| 264069 O    | 122150        |
| 264069 O    | 122475        |
| 264069 O    | 123260        |
| 264069 O    | 126562        |
| 264069 O    | 128020        |
| 264069 O    | 142105        |
| 264069 O    | 147030        |
| 264027 O    | 122421        |
| 264027 O    | 123451        |
| 264027 O    | 124611        |
| 264027 O    | 126372        |
| 264027 O    | 126576        |
| 264027 O    | 127577        |
| 264027 O    | 127579        |
| 264027 O    | 129810        |
| 264027 O    | 129816        |
| 264027 O    | 129817        |

As seen in Table 3.1, the company provided us with a list of orders. Per year one list. This is a small part of the total order list. To see the amount of pick face visits in a period, we counted the product numbers with different order numbers in front of it. In figure 3.1, the VBA code to gather all pick face visits is displayed.

```

Sub pickvisits()

'In how many different orders does a product appear?

Dim i, j, k, counter As Integer
Dim ws As Worksheet

k = 1
For i = 120032 To 850534
    If Application.WorksheetFunction.CountIf(Range("B2:B10730"), i) > 0 Then
        counter = 0
        k = k + 1
        For j = 2 To 10730
            If Cells(j, 2) = i Then
                counter = counter + 1
                Cells(k, 7) = counter
                Cells(k, 6) = i
            End If
        Next j
    End If
Next i

End Sub

```

**Figure 3.1** VBA code used to derive pick face visits from the order list

As a result of the gathering, the average over the three different years could be made. This is used with determining the new layout. Within the average, only products that appeared in all three different periods were considered. The results per year and the average of all products can be found in the Excel file: Order Analysis results + Current Layout on sheet 1.

### 3.1.2: Items ordered frequently together

In this report, we are looking at the large orders that are coming in for Company X. That is why for the products frequently ordered together, we only looked at those orders. Because these are orders with a lot of products and the chance of products being ordered together increases, we only looked at products that were together in 13 of the large 13 orders or 12 of the 13 large orders. The products found with these criteria were so to say certainties.

With VBA, we made a code that put every possibility together and checked if that possibility appeared in any of the orders. After we got the whole table with every possibility and their number of appearances, we looked at all the numbers 12 and 13 in that table to get the combinations that appeared that number of times. To get every possibility, we put all the product numbers against each other as seen in Table 3.2.

**Table 3.2** The table used to see products frequently ordered together

|          | 121519 | 121556 | 122150 | 122250 | 122256 | 122405 | 122450 | 122475 | 123110 | 123130 | 123140 | 123150 | 123152 |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 121519 X |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 121556   | 8 X    |        |        |        |        |        |        |        |        |        |        |        |        |
| 122150   | 8      | 9 X    |        |        |        |        |        |        |        |        |        |        |        |
| 122250   | 7      | 8      | 8 X    |        |        |        |        |        |        |        |        |        |        |
| 122256   | 6      | 7      | 7      | 6 X    |        |        |        |        |        |        |        |        |        |
| 122405   | 4      | 4      | 4      | 3      | 3 X    |        |        |        |        |        |        |        |        |
| 122450   | 5      | 6      | 6      | 6      | 5      | 2 X    |        |        |        |        |        |        |        |
| 122475   | 7      | 8      | 8      | 7      | 6      | 4      | 5 X    |        |        |        |        |        |        |
| 123110   | 8      | 8      | 8      | 7      | 6      | 4      | 5      | 7 X    |        |        |        |        |        |
| 123130   | 8      | 8      | 8      | 7      | 6      | 4      | 5      | 7      | 8 X    |        |        |        |        |
| 123140   | 8      | 8      | 8      | 7      | 6      | 4      | 5      | 7      | 8      | 8 X    |        |        |        |
| 123150   | 8      | 8      | 8      | 7      | 6      | 4      | 5      | 7      | 8      | 8      | 8 X    |        |        |
| 123152   | 7      | 7      | 7      | 6      | 5      | 3      | 5      | 6      | 7      | 7      | 7      | 7 X    |        |
| 123215   | 8      | 9      | 9      | 8      | 7      | 4      | 6      | 8      | 8      | 8      | 8      | 8      | 7 X    |
| 123225   | 7      | 7      | 7      | 7      | 5      | 3      | 5      | 6      | 7      | 7      | 7      | 7      | 6      |
| 124645   | 7      | 7      | 7      | 7      | 5      | 3      | 5      | 6      | 7      | 7      | 7      | 7      | 6      |
| 124646   | 5      | 6      | 6      | 5      | 5      | 2      | 4      | 5      | 5      | 5      | 5      | 5      | 5      |
| 124647   | 5      | 5      | 5      | 4      | 4      | 4      | 3      | 4      | 5      | 5      | 5      | 5      | 4      |
| 124648   | 5      | 6      | 6      | 6      | 5      | 3      | 5      | 5      | 5      | 5      | 5      | 5      | 4      |

A small part of the whole table is shown. For obvious reasons, only half of the table is needed. The whole table has around 600 products. In figure 3.2, the VBA code used to derive the numbers for the combination can be found. Underneath the table shown in table 3.2, the 13 large orders are stored (in the Excel file itself). In these cells, the code is looking to see if a combination is in one of the orders or not. If it is the case, a counter goes plus one and will place the value of the counter in the correct cells that go with that combination.

```
Sub tellenproductensamenbesteld2019erbij()
Dim i, counter, j, k, n As Integer
For n = 2 To 605
    For k = n + 1 To 605
        counter = 0
        For j = 3 To 15
            If Application.WorksheetFunction.CountIf(Range(Cells(614, j), Cells(918, j)), Cells(1, n)) > 0 And Application.WorksheetFunction.CountIf(Range(Cells(614, j), Cells(918, j)), Cells(1, k)) > 0 Then
                counter = counter + 1
                Cells(k, n) = counter
            End If
        Next j
        counter = 0
    Next k
Next n
End Sub
```

**Figure 3.2** VBA code used to determine products that are frequently ordered together

The code in figure 3.2 fills the table for every combination as seen in table 3.2. After the whole table filled up, we needed to derive the numbers 12 and 13 from the table and see which products wherein that combination. That was done with the code in figure 3.3.

```
Sub zoekdel3()
Dim i, k, counter As Integer
counter = 1
For i = 2 To 605
    For k = i + 1 To 605
        If Cells(k, i) = 13 Then
            counter = counter + 1
            Cells(counter, 610) = Cells(1, i)
            Cells(counter, 611) = Cells(k, i)
            Cells(counter, 612) = Cells(k, i)
        End If
    Next k
Next i
End Sub

Sub zoekdel2()
Dim i, k, counter As Integer
counter = 1
For i = 2 To 605
    For k = i + 1 To 605
        If Cells(k, i) = 12 Then
            counter = counter + 1
            Cells(counter, 614) = Cells(1, i)
            Cells(counter, 615) = Cells(k, i)
            Cells(counter, 616) = Cells(k, i)
        End If
    Next k
Next i
End Sub
```

**Figure 3.3** VBA code used to gather the combinations appearing in 12 of the 13 orders or all 13 orders

This information is used when making our layout for Company X's order picking warehouse. The complete table used and the results can be found in the Excel file: Order Analysis results + Current Layout on sheet 2.

