Selecting an adequate order pick supporting technique

A research on a more convenient fulfilment of order picking activities

Bachelor project thesis

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Industrial Engineering & Management

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Preface

This bachelor thesis has been written in the period of February 2018 up until August 2018. It contains the main outcomes of my research *"Selecting an adequate order pick supporting technique",* in order to finish the bachelor's program Industrial Engineering and Management at the University of Twente. I have written this thesis in English, because academic writing in English has been part of my personal development plan during the first quartile of the research period.

I want to thank the supervisor and employees from the company where I have conducted this research. The collaborative and supporting environment within the company really helped me during my research period. Furthermore, I would like to thank Sandor Löwik and Peter Schuur for their support and useful feedback on preliminary versions of my report. Their critical but necessary input have really contributed to a successful completion of the research.

Managementsamenvatting

De titel van dit rapport draagt “*selecting an adequate order pick support technique”,* wat op de juiste wijze vertaalt wordt als “Het selecteren van een geschikte order-pick ondersteunende techniek”. Dit bachelor onderzoek is uitgevoerd van februari 2018 tot en met augustus 2018 bij een niet-nader noemen te bedrijf. Het betreft een snelgroeiend bedrijf met ongeveer 30 werknemers. Het assortiment bestaat uit meer dan 400,000 verschillende producten, waarvan er ongeveer 10,000 zijn opgeslagen in het magazijn. In de aanvangssituatie van het onderzoek bestond er de wens van het managementteam van het bedrijf om een order-pick ondersteunende techniek te introduceren, om zo het order-picken beter te laten verlopen. Er is een theoretisch kader opgesteld om de richting van dit onderzoek in grote lijnen af te bakenen. Het theoretisch kader wat hiervoor gekozen is, zijn de principes van Lean en dan met name de focus op het reduceren van verspilling. Binnen het order-pick proces van het bedrijf werden de orders voornamelijk volgens de “single-order-pick strategy” verzameld. Daarnaast bestonden er op dat moment nog andere activiteiten die zorgden voor verspilling binnen het order-pick proces, zoals de allocatie van producten of het printen van paklijsten.

Het bedrijf is gedurende het onderzoek uitvoerig geanalyseerd. Er is echter al gauw toegespitst op waar het binnen dit onderzoek daadwerkelijk om gaat: waar liggen de mogelijkheden om het order-picken te verbeteren en welke techniek kan daar het beste aan bijdragen? Allereerst is het order-pick proces uitvoerig geanalyseerd en zijn daarin twee belangrijke kritieke prestatie indicatoren (KPI’s) meegenomen. Deze zijn: gemaakte fouten en verspilling. Er is inzicht gecreëerd in hoe deze KPI’s daadwerkelijk presteerden en deze bevindingen zijn uiteindelijk ook meegenomen in de overweging van de eindconclusie. Naast het inzicht in deze KPI’s, is er ook inzicht gecreëerd in de verschillende criteria en wensen die de betrokkenen binnen het order-pick proces hebben, wanneer er een nieuwe order-pick ondersteunende techniek zal worden geïntroduceerd. Op dat moment in het onderzoek was er een goede basis om meer kennis op te doen over de bestaande order-pick ondersteunende technieken, in de literatuur en in de markt. Er is informatie verzameld over talloze opties en uiteindelijk zijn er vier technieken met de meeste potentie geselecteerd voor een nog diepgaandere analyse. Deze technieken zijn uiteindelijk kwantitatief geëvalueerd aan de hand van de lijst met criteria en wensen van de betrokkenen en hier is de best passende techniek voor het betreffende bedrijf uit gekomen: “*pick-by-light”* in combinatie met “*put-to-light”*.

De best passende techniek is de belangrijkste uitkomst van dit onderzoek. Er zijn echter nog wel enkele aanvullende aanbevelingen voor het bedrijf om het order-pick proces in totaliteit te verbeteren, voordat de eindoplossing in fases geïmplementeerd kan gaan worden. Zo zou het bedrijf meer data-onderzoek kunnen doen naar producten die vaak samen besteld worden. Met name in het geval van order-picken in batches, wat door de gevonden techniek mogelijk is, kan dat veel tijd besparen. Verder heeft het bedrijf recentelijk enkele veranderingen binnen het ERP-systeem doorgevoerd. Dit zorgt ervoor dat order-pickers minder onnodige afstand afleggen binnen het magazijn. De uitkomsten van deze wijziging moeten geëvalueerd worden, maar de verwachting is dat dat een positief effect zal hebben op het order-pick proces. Verder is het nodig dat alle producten in het magazijn een unieke locatiecode krijgen. Wanneer dat het geval is, zal de techniek “*pick-by-light”* in combinatie met “*put-to-light”* uiteindelijk een waardevolle toevoeging zijn voor het order-pick proces binnen het bedrijf.