### 3.1.3: The dimensions and weight of the product

For the dimensions and weight of the product, less VBA was needed. Company X provided us with a list that contains the dimensions and the weight of a product. The only thing we needed to do was derive the information for the products in zone AB. Most of the products occurred more than once in the list with product numbers. This is because products could be single, in a box, or pallet. For this research single products were needed. With the code that was made for this, it was not possible to get it for a single product. For that reason, the products in zone AB were done by hand with the use for searching the product number with ctrl + f. This results in table 3.3. The complete data list can be found in the Excel file: Order Analysis results + Current Layout on sheet 3.

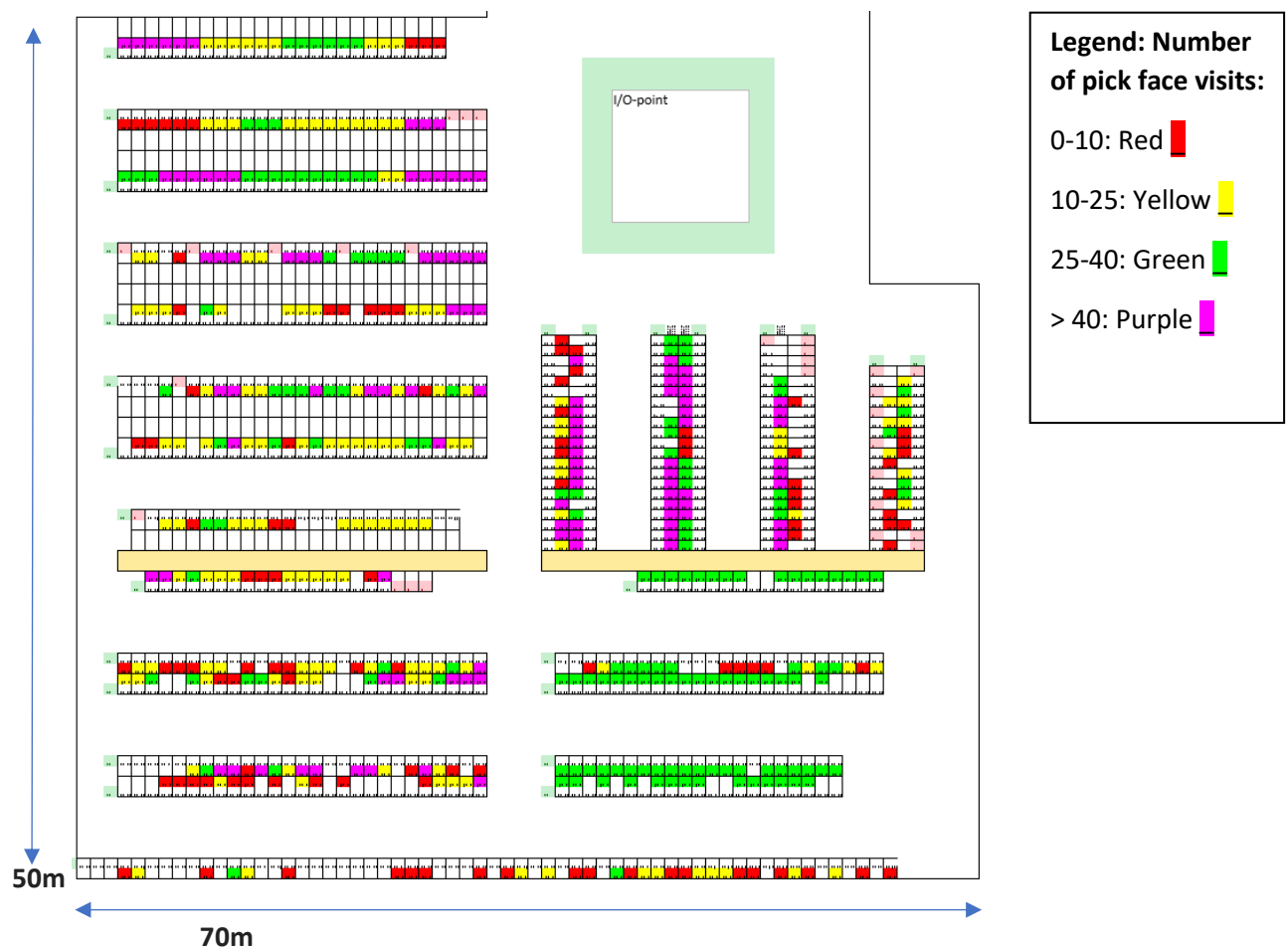
**Table 3.3** Results of gathering the weight and dimensions of the products for zone AB

| Productnumber | Location | Pick face visits | Weight | Volume cm3 |
|---------------|----------|------------------|--------|------------|
| 123034        | AB.00.19 | 8                | 32,8   | 37500      |
| 143015        | AB.00.22 | 16,66666667      | 27,5   | 37500      |
| 123053        | AB.00.23 | 29,33333333      | 10     | 17888      |
| 143010        | AB.00.24 | 23,66666667      | 16,1   | 22446      |
| 143055        | AB.00.25 | 48               | 16,7   | 17888      |
| 123032        | AB.00.30 | 9,66666667       | 18,4   | 17888      |
| 181982        | AB.00.37 | 4                | 20,25  | 19200      |
| 123225        | AB.00.39 | 10               | 12,6   | 10500      |
| 123144        | AB.00.41 | 25,33333333      | 8,8    | 15360      |
| 143005        | AB.00.43 | 17,66666667      | 8,3    | 7252       |
| 123270        | AB.00.44 | 14,33333333      | 13,8   | 10200      |
| 143050        | AB.00.45 | 11               | 7      | 10395      |
| 123140        | AB.00.48 | 40,66666667      | 7,6    | 7252       |
| 123215        | AB.00.53 | 48               | 7,2    | 5994       |
| 123260        | AB.00.57 | 44,33333333      | 7,2    | 5994       |
| 123030        | AB.00.60 | 12,66666667      | 6,6    | 12600      |
| 123205        | AB.00.62 | 30               | 2,6    | 7000       |
| 123020        | AB.00.64 | 34               | 3,08   | 1800       |
| 123152        | AB.00.69 | 35,33333333      | 22     | 25600      |
| 123150        | AB.00.73 | 67,33333333      | 8,4    | 13464      |
| 123134        | AB.00.82 | 28,66666667      | 9,4    | 13464      |
| 143106        | AB.00.85 | 15,33333333      | 6,8    | 12800      |
| 181981        | AB.00.88 | 2,33333333       | 0      | 0          |
| 123110        | AB.00.91 | 63,33333333      | 5,2    | 11520      |
| 123143        | AB.00.92 | 1,33333333       | 0      | 0          |
| 143100        | AB.00.94 | 15,33333333      | 3,1    | 11520      |
| 123130        | AB.00.96 | 47               | 4,6    | 11520      |
| 122323        | AB.00.99 | 30,33333333      | 4,8    | 37800      |
| 144350        | AB.01.02 | 26,66666667      | 1,4    | 16200      |
| 144450        | AB.01.05 | 58,66666667      | 4,99   | 16200      |
| 144405        | AB.01.08 | 64,33333333      | 1,44   | 16200      |

Mainly the volume of the products was used during the comparison between the current layout and the new layout. Furthermore, the pick face visits and weight were used when creating the new layout (see Section 3.3). The current layout is shown in section 3.2.

### 3.2: Current layout

To understand how the orders are handled in the current situation, the current layout of the order picking warehouse is needed. Company X only had the locations in their system and did not have a floorplan of the current layout. For that reason, during this research, this floorplan has been created in Excel. In this floorplan, the products are also highlighted with a color. There are 4 different colors: Red, Yellow, Green, and Purple. These colors depict the pick face visits of the products. If the products are visited less than 10 times in the last three high seasons, then it gets the color red. If the products are visited between 10 to 25 times during the last three high seasons it gets the color yellow. If the products get visited between 25 to 40 times during the last three high seasons it gets the color green. And if the colors get visited more than 40 times during the high season then it gets the color purple. All the data for the color division and pick face visits per product are found during the order analysis mentioned in section 3.1 (see figure 3.4). With the figure, also the real length and width of the warehouse are given. In real life, the aspect ratio of the warehouse is different from that in Excel. This is because the exact ratio was difficult to put in the cell of excel. Furthermore, a legend is made to make it easier to see what color corresponds to what number of pick face visits.



**Figure 3.4** The layout of Company X's order picking warehouse with colors for the pick face visits

To give each product the correct location and correct color, a VBA code was used. After putting in all the locations by hand. We let Excel fill in the product in the right locations. Company X provided us with a list that contained all the locations and product numbers, to be able to let Excel create the current situation for us. First, the products needed to go to the correct locations (see figure 3.5). The code shown in figure 3.5, is duplicated for every row. This code only fills in one side of an aisle. Copying the code and changing the rows and columns, was used to fill in the complete current layout.

```
Sub ABILocatiesproductengeven()
    Dim locatie, plek As String
    Dim i, j, k As Integer
    Dim n As Long

    For i = 2 To 655
        locatie = Cells(i, 81)
        For j = 6 To 29
            plek = Cells(9, j)
            If locatie = plek Then
                n = Cells(i, 80)
                Cells(8, j) = n
            End If
        Next j
    Next i
End Sub
```

**Figure 3.5** VBA code used to give product numbers the correct locations

After the product number was linked to the correct location in the layout. The product needed to get the correct color to get a quick idea of how many times the products are ordered. That was done with the code in figure 3.6.

```

Sub ABILocatieskleurenaarpickfacevisits()
Dim i, j, k, n As Integer
For i = 2 To 655
    For j = 6 To 29
        If Cells(8, j) = Cells(1, 73) Then
            If Cells(1, 75) >= 40 Then
                Cells(8, j).Interior.Color = vbMagenta
            ElseIf Cells(1, 75) < 40 And Cells(1, 75) >= 25 Then
                Cells(8, j).Interior.Color = vbGreen
            ElseIf Cells(1, 75) < 25 And Cells(1, 75) >= 10 Then
                Cells(8, j).Interior.Color = vbYellow
            ElseIf Cells(1, 75) < 10 Then
                Cells(8, j).Interior.Color = vbRed
            End If
        End If
    Next j
Next i
End Sub

```

**Figure 3.6** VBA code used to get the correct color to product number in a certain location

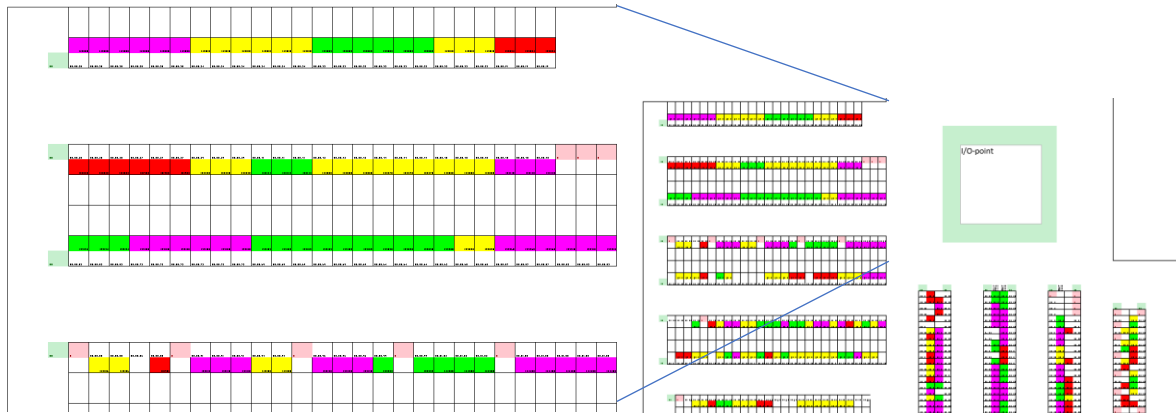
Both these codes were used in combination with the data in table 3.4.

**Table 3.4** The table containing location and pick face visits

| Productnumber | Location | Pick face visits |
|---------------|----------|------------------|
| 123034        | AB.00.19 | 8                |
| 143015        | AB.00.22 | 16,66666667      |
| 123053        | AB.00.23 | 29,33333333      |
| 143010        | AB.00.24 | 23,66666667      |
| 143055        | AB.00.25 | 48               |
| 123032        | AB.00.30 | 9,66666667       |
| 181982        | AB.00.37 | 4                |
| 123225        | AB.00.39 | 10               |
| 123144        | AB.00.41 | 25,33333333      |

Table 3.4 is a small part of the entire table. This is to give an idea of what the table was used to give the product the correct location and correct color.