Table of contents

1 Introduction to the research and the company

In the period of February 2018 up to mid-August 2018, I have been busy with writing my bachelor thesis for the study programme Industrial Engineering and Management from the University of Twente. After two and a half years of following courses and lectures, this research is the last step in finishing the bachelor programme. The first period of the research, from February up until May, I have conducted research on the origin of the problem. Eventually it appeared that the company wishes to implement an order pick supporting strategy within their warehouse. The second period, from June up until mid-August, I have conducted research on which strategy fits the best among the alternatives.

The company concerned is established in 2006. It is an online electrotechnical wholesaler which has been active in the electrotechnical sector for over 10 years now. The company is specialized in the development and distribution of electro and electronical products. It operates as an online store with more than 400,000 products and delivers all requested orders to the desired location of a customer. The online store offers various components with regard to fuse boxes (Dutch: groepenkasten), fuse box components, cable and wiring, ground cable, switchgear, installation material and much more. The company is specialized in the development of fuse boxes. For customers, it is possible to customize their own fuse box according to their preferences. The fuse boxes are purchased at various well-known providers, for example Schneider Electric or Attema, but then fully customized to customer's preferences with components of the company itself. Quality is a very important aspect in the electrotechnical world. Every house, company building or other building needs to be provided of the best materials, installed by high-skilled workforce. The company always strives for the best quality, in both products and services.

The company consists of 30 full-time employees nowadays. Within the company, there is an open and friendly working atmosphere. Obviously, there is a hierarchy in terms of responsibilities, with the management team on top of this hierarchy tree. However, there is always the possibility for warehouse employees, the marketing team or employees of customer care to pass by with a problem. The management team has a central place in the office in between the marketing team and the customer care. The office is centred above the warehouse and it is easy to enter the office for warehouse employees as well. A further description of the order picking process and the layout of the warehouse will be provided in the following chapters of this report.

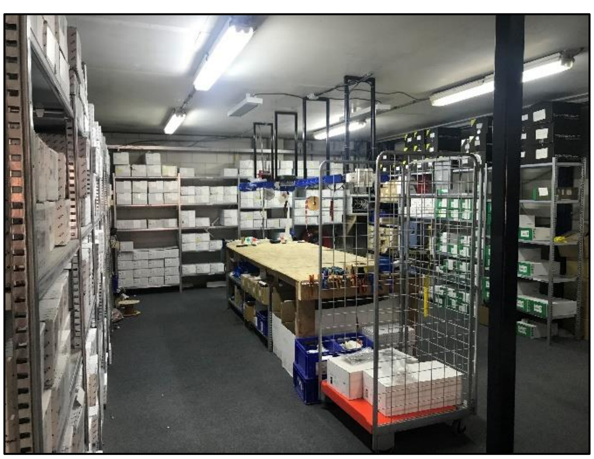

Figure 1: Workshop within the warehouse

Figure 2: One section with storage of small components

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2 Research methodology

2.1 Identification of action problem

Heerkens and van Winden (2012) describe the utility of the Managerial Problem Solving Method (MPSM). The MPSM is a framework which helps to identify the main problem among several problems within a specific research environment. In the problem identification phase of the MPSM in this research, multiple problems were identified at the company. At first, the problem of redundant stock was mentioned. Some products which are further distributed by the company, can only be delivered in bulk batches with a minimum order quantity of, for example, 100 units. However, some of these products do have a low turnover time, like 10 or 15 units per year. This consequences unnecessary high stock levels, and thus high stock costs. The second problem which was mentioned, was the allocation of products in the warehouse. The products were allocated based on their specific turnover rate. So, products with a high turnover rate were stored in front of the warehouse and products with a low turnover rate were stored in the back. Although there is a somewhat systematic layout in the warehouse, there is still room for improvement.

Both problems mentioned above, however, eventually turned out as problems which can be solved by the management of the company themselves. Their education and experience in the field enables them to solve this. After comprehensive investigation in the warehouse process and meetings with the management team, another problem appeared. To understand the problem, one should be aware of the order picking process at the company. This process is depicted in figure 3.

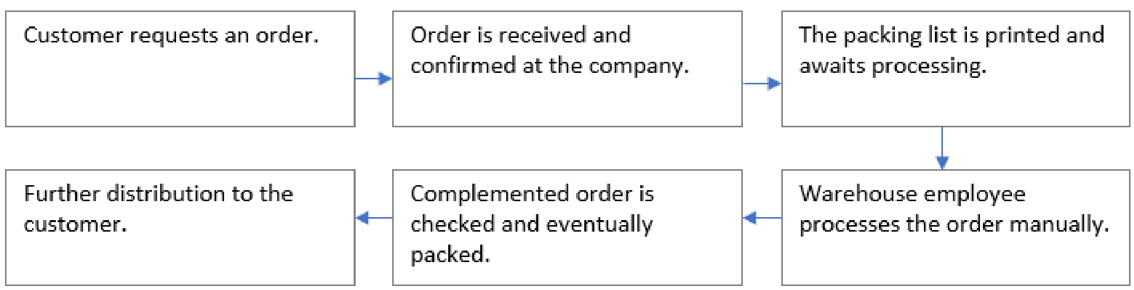

Figure 1: Order picking process at the company

The order picking process is practically divided into six main stages. The first, second and sixth stage of this process do not carry main problems for the company. However, the other three stages are stages where problems occur regularly. Especially in the fourth stage, “warehouse employee processes the order manually”, is plenty of room for improvement according to the management and employees. When an order is ready to be picked, a warehouse employee goes through the warehouse with the packing list in his hand. The employee picks all the items, but there is no standardized format for the employee in which sequence he has to collect the items. It can occur, for example, that an employee passes by a shelf three times, and then picks the item eventually the fourth time he passes by. This involves a lot of waste of motion (Womack & Jones, 1996) and it is not time-efficient. The employees do not know how they can collect all

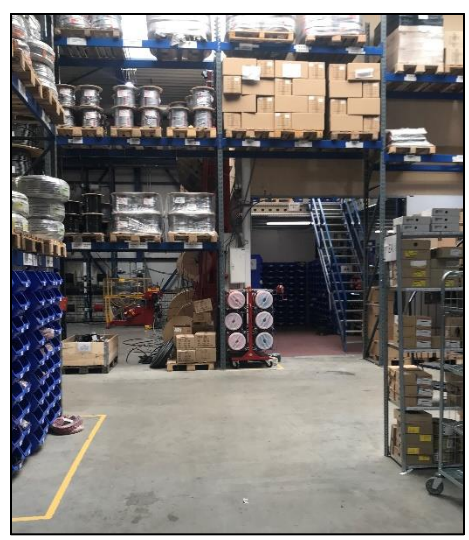

Figure 2: Central section of the warehouse

the different components to complete the order in the most efficient way, so this requires a solution. Also, problems occur in the order picking process in terms of number of mistakes. The allocation of components in the warehouse changes sometimes. When a warehouse employee does not know which exact component to pick to complete an order, it might occur that the wrong components are picked for an order. According to the management team, the number of mistakes in the order picking process must decrease. At the end of the problem identification phase, the action problem is defined as follows*: In the order picking process of the company, the waste of motion and the number of mistakes must decrease.*

2.2 Problem cluster and motivation of the design of the core problem

To eventually solve the action problem, the core problem should be identified. In a problem cluster, the researcher goes back to the problems which do not have a cause themselves (Heerkens & Winden, 2012). Eventually, a core problem must be identified, which also obtains the potential to be solved. For example, the weather cannot be influenced. Figure 3 (see page 6) depicts the problem cluster which is developed according to the problem identification at the company. The main blocks from this problem cluster, will be discussed below.

2.2.1 Action problems

The problem cluster focusses purely on the situation in the warehouse itself and does not reflect problems within the company which are not related to the events in the warehouse.

The identified action problem, which is already mentioned in section 2.1, consists of two elements:

1. **Less orders are completed per time unit than possible.**

The management team of the company notices a discrepancy in the current speed level in which the orders are processed by warehouse employees, and the possible speed. This is caused by waste of motion. Warehouse employees cover more distance in the order picking process than necessary. However, there is no quantification of the current speed and the desired speed yet. Data should be analysed to identify the current speed level of the order picking process. If the average distance needed for a particular order picking process decreases, more orders could be completed per time slot.

2. **The wrong components are collected for a specific order.**

As already mentioned in section 1.1 the orders at the company are picked according to a packing list. However, the locations of the different components in the warehouse must be registered real-time. Only when the locations of components are adjusted in the ERP system, the location of the components on the packing lists will be updated as well. If this does not happen, employees in the warehouse do make mistakes in the order picking process. In the fifth stage of the order picking process (see figure 1), the order is checked. Here, a high-skilled and experienced employee checks the orders to see whether these are completed well or not. If not, the order should be revised, which is a waste of time and motion.

2.2.2 Analysis of problems in the problem cluster

1. **Changes in the location of products in the warehouse are not registered automatically.**

The location of the components in the warehouse changes sometimes, and the location of the components in the warehouse must be registered real-time. If this does not happen, employees might not know where a component is located exactly. The management team of the company has its own reasons to change the location of components in the warehouse over time, for example because of changing throughput-times or stock costs. That is why the allocation of components in the warehouse, will not be part of the eventual solution of this research. Although it is important that the changes in the location of components in the warehouse must be registered real-time, the main focus of the research will not be on this problem. This is because of the fact that the company already has an ERP system which provides locations of components. However, there must be an employee who modifies these changed locations in the ERP system as well.

2. **There is no order pick supporting technique for warehouse employees at the company.**

When the packing list of an order has been printed and the order is ready to be processed, a warehouse employee analyses which components are on the packing list. Then, the warehouse employee starts picking all the components based on his experience. However, there is no standard order picking strategy for warehouse employees which provides the optimal picking route per order. Because there is no standard order picking strategy, waste of motion is involved in the order picking process.