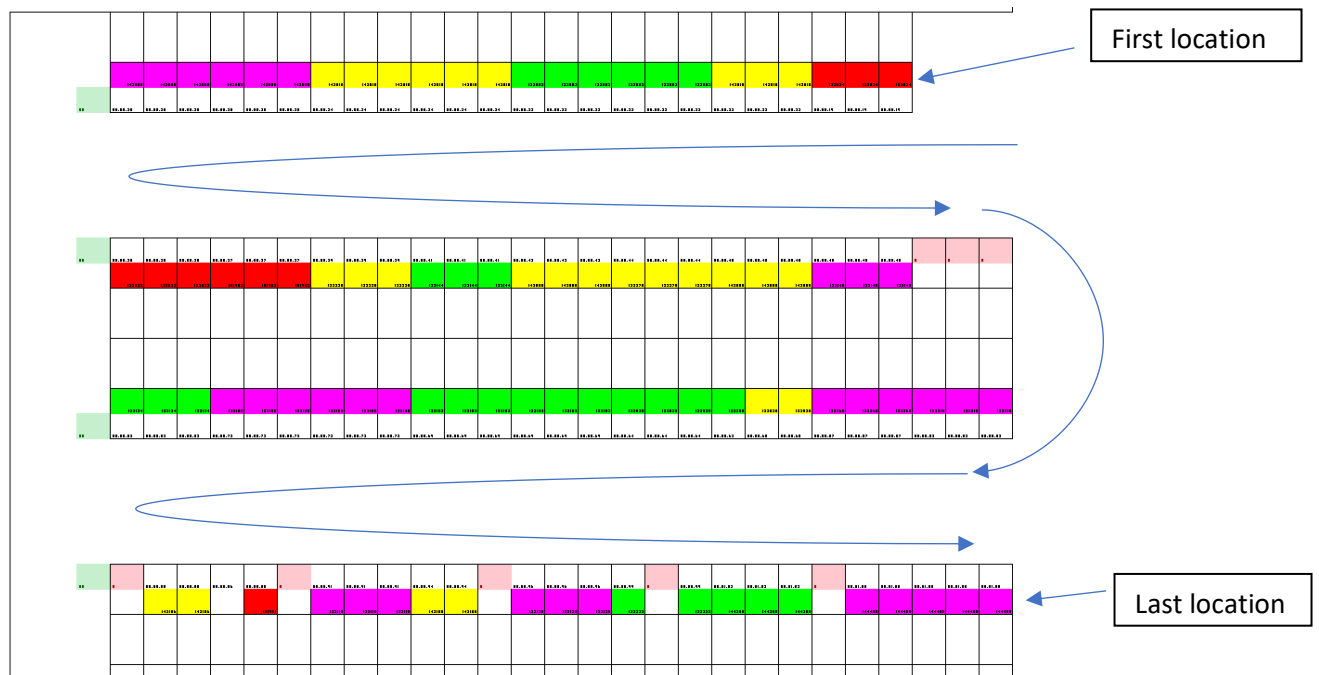
With the current situation known, a new layout must be created. To start with the whole warehouse would be too big of a project. That is one reason why in the beginning there is only focus for a smaller part of the warehouse namely all the locations starting with the letters AB. The reason we started with zone AB is that when Company X starts with picking orders they always start with that zone. Making it a logical starting point for this research. As mentioned in Chapter 1, looking at a smaller part of the warehouse will also make a comparison doable and not too much work. A smaller part also has another advantage. This is because the products of Company X are very difficult to stack. This is because, the products are bags, pots, or boxes. There are even products that are more difficult to stack. In the current situation products that are stackable pretty good are close together in the same zone. For example zone AB. To not make the thesis too difficult, the assumption is made that every product in the same zone is stackable. This is an assumption that can be made, because in their current way of working the products that now are in the same zone end up on the same pallets (see section 3.3). This assumption is made to be able to make an own layout and be able to test this without having to check every possibility if the products are stackable. Likely, products from other zones are not stackable, so those will also not be mixed. For the remainder of this research, only zone AB (see figure 3.7) is taken into consideration. Also, if the new allocation method is working within the AB zone, it is likely to work for the other zones as well and it is worth looking at.



**Figure 3.7** Zone AB of the current layout of Company X's order picking warehouse

### 3.3: Company X's current way of handling large orders

At this moment, when Company X gets a large order in and the order pickers start with order picking. The routing of the order pickers is determined by the locations. The products that are coming in are sorted by their location. For example, if we have 5 locations with 5 products. Where products 1 has location 1 and so on. If we then would get an order with products 1, 2, 5. The order picker in Company X's order picking warehouse goes first to location 1, after that to location 2, and last to location 5. Some order pickers are convinced that this is the best way of working because they have put products together that are stackable. Furthermore, the product in location 1 is the heaviest and the product in location 5 is the least heavy. If the order picker then follows the locations, the heaviest product is also on the bottom. In figure 4.8, the way of how the locations go up is depicted.



**Figure 3.8** Walking way of order pickers in the current system

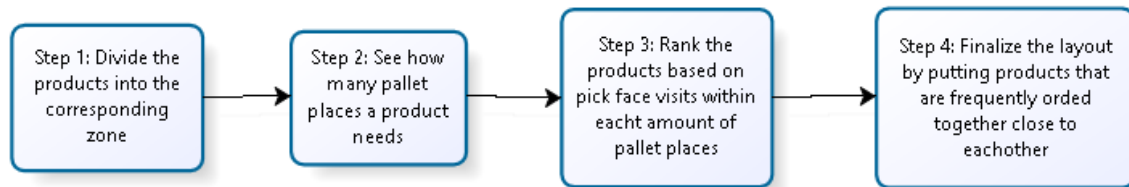
In Chapter 3, we have found all kinds of data and we know what the current situation in Company X's order picking warehouse is and how it works. This is used when creating the improved layout and during the comparison of the two layouts. In the next chapter, the allocation method used to create an improved layout is explained and described.

## Chapter 4: Allocation method

In this section, the allocation method is described and explained. This allocation method is based on existing methods, as mentioned in Chapter 2. After the method is explained, the result for zone AB in Company X's order picking warehouse after using this method is shown in Chapter 5.

### 4.1: Allocation method

Our procedure consists out of four steps. In figure 4.1, the steps are put together and after that, the steps are described in more detail.



**Figure 4.1** Overview of the steps within the allocation method

#### 4.1.1: Step 1: Zone division

First, the products need to be divided into zones. For Company X, this was an easy job, because their warehouse has letters in the location name to mark the zone. As the zone we were looking at is zone AB.

#### 4.1.2: Step 2: Space division

Second, the amount of pallet places per product in storage is needed. Also, we need to know where the different amounts of pallet places can be stored. For zone AB, there were four options. The products needed 6, 3, 2, or 1 pallet places in storage. The advantage of keeping the products in their zone is that you know for sure that there are always enough of each amount of pallet place because they were stored there before. The products only get moved around in the specific zone. When the places of the different amount pallet places are known, the locations need to be ranked with the highest rank for the location closest to the I/O-point. For Company X's zone AB, this resulted in a ranking for locations with 6 pallet places, 3 pallet places, 2 pallet places, and 1 pallet place. The reason for looking at the pallet places that a product needs is because then Company X can easily implement the new layout. In the system, the locations will remain the same. Also, the amount of pallet places per location remains the same. Of course, the possibility of getting a better working layout by changing these locations is there.