2.2.3 Motivation of core problem

The problem cluster has been developed to visualize various (potential) problems and relations related to the order picking activities in the research environment. The problems mentioned in this cluster present three core problems. These are indicated in bold. However, as already mentioned In the previous section, the management team of the company is already solving some of these problems as well. That is why this research will focus on one core problem. The main motivation for this core problem is actually linked to "*there is no order pick supporting technique for warehouse employees at the company.*"

Design of research: fulfilling the desire of the management team.

As mentioned in section 2.1, the action problem of this research has been identified as *"In the order picking process of the company, the waste of motion and the number of mistakes must decrease".* However, this is not the core problem of the company. This has been identified as that there is not an supporting technique for order pickers. Eventually, it appeared that the company just wants to implement such a supporting technique. Not because they experience dramatic consequences of that such techniques are absent, but because they think it will reduce the number of mistakes and increase the speed of orders to be picked. So, the management team of the company wants to implement a supporting technique for order pickers which fits best among the alternatives. The designed problem cluster still holds for the research, because the relations between the identified problems and situations still exist. The main research question is therefore defined as follows: "*What is best order-pick support technique for the company in order to reduce the waste of motion and the number of mistakes?".*

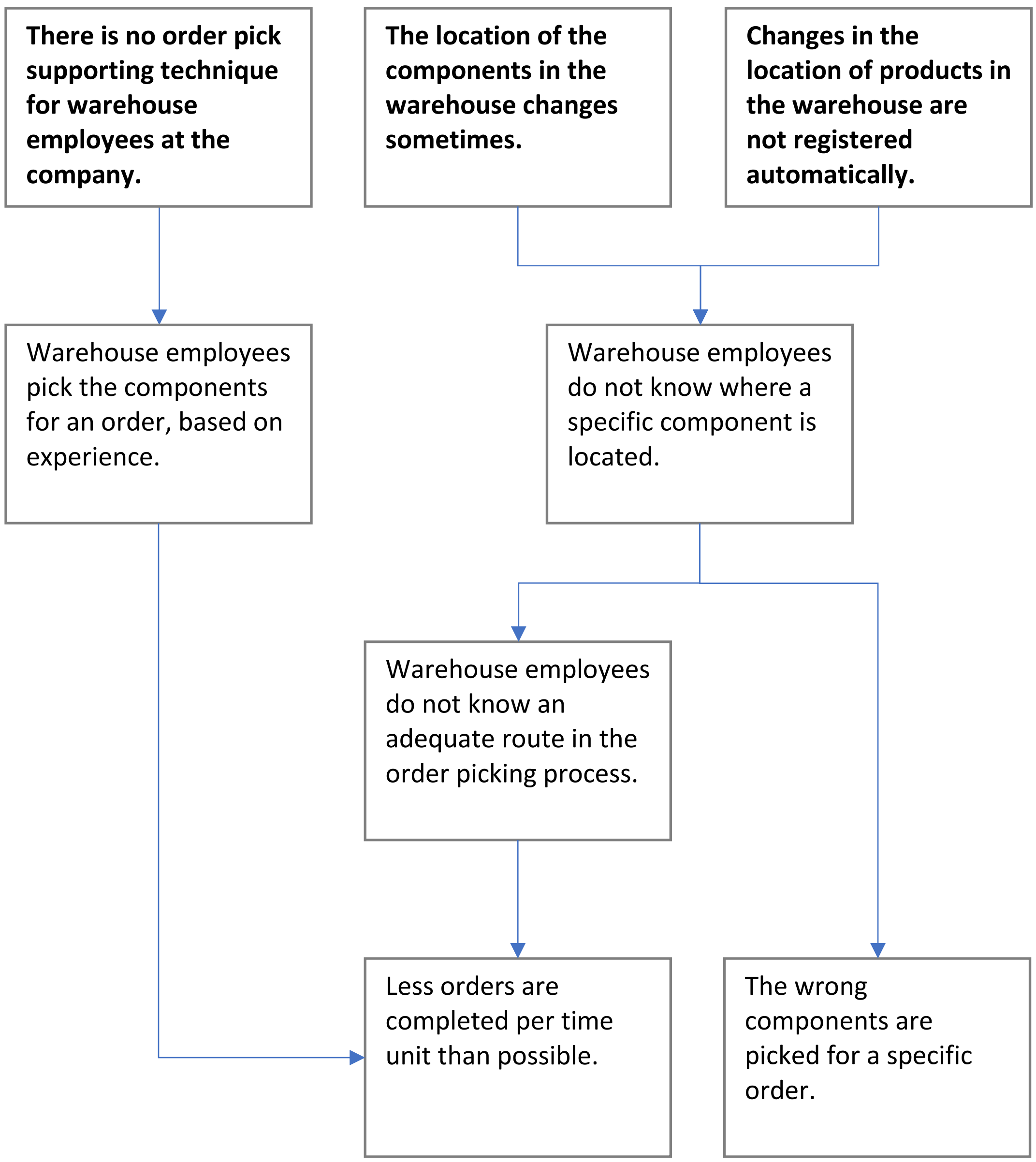

Figure 3: Problem cluster.

2.3 Variables and indicators

The action problem defined in section 1, contains two variables: waste of motion and number of mistakes. According to Womack and Jones (1996), waste of motion is defined as follows: “movement of employees and transport of goods from one place to another without any purpose’’. Waste of motion occurs mainly in the distance covered by the warehouse employees. When an employee crosses similar routes multiple times, then there is no value-adding activity to the customer and thus waste occurs. So, if the distance covered for picking all components of an order is minimal, the waste of motion will be solved.

2.3.1 Measurement of number of mistakes

The variable “number of mistakes”(NoM), for this research, is concretized by the following indicators:

- The number of components collected per order which are not requested by the customer.
- The number of missing components per order, according to the customer’s request.

Adding-up both indicators quantifies the NoM. For this research, the $\%NoMtot$-ratio is determined. This ratio concretizes the number of mistakes made during the order picking process. It consists of the following values:

- $\#Omc$: the number of orders with missing components.
- $\#Ouc$: the number of orders with components not requested by the customer.
- $\#Omuc$: The number of orders with both missing components and components not requested by the customer:

The $\%NoMtot$-ratio can be determined as follows. The number of orders with missing components and the number of orders with components not requested by the customer should be added up. However, it could occur that an order contains both types of mistakes. That means that the number of orders with mistakes would increase with 2, while it concerns just 1 order. Therefore, the number of orders with both type of mistakes should be subtracted. This ensures that the orders which include both mistakes, just count as 1. According to the assumptions described in this section, the $\%NoMtot$-ratio can be calculated as follows:

$$\%NoMtot = \frac{\#Omc\ + \#Ouc\ -\ \#Omuc}{\#\ total\ orders} * 100\%$$

Still, problems can occur when the values in the inventory system do not agree with the physical values of components in the warehouse. For example, the inventory system shows that there are still two products in stock, while there is actually no component left. Then, the order will be left out from the ratio but will be added up to the $NoMpre$. This indicator indicates how many times a mistake in a previous phase than the order picking process is the main reason that not all the components for a specific order can be picked.

2.3.2 Measurement of waste of motion

Waste of motion can be measured by the use of spaghetti diagrams. This technique provides insight in the path an order picking walks when picking an order. The paths of these diagrams within this research refer to the route which warehouse employees cross during the order picking process. Since every order is different, the optimal route for every order is different as well. By conducting observations, the route of a warehouse employee which is picking an order can be determined. Afterwards, the route for the same order can be analysed as well. The difference between the observed route and the optimal route can be defined as waste of motion. This waste of motion will be measured in distance covered.

2.3.3 Assessment of validity and reliability of measurement

The interest of the first phase of this research is in the number of mistakes and the waste of motion. The content validity of a measuring instrument is the extent to which it provides adequate coverage of the investigative questions guiding the study (Cooper & Schindler, 2014, p. 257). When reviewing the measurement instruments, the $\%NoMtot$ and the spaghetti diagram techniques, it shows that a spaghetti diagram is a very commonly used method of Lean to identify waste within a company. Also, in section 3.2, the measurement instrument is extensively linked to the research environment, so it is safe to state that this will not have an influence on the content validity. The $\%NoMtot$ is a measurement instrument which is specifically designed for this research, so this will obviously fit in the research.

As stated by Cooper and Schindler (2014, p. 260), reliable instruments are robust. They work well at different times under different conditions. Both the values of the $\%NoMtot$ and the waste of motion will be obtained from observatory studies. There is especially chosen to conduct multiple observation sessions with several objects, in order to ensure the reliability of the results obtained from the observatory research.

2.4 Theoretical perspective

In this section, the theoretical perspective of the research will be explained. The theoretical perspective mainly contributes to this report because it provides insight in which theories and ideas already exist with regard to waste of motion and identifying mistakes. As already explained in the problem identification phase of the research, waste of motion occurs often in the order picking process at the company. Especially when an employee passes by a components multiple times before picking, or when an employee forgets to pick a components, there employee covers more distance than necessary. The next section of this research will provide better insight in the perspective from which this waste will be reduced.

First, it is important to have a clear understanding of the term “waste”. This understanding is provided by the book of Womack and Jones (Lean Thinking, 1996). “Muda” is the Japanese word for waste; specifically any human activity which absorbs resources but creates no value. One of the non-value activities they mention is the movement of employees and transport of goods from one place to another without any purpose. This is one of the eight types of waste which are identified by Womack and Jones (1996). However, they identify a powerful antidote to “muda” as well: lean thinking. Lean thinking provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean thinking provides a way to do more and more with less and less, while coming closer to providing customers with exactly what they want. This process will be explained extensively with regard to the specific research environment of the company, according to the beliefs of Womack and Jones.