#### 4.1.3: Step 3: Ranking the products

In this step, the products are assigned to the locations in the different ranking lists. This is based on the amount of pick face visits during the high season. This means that products that appear more in different orders will lay close to the I/O-point and products that do not get ordered a lot in different orders are placed further away from the I/O-point. This way of assigning locations is called a COI-based policy. This policy is found and discussed in Chapter 2. The division between the number of pallet places is still made. So, a product with more pick face visits may lay further away than a product with less pick face visits, because then there is no location for that amount of pallet places available closer. To get an idea of how we did this step, see the screenshot from excel (table 4.1).

**Table 4.1** Way of ranking the products used to create an improved layout for zone AB

| Ranking 6 pallet places |        | Ranking is based on the amount of pallet places and after that the number of pick face visits |            |          |        |               |        |
|-------------------------|--------|-----------------------------------------------------------------------------------------------|------------|----------|--------|---------------|--------|
| 1                       | 123150 | product number appeared in products number that are ordered frequently                        |            |          |        |               |        |
| 2                       | 143055 |                                                                                               |            |          |        |               |        |
| 3                       | 123152 |                                                                                               |            |          |        |               |        |
| 4                       | 123053 | product number appeared in products number that are ordered frequently                        |            |          |        |               |        |
| 5                       | 143010 |                                                                                               |            |          |        |               |        |
| Ranking 3 pallet places |        | productnumber                                                                                 | Combi 12/1 | pickface | weight | places        |        |
| 1                       | 144405 | Nee                                                                                           |            | 64       | 120,00 | 3             | 144405 |
| 2                       | 123110 | Ja                                                                                            |            | 63       | 634,00 | 3             | 123110 |
| 3                       | 123215 | ja                                                                                            |            | 48       | 810,00 | 3             | 123215 |
| 4                       | 123130 | ja                                                                                            |            | 47       | 610,00 | 3             | 123130 |
| 5                       | 123260 | Nee                                                                                           |            | 44       | 810,00 | 3             | 123260 |
| 6                       | 123140 | ja                                                                                            |            | 41       | 535,00 | 3             | 123140 |
| 7                       | 123020 | Nee                                                                                           |            | 34       | 240,00 | 3             | 123020 |
| 8                       | 123134 | Nee                                                                                           |            | 29       | 610,00 | 3             | 123134 |
| 9                       | 144350 | Nee                                                                                           |            | 27       | 125,00 | 3             | 144350 |
| 10                      | 123144 | Nee                                                                                           |            | 25       | 760,00 | 3             | 123144 |
| 11                      | 143005 | Nee                                                                                           |            | 18       | 535,00 | 3             | 143005 |
| 12                      | 143015 | Nee                                                                                           |            | 17       | 470,00 | 3             | 143015 |
| 13                      | 123270 | Nee                                                                                           |            | 14       | 750,00 | 3             | 123270 |
| 14                      | 143050 | Nee                                                                                           |            | 11       | 460,00 | 3             | 143050 |
| 15                      | 123225 | Nee                                                                                           |            | 10       | 750,00 | 3             | 123225 |
| 16                      | 123032 | Nee                                                                                           |            | 10       | 810,00 | 3             | 123032 |
| 17                      | 123034 | Nee                                                                                           |            | 8        | 610,00 | 3             | 123034 |
| 18                      | 181982 | Nee                                                                                           |            | 4        | 810,00 | 3             | 181982 |
| Ranking 2 pallet places |        | productnumber                                                                                 | location   | pickface | weight | pallet places |        |
| 1                       | 144450 | AB.01.05                                                                                      |            | 59       | 500,00 | 2             | 144450 |
| 2                       | 122323 | AB.00.99                                                                                      |            | 30       | 320,00 | 2             | 122323 |
| 3                       | 143106 | AB.00.85                                                                                      |            | 15       | 610,00 | 2             | 143106 |
| 4                       | 143100 | AB.00.94                                                                                      |            | 15       | 610,00 | 2             | 143100 |
| 5                       | 123030 | AB.00.60                                                                                      |            | 13       | 760,00 | 2             | 123030 |
| Ranking 1 pallet places |        | productnumber                                                                                 | location   | pickface | weight | pallet places |        |
| 1                       | 123205 | AB.00.62                                                                                      |            | 30       | 980,00 | 1             | 123205 |
| 2                       | 181981 | AB.00.88                                                                                      |            | 2        | 0,00   | 1             | 181981 |

#### 4.1.4: Step 4: Finalizing the layout

In the last step, the products that are frequently ordered together need to be put close to each other. This way of assigning is based on the OOS strategy from Mantel et al. (2007) discussed in Chapter 2. For Company X's order picking warehouse, we had 13 large orders that we could look at to see which products are ordered together. We marked the products that were together in 13 of the 13 orders or 12 of the 13 orders. These products were then, still considering pick face visits, put together. This is a little bit of a vaguer step, but if the zone is not that big and the person making the layout uses only the products that are almost certainly in the same order together it is an easy puzzle. As in Company X's zone AB, we only had to move around a couple of products that match the criteria of being together in either 13 of the 13 orders or 12 of the 13 orders. The products in Company X's order picking warehouse are not all stackable. This is something that can also be taken into consideration in this last step. Looking at frequently ordered together while thinking of the products that are stackable together. So, this is a bit vaguer, but it does not have to be a difficult puzzle to put the last part together and it leaves some freedom for the maker of the layout.

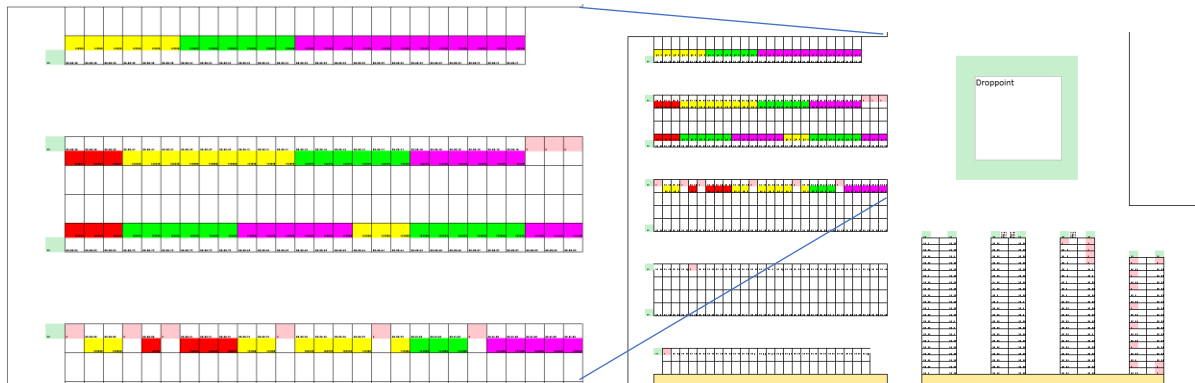
During this chapter, we have described and explained the allocation method that is used during this research in a couple of steps. After executing this method ourselves, we were able to create an improved layout. The result of this layout is found in the next chapter.