1 Specify value.

The critical starting point for lean thinking is value. Value can only be defined by the ultimate customer. This value is created by the producer or supplier. In this research, the company is the institution which provides products to its customers. However, not all activities which are executed by the company, are value-adding in the end. In this research, value is determined as an action where the end-customer is willing to pay for. The reverse product of value is waste. Waste has already been defined as “*any human* *activity which absorbs resources but creates no value.*" The waste of motion in this research may occur in terms of unnecessary movement of employees, as well as unnecessary executed actions.

2 Identify the value stream.

Womack and Jones identify the value stream as the set of all the specific actions required to bring a specific product through the three critical management tasks of any business: the problem solving task (running from concept through detailed design and engineering to production launch), the information management task (running from order-taking through detailed scheduling through delivery) and the physical transformation task (proceeding from raw materials to a finished product in the hands of the customer). However, in this research, the value stream needs to be delimited to the order picking process. This is actually the information management task and the physical transformation task. The existing value stream has already been identified in figure 1 (see page 3). However, within this existing value stream, waste still exists according to the problem identification phase. The management team is looking for a order-pick supporting technique to reduce the waste in the value stream. The research eventually aims to find an order pick supporting technique which fits best within the company and contributes to reducing waste within the value stream.

3 Once value has been precisely specified.

Make the remaining, value creating steps, flow. In production, this refers to continuous production from raw materials to finished goods, instead of batch picking. However, in the research environment, batch picking might be a good alternative to decrease the waste of motion for the warehouse employees. When an employee picks the component from a rack for the upcoming three orders, there is less distance covered than when the employee walks that specific distance three times.

4 Pull

The pull strategy refers to the fact that the company can let the customer pull the product, instead of pushing products to the company. The demand of customers becomes much more stable when they know that they can get what they want right away. When relating this to the research environment, of course it is very important that all the products offered are produced in a flow. However, to successfully accomplish the pull strategy, not only the production stage should be designed in order to reach this. Since the company offers a delivery service within 24-hours, also the order picking strategy should contribute. If the order picking strategy lacks efficiency and involves waste of motion, the pull strategy might not be fulfilled, which might lead to customer dissatisfaction. The concerning company of the research partly practices the pull strategy for their business. Obviously, they maintain stock keeping units (SKU's). On the other hand, for example, the fuse boxes which they offer, will be made according to a specific request of the customer. However, components of these fuse boxes need to be stored in order to deliver to requested fuse boxes in time.

5 Perfection

The four principles above interact with each other in a virtuous circle. For example, getting value to flow faster always exposes hidden waste in the value stream, and the harder you pull, the more the constraints to flow are revealed.

The most important insight from this theoretical perspective, is that the order picking process at the company should add value in the process of delivering the right products to the customer, or at least should be eliminated from major waste of motion. The customer's expected value should be met in terms of physical value (the requested components), as well as the non-physical value (the delivery of the components in the time slot which is promised by the company).

2.5 Properties of batch picking

In addition to the above theoretical perspective on Lean, there should be obtained more insight in the principles of batch picking. This is necessary, because (later on) in the research it appeared that batch picking within the order picking activities is a desire from the management team. Theory on batch picking will be discussed here, and later on in the research this theories will be related to the possible solutions. In a warehouse, in addition to storage, the major facility logistics activity is order picking. It has been identified as the highest priority activity in a warehouse for productivity improvement due to its relatively high contribution to the total warehouse operating costs. The most commonly known order pick strategies among companies are the following:

1. In *single order picking* is a picker responsible for picking all the items in a single order during a pick-tour.
2. In *batch-picking* several orders are batched together and a picker picks all the items given in a batch.

This section elaborates more on batch picking, since the management team is interested in the application of batch picking. Two common strategies of batch picking strategies exist. In *pick-and-sort* batch picking, the pickers do not sort (while picking) the items into customer orders. The picked items are eventually sorted manually. This means that pick-and-sort batch picking maintains a high pick-rate (items picked per time unit) for the pickers, but eventually considerable time is needed to sort the products to the right order. In *sort-while-pick* batch picking the pickers simultaneously pick and sort the items into customer orders. Such situation is applicable if the pick-cart capacity is large enough for the pickers to sort the picked items in available compartments in the pick-cart. *Sort-while-pick* batching reduces the pick-rate of pickers, but eliminates the need for an additional sorter (Parikh & Meller, 2008). The reason for its importance is that order picking is a labour intensive process and, by the use of good batching methods, substantial savings can be obtained. However, batching and routings problems are complex to solve. Once clusters of orders have been formed, the calculation of the travel time for the routes requires the solution of a number of travelling salesman problems (De Koster et al, 1999).

Now, the theory from de Koster et al. will be related to the research environment. The order picking process at the company is driven by customers' orders, each consisting of a number of order lines. These order lines are represented on the package list, which the order picker carries with him while picking an order. Each order line represents one product or article code that has to be shipped to the customer in a certain quantity, the order line quantity. The *order picking by order* strategy means that all the pickers in the warehouse work on one order at a time. This can be realized by pickers passing on to each other a product carrier, in which the order has to be picked (De Koster et al, 1999). However, considering the research environment, this might involve lots of waste of waiting. Pickers in a zone where no product is requested for a specific order, will not be executing order picking activities for a specific time. Also, it is obviously not very time efficient to pick an order with e.g. 10 order pickers.