## Chapter 5: Results

In this chapter, the results of our research are presented. First, we show the improved layout, and second, we show the testing procedure and results of the comparison.

### 5.1: Improved layout

In Chapter 4, the allocation method used is described and explained. Here the result is shown after we used the allocation methods. There are some remarks on how we used this for Company X's zone AB. In this section, the results of the method explained above are shown.



**Figure 5.1** Zone AB of Company X's order picking warehouse using the allocation method described in section 4.1

### 5.2: Explanation

In figure 5.1, the new layout can be seen. In the layout compared to the old layout (see figure 3.7), it is immediately clear that the purple products are closer to the I/O-point. As seen in figure 3.4, the I/O-point is on the right side of this zone AB. This is also happening with the colors green, yellow, and red. Because the amount of pallet places is taken into consideration, sometimes yellow is closer to the I/O-point than for example purple. Also, some products seem to have more than 6 pallet places. These are different products, but with the zoomed-out version, this is not visible. In figure 5.2, it is focused on a smaller part of zone AB to make clear how it works. In the top part, there are three products in the purple part. One product with 6 pallet places and two products with 3 pallet places.



**Figure 5.2** Zoomed in on a smaller part of zone AB of Company X's order picking warehouse

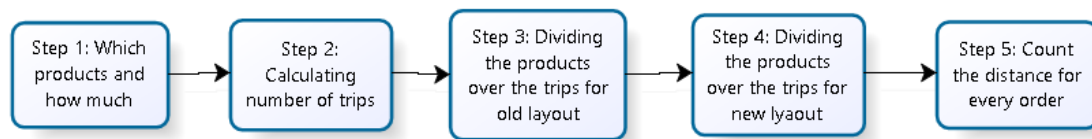
### 5.3: Testing improved layout

After creating our improved layout, we tested it against the current layout of Company X's order-picking warehouse. To test our layout, we used the 13 large orders that came in during the last three high seasons. This is from the years 2018, 2019, and 2020. First, we describe the testing procedure

and after that the results of testing the 13 orders in both layouts. The orders that are used in the test were very much alike and this indicates that it is very likely that orders coming in next year will also look something like this.

### 5.3.1: Testing procedure

The two layouts are tested against each other by looking at the total travel distance the order picker needed to cover to be able to pick all the 13 orders. In this research, we are looking for a solution for improving the efficiency in handling the large orders that are coming in during the high season. This test represents that. To measure the travel distance, we counted the number of blocks passed by the order picker to complete an order. In figure 5.3, an overview of the steps in the testing procedure is found.



**Figure 5.3** Overview of the testing procedure

#### 5.3.1.1: Step 1: Which products and how much

First, we needed to know which products were ordered in the 13 large orders that were placed in zone AB. For these products, the following information was needed: volume of one product and amount ordered per product. Furthermore, the volume that could be stored on a pallet was needed. The information for the volume of a pallet and the amount ordered could directly be provided by Company X. The volume of one product needed to be calculated by multiplying height, length, and width.

#### 5.3.1.2: Step 2: Calculating the number of trips

Multiplying the number of products ordered by the volume of a product results in the total amount of volume that products fill on a pallet. If you then divide that total volume of a product by the volume of a pallet it will result in the pallet place needed by the ordered product. If you then add up all the needed pallets place the ordered products filled up together, you know how much pallet needs to be filled to complete zone AB for that order. The order picker can go around with a maximum of one pallet. The amount of pallets to complete zone AB for an order is then also automatically the number of trips needed to complete an order. This is a lot of text and maybe confusing, see table 5.1 for a visible table of how it works. Also, here is an example of how we calculated the pallets needed for product 123225:  $(10500 * 50) / 2112000 = 0,248579545$ .

**Table 5.1** An example table of how we calculated the number of trips that were needed to complete zone AB for an order

| Productnumber         | Volume cm3 | Amount ordered | Total cm3    | Pallets needed     |
|-----------------------|------------|----------------|--------------|--------------------|
| 123225                | 10500      | 50             | 525000       | 0,248579545        |
| 123140                | 7252       | 75             | 543900       | 0,257528409        |
| 123215                | 5994       | 100            | 599400       | 0,283806818        |
| 123152                | 25600      | 36             | 921600       | 0,436363636        |
| 123150                | 13464      | 60             | 807840       | 0,3825             |
| 123110                | 11520      | 120            | 1382400      | 0,654545455        |
| 123130                | 11520      | 100            | 1152000      | 0,545454545        |
| 144350                | 16200      | 100            | 1620000      | 0,767045455        |
| 144450                | 16200      | 100            | 1620000      | 0,767045455        |
| 144405                | 16200      | 100            | 1620000      | 0,767045455        |
|                       |            |                |              |                    |
|                       |            |                |              |                    |
| <b>Volume pallet:</b> |            |                | <b>Total</b> | <b>5,109914773</b> |
| 2112000               |            |                |              |                    |
|                       |            |                | 6 trips      |                    |

The volume of a pallet was different for different clients of Company X. This had to do with the maximum height that could be used by Company X when stacking the products while picking the orders. For all the 13 orders used to test the layout a table as shown in table 5.1, was made.

### 5.3.1.3: Step 3: Divide products over the trips for the current layout

The number of trips needed to complete all orders is known. The next step is to see which products need to be picked up on the same trip. For the old layout, we tried to copy the structure that Company X is using right now. This means that the products as listed in table 5.1, already in the sequence on how they pick them up. Starting from above and see if the product beneath it fits on the same trip. If not, the order picker needs to go back to the I/O-point. Trying to switch aisles as little as possible. To divide the trips, a column was added to the table shown in table 5.1 (see table 5.2).