In batch picking, it is assumed that the customer orders are available in the system at a certain point in time such that the order line quantities can be accumulated per product. However, the decision should be made between *pick-and-sort* batch picking and *sort-while-pick* batch picking. Before the order picker can start picking orders, the batch size needs to be determined. Clustering multiple orders into one eventual batch can be executed by to the following strategies, described by De Koster et al, (1999):

- **First-come, first-served**. This algorithm adds orders to a route in the sequence they arrive. If the pick cart for one batch is full, a new route will be started.
- **The seed algorithm**. In this strategy, the initial order has to be selected from those orders that are not added to a route yet. Then, not yet selected orders have to be added to the seed order until the order pick cart has reached its maximum capacity. However, different strategies can be applied to determine which orders will be picked within the same order picking device. For example, a random order, the order with the farthest items or the order with the longest travel time. All these selection rules can be applied in two different ways. In a single mode, the selection strategy for the next order is selected only once. In a cumulative mode, the selection strategy for the next order is renewed every time an order has been added to the route.
- **The savings algorithm** determines the saved time while picking an order in batches.
    - $Sij = Ti + Tj - Tij$ with,
        - Sij: the saved time while picking an order in batches.
        - Ti: the time needed to pick order *i.*
        - Tj: the time needed to pick order *j.*
        - Tij: the time needed to pick a batch consisting of orders *i* and *j.*

  This savings algorithm is interesting when determining the waste of motion within the order picking process. It is also is the most time efficient strategy of these three. However, a system which enables this algorithm, should also be able to distinguish the optimal number of orders to be clustered in a batch.

2.6 Problem solving approach

Now that the core problem and action problems are identified, a problem solving approach should be designed (Heerkens & Winden, 2012). The goal of a problem solving approach is to provide a clear and structured overview on how the research will be conducted. To make the problem solving approach of this research even more clear, different phases of research are distinguished. All the separate phases have an individual purpose and eventually contribute to an adequate solution of the core problem. In this section, the phases of the problem solving method will be introduced. After this section, the corresponding research questions will be elaborated on.

Phase 1: Analyse the order picking processes at the company.

It is useful to have insight in how the current order picking process is designed at the start of the research. This might provide additional information which will support in finding the ultimate best solution for this research. Therefore, I will go into the warehouse and pick orders myself. This will help in getting a better understanding of how this process works. Also, the activities of employees when picking an order will be analysed. At the end of the research, an (expected) improvement should be visible. Therefore it is necessary to have insight in the current situation and the current values of waste and mistakes made in the order picking process. Data of both waste and number of mistakes is provided by the company and ready to be analysed. This data will be compared to the experiences in the warehouse and any main differences the perceptions and data need to be drawn conclusions on. Also, an analysis on the various stakeholders in the order picking process will be provided. This is necessary to meet all the needs of the stakeholders involved, when choosing the eventual solution.

Phase 2: Conduct a systematic literature review on waste of motion within order picking.

In the problem identification phase, it is already identified that waste of motion occurs within the order picking process at the company. The theoretical perspective elaborates more on waste of motion. In phase 2 of the problem solving approach, a systematic literature review will be conducted on the possible solutions of waste of motion, according to the lean principles. These possible solutions will be related to the research as well.

Phase 3: Decide which criteria should be involved in an eventual solution.

Implementing a solution might involve some severe consequences. For example, high investments or reducing the number of employees. Several trade-offs must be considered, and it is up to the management team to decide which possible consequence of a solution is less important than one other. According to the opinion of the stakeholders, a multicriteria list could be drawn up. Eventually, the decision for a specific solution could be made according to this multicriteria list.

Phase 4: Analyse potential order picking strategies for improving the order picking process.

Literature and field study will be conducted in order to provide insight in which methods are known in order to improve the order picking process. First, a literature review will be conducted in order to get insight in which order picking methods are available. Also, companies who already have introduced such methods for order picking will be visited, to obtain a clear overview of overall benefits and disadvantages. Both the literature and field study, will contribute in stating substantiated assertions about the possible order picking methods.

Phase 5: Predict the impact of the suitable solutions for the company's order picking process.

The order picking methods which are found in phase 3 will be extensively reviewed according to the circumstances in the research environment. In order to measure the reduction of waste of motion, the optimal routes for specific orders according to the several order picking methods is determined. Afterwards, this distance can be compared to the analysis of the waste of motion in phase 1. The same counts for the number of mistakes. The suitable solutions will be analysed and an expectation will be drawn out in Excel about the expected impact of the possible solutions. This will be predictions, because there might not be the time to really implement several solutions and then evaluate them.

Phase 6: Choose an adequate alternative.