**Table 5.2** The same table as table 5.1 with a column added to divide the trips

| Productnumber         | Volume cm3 | Amount ordered | Total cm3    | Pallets needed     | Trip number old layout |
|-----------------------|------------|----------------|--------------|--------------------|------------------------|
| 123225                | 10500      | 50             | 525000       | 0,248579545        | 1                      |
| 123140                | 7252       | 75             | 543900       | 0,257528409        | 1                      |
| 123215                | 5994       | 100            | 599400       | 0,283806818        | 1                      |
| 123152                | 25600      | 36             | 921600       | 0,436363636        | 2                      |
| 123150                | 13464      | 60             | 807840       | 0,3825             | 2                      |
| 123110                | 11520      | 120            | 1382400      | 0,654545455        | 3                      |
| 123130                | 11520      | 100            | 1152000      | 0,545454545        | 4                      |
| 144350                | 16200      | 100            | 1620000      | 0,767045455        | 5                      |
| 144450                | 16200      | 100            | 1620000      | 0,767045455        | 6                      |
| 144405                | 16200      | 100            | 1620000      | 0,767045455        | 7                      |
|                       |            |                |              |                    |                        |
|                       |            |                |              |                    |                        |
| <b>Volume pallet:</b> |            |                | <b>Total</b> | <b>5,109914773</b> |                        |
| 2112000               |            |                |              |                    |                        |
|                       |            |                | 6 trips      |                    |                        |

To divide the trips, we puzzled everything together ourselves. This is because we know that it would have probably taken us longer to try and write code to do it than doing it by hand. This is something that can be improved if more time was available. For the test itself, both the old and the new layout are done by hand, so the same chance of error occurs.

#### 5.3.1.4: Step 4: Divide products over the trips for the new layout

For the new layout, we could not use the sequence of how the products are listed. The products were possibly in another aisle and combining the products could not just be done in one blink of an eye. That is why another two columns were added to table 5.2. One column to divide the products over the trips. The other column to see in which aisle the product is located within the new layout (see table 5.3).

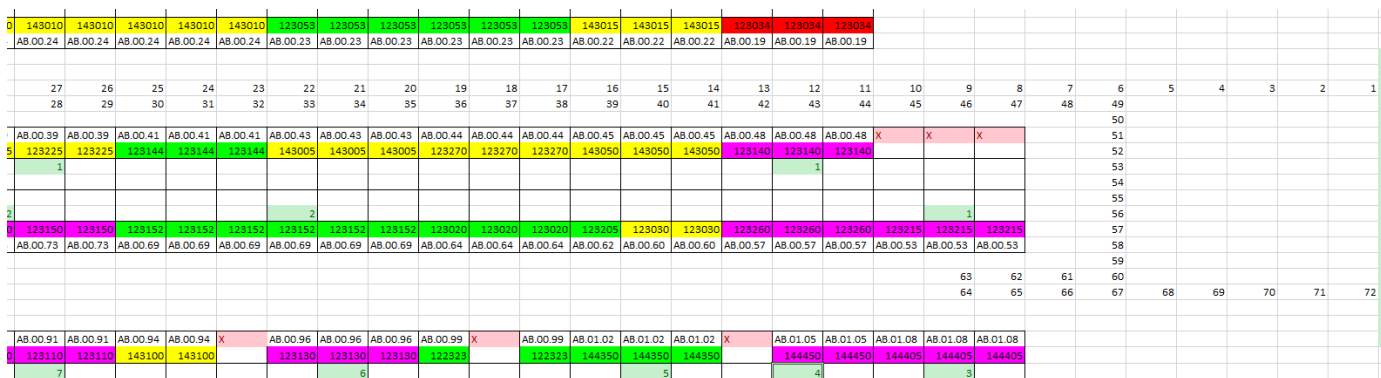
**Table 5.3** Table as shown in table 5.2 with two new columns added to divide the trips for the new layout

| Productnumber  | Volume cm3 | Amount ordered | Total cm3 | Pallets needed | Trip number old layout | Trip number new layout | Aisle new layout |
|----------------|------------|----------------|-----------|----------------|------------------------|------------------------|------------------|
| 123225         | 10500      | 50             | 525000    | 0,248579545    | 1                      | 2                      | 1                |
| 123140         | 7252       | 75             | 543900    | 0,257528409    | 1                      | 2                      | 1                |
| 123215         | 5994       | 100            | 599400    | 0,283806818    | 1                      | 1                      | 1                |
| 123152         | 25600      | 36             | 921600    | 0,436363636    | 2                      | 3                      | 2                |
| 123150         | 13464      | 60             | 807840    | 0,3825         | 2                      | 2                      | 1                |
| 123110         | 11520      | 120            | 1382400   | 0,654545455    | 3                      | 1                      | 1                |
| 123130         | 11520      | 100            | 1152000   | 0,545454545    | 4                      | 3                      | 1                |
| 144350         | 16200      | 100            | 1620000   | 0,767045455    | 5                      | 4                      | 2                |
| 144450         | 16200      | 100            | 1620000   | 0,767045455    | 6                      | 5                      | 2                |
| 144405         | 16200      | 100            | 1620000   | 0,767045455    | 7                      | 6                      | 2                |
| Volume pallet: |            |                | Total     | 5,109914773    |                        |                        |                  |
| 2112000        |            |                |           |                |                        |                        |                  |
|                |            |                | 6 trips   |                |                        |                        |                  |

When dividing the trips, it was not possible to start at the top of the list and work down from there. That is why we started with the product that is the furthest away in an aisle (starting in aisle 1). Then from there looking at a product closest to that location to see if it fits on the pallet. If it did not fit, go the product then closest to the product, and if nothing in that aisle fitted on the pallet return to the I/O-point. There were some exceptions where the trips contain products that were in both the aisles. This was because otherwise, some pallets were very empty, because of the high amount of volume some products had in some orders. Most of the trips only contained products from the same aisle. This is also mentioned above by dividing the products for the old layout. The goal was to switch aisles as little as possible.

#### 5.3.1.5: Step 5: Counting the distance

Creating tables as table 5.3 for all the 13 orders to able to see which layout is more efficient in handling the larger orders. Now we needed a way to see what the distance of each trip is. If you then add all the distances found for the trips, the distance for an order is known. Adding all the distances for the orders, the total amount of distances traveled to complete all the 13 orders is known. In figure 5.4 and figure 5.5, the way of counting the blocks to see what the distance of a trip is.



**Figure 5.4** Example of how the distance of a trip is measured where the green block is the I/O-point

**Figure 5.5** Another example of how the distance of a trip is measured where the green block is the I/O-point

**Table 5.4** Example of how the total distance of all the trips of one order for zone AB is calculated

### 5.3.2: Test results

**Table 5.5** *Results of the comparison between current and new layout*

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The results show that Company X's order picking warehouse can be improved and the allocation method used in this research is one way of doing that. In the following and last chapter, a conclusion is given and we give the company recommendations on where to go from here.

## Chapter 6: Conclusion and recommendations

In this chapter, the conclusion is given in section 6.1 and the recommendations for Company X are given in section 6.2.

### 6.1: Conclusion

Company X was facing a problem with handling their large orders. This does not happen in the most efficient way and because of that other smaller orders will not be shipped on time. The company needed a person to investigate how they can improve the efficiency of their order picking warehouse. This was the perfect time for Company X to take a look at optimizing their warehouse because the company is implementing a new scanning system that the order pickers are going to use while order picking. This research is the first step for Company X to optimize their warehouse.

In this research, we are looking for the answer to the main research question:

*How can Company X handle large orders efficiently to make sure all orders can be shipped on time?*

To answer this question research needed to be done. First, we looked into literature that can be found on warehouse optimization. After selecting useful literature, we used the things that we found to start with the optimization of Company X's order picking warehouse. We did an order analysis to collect order and product characteristics. After that, the current situation needed to be described. Doing interviews with employees in the warehouse and going through the warehouse ourselves to get the current layout and current way of working.

Based on the data found with the data analysis, a new layout was created using a new allocation method. This new layout is tested against the current layout. In the comparison, the travel distance to complete an order is measured in both situations and the total travel distance is compared. This resulted in an 11.48% improvement using the new layout. This is a good result, but still, there are some assumptions and limitations. Which are a direct starting point for further research for Company X. When answering the main research question, it can be said that handling large orders more efficiently is possible, but unfortunately this research does not include the effect on the smaller orders. The assumption is that smaller orders are on time because time is saved with the large orders. This needs to be investigated further.

### 6.2: Recommendations

With the results of this research, Company X has a starting point for increasing the efficiency of their order picking process. This research comes with a couple of assumptions and limitations, but also comes with promising results. In this section, recommendations for Company X are described and explained.

First, within this research, only the high season has been taken into consideration. A year exists of more weeks than only the 4 weeks in a high season. The first recommendation is to do an order analysis for the whole year from the last couple of years. This will take some time, but these results can then be compared with the order analysis results in this research. With this comparison, Company X will be able to see how representative the high season is for the whole year. If the same products come forward with high pick face visits, the assumption can be made that the layout presented in this research can also be used throughout the whole year.

This research focused on the large orders because Company X wanted to increase their efficiency for those orders. The layout presented in this research looks at products that are frequently ordered together, but only considers these large orders. If only looking at the high season, still the products

that are frequently ordered together need to be found for all the orders and not only for the large orders. This was for now outside of the scope of this research.

The assumption is made that all products in the same zone are stackable. This is a big assumption to make the research doable in the given time frame. Still, this is an assumption that needs to be taken a closer look at. This can be done by testing this in real life. By trying the trips that are created in this research in real life, it will show if the layout and trips are possible.

For the division of the trips, there is a possibility that this is not the most optimal division, because it is done by hand. To make sure that these are the most optimal, a code or program needs to be created. This can for example be done in VBA. Due to time restrictions, this was too much work in this research. Looking for or hiring a person that has the time to do this can make the trips possibly even more optimal and that will increase the efficiency even more.

In the comparison of the two layouts, the return policy is used as a routing policy. This could be a good policy for the simplicity of it, but also this can be investigated further to see if other policies are potentially better for Company X's order picking warehouse.

Another part that can be investigated further is, to change the locations in the system and not take the number of pallet places in the system into account. This way some products that are sold a lot but are now stored further away because a place with the number of pallet places that the product needs is not available any closer can be stored closer to the I/O-point.

This research is the starting point for the optimization of Company X's order picking warehouse. This research already shows a lot is possible, but also a lot can still be investigated. Company X had trouble with convincing some of the order pickers that there is a layout that can be more efficient than the one they are using right now. This research can help to convince these order pickers. Included is a roadmap (see table 6.1) for Company X on what are the next steps to continue working on this project.

**Table 6.1** Roadmap

|                                    | <b>6 weeks</b>                                                                      | <b>12 weeks</b>                                                                    | <b>18 weeks</b>                                                                                                | <b>24 weeks</b> |
|------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------|
| <b>Zones</b>                       | <i>Test one other zone</i>                                                          | <i>Test half of the warehouse</i>                                                  | <i>Test whole warehouse, using the two scripts for dividing the trips and measuring the distances per trip</i> | -               |
| <b>Period</b>                      | <i>Investigate one other timeframe outside of the already researched four weeks</i> | <i>Investigate the months from February till July</i>                              | -                                                                                                              | -               |
| <b>Assumptions and limitations</b> | <i>See if the stackable assumption holds with testing this in real life</i>         | <i>Investigate products that are ordered frequently together for normal orders</i> | -                                                                                                              | -               |

|                              |                                                                      |                                                             |                                                                                            |                                                       |
|------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------|
| <b>Division of the trips</b> | <i>Write a VBA script to divide the trips, used in testing zones</i> | <i>Write a VBA script to measure the distances per trip</i> | -                                                                                          | -                                                     |
| <b>Implementation</b>        | -                                                                    | -                                                           | <i>Investigate how the improved layout can be implemented with the new scanning system</i> | <i>Implement the improved layout in the warehouse</i> |

## Reflection

Overall the whole process of finishing the project went smoothly. Looking for a company during the corona crisis was not the easiest. Most of the companies that I contacted, did not respond or would even say on the phone that they did not need a student right now. Eventually through some people that I know from my dispuut. I got in contact with the CEO of Company X and that is when the ball started rolling. After the first meeting, I could start with my bachelor's research at Company X. I was very glad that I could start that quickly.

I knew that Company X wanted to see how and if their order picking warehouse could be more efficient. But that is a very broad objective. When I started with my project plan and started searching for the problem that I wanted to solve, that was the hardest part of this whole process. Looking into warehouse optimization can be a lot of different things and setting barriers to not make it too broad, was where in the beginning, I struggled the most. When I lost my focus, I planned a meeting with Peter and Alexander. This meeting got me on track and from there everything went how I wanted it to go. Every time I was working on something, a new thing to do came up. I never really had nothing to do and I never really got stuck anywhere. I know that some things could have been done better, but knowing that I did everything myself gives me a good feeling. I think that I did everything that I have in me to do the best I could.

I hope that if you have read the whole research, that everything was clear and good to understand. Thank you for reading!

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## Appendix

Within this research, Excel and VBA are used a lot for data analysis. For the person that is interested in all the results and code for the data analysis. The Excel file 'Order Analysis results + Current layout' is put together. In this file, the following data can be found: Pick face visits, Products ordered together, Weight and dimensions, and Current layout. These are divided into four sheets. Also, in the developer part where VBA is used, all the code that is used is put together and with green text, some explanation is given.

In the second Excel file 'Test results + Procedure', that goes with this research all the results and steps for the comparison between the two layouts can be found. This file is mainly to show the whole testing procedure. Most of the work in this file is done by hand. Only one small piece of code in VBA is used.

These Excel files are really to show all the work that has been done more completely. There has been done more data analysis, but that would make it more complicated to follow. Only the main results of the order analysis are put together as these are the most important. Please contact the author of this research to request the Excel files.