According to the findings from the expected impact and the multicriteria list, the best option among the possible solutions will be selected.

Phase 7: Write an implementation plan.

The last step is to write an implementation plan. This plan provides information on how the selected solutions could be implemented most efficiently. An advise report on the implementation of the most adequate order pick supporting technique will be delivered eventually.

2.7 Research questions and research design

In this section, the research questions are introduced and an explanation follows on why and how these research questions contribute to finding a solution for the core problem.

RQ 1.1: How is the current order picking process structured?

In order to fully understand the circumstances in the research environment, it is useful to provide insight in how the current order picking process is designed. The answer on this research question is already partly answered in the problem identification phase of the research, but will be further clarified.

Research design: The current order picking process will be visualized according to observatory research in the warehouse. To obtain a really broad perspective of how this process works, I will pick orders myself. This will help in order to fully understand where main problems occur, or which activities may lead to problems eventually.

RQ 1.2: Which stakeholders are involved in processing an order at the company?

When trying to obtain a clear overview of the research environment, it is necessary to provide insight in which stakeholders are involved when picking an order. Do these stakeholders have contradicting interests? To what extent are these stakeholders communicating with each other? This, among others, are important questions to consider when conducting research in the order picking process. It provides insight in the (lack of) collaboration between stakeholders and thus it will contribute to eventual improvements.

Research design: This research question will be answered by conducting an observation study, but also by conducting interviews. The observation study is also part of research question 1.1, but the interviews with different stakeholders found by this observation study, might provide better insight in the relations between theses stakeholders. If the order picking process structure is represented sufficiently, it is easier to distinguish which stakeholders are involved at which specific stage.

RQ 1.3: What are the values of the number of mistakes and the waste of motion?

In this phase, the number of mistakes and the waste of motion will be measured as well. These values can be used later on, to measure potential improvements.

Research design: The number of mistakes will be obtained by an observation study. Six warehouse employees will be followed for 90 minutes during the order picking process. The number of mistakes and the type of mistakes will be written down. Then, the $\%NoMtot$ can be determined. The waste of motion will be determined according to spaghetti diagrams in the same sessions with the 6 employees. The outcomes of these spaghetti diagrams will be evaluated and anticipated on in the further conduction of the research.

RQ 2.1: Which methods of lean exist to reduce waste of motion, according to literature?

It is already explained that the distance covered by warehouse employees is a problem. Therefore, it is useful to obtain understanding about the methods lean describes to reduce this waste of motion.

Research design: A systematic literature review will be conducted in order to answer this research question. How this systematic literature review will be executed, is explained appendix 10.2.

RQ 2.2: How are the methods found in literature applicable to an order picking process?

Now we have found several methods of lean which might reduce waste of motion, it is necessary to check whether these methods are applicable to order picking processes. Also, the reduction of numbers of mistakes should be taken into account when evaluating these methods.

Research design: When an answer on research question 2.1 is found, a data set with a number of articles is available. The next step is to evaluate these articles on how they could provide a sufficient contribution to solving problems within an order picking process, in terms of waste of motion and number of mistakes.

RQ 3: What are the main criteria for a new order picking strategy at the company, according to the stakeholders?

An overview of the stakeholders will be provided in the answer of research question 1.2. However, research question 2.1 is designed in order to find a direct answer to what is explicitly important for an order picking strategy, according to the same stakeholders.

Research design: The answer to this research question will be found by conducting interviews among the main stakeholders which are identified in phase 1 of this research. Before these interviews, various variables which might be involved when adapting a new order picking strategy should be considered. Then, discussion with the stakeholder should take place in order to identify which variables are more important, according to each stakeholder individually.

RQ 4.1: Which strategies for order picking are known, according to literature?

It is necessary to obtain knowledge on which strategies for order picking are available, in order to extent the research eventually. This research question is related to research question 2.2, because there are might have been found some strategies already.

Research design: A literature study will be conducted on which standard approaches already exist in order picking processes. This will be a systematic literature review. It is necessary to perform a very extensive literature review, to obtain a very broad perspective of possible order picking strategies. A literature study is the first step in answering this research question. However, it might be possible to visit companies which have implemented such strategies successfully. This kind of field study provides insight in implementation of a certain structured approach as well.

RQ 4.2: How are the strategies found going to improve the order picking process?

Here, the features of the order picking strategies will be reviewed, according to the circumstances in the research environment. The main benefits of each order pick supporting strategy will be shortly discussed, with the use of a table.

Research design: The pros and cons of every order picking strategy will be reviewed extensively. The answer to this research question can be found by applying the findings from the literature about multiple structured approaches to the multicriteria list. Then, it is visible which structured approach fits which needs and preferences from the company. Next, the outcome of these strategies will be predicted by using Excel. The data provided at the beginning of the research will be used to predict the effects of the possible strategies which are found in the literature study.

RQ 5: What are the main constraints for the implementation of the strategies found?

The research environment in this research is limited. For example, the company does not have infinite space to extend their warehouse, nor does the company have an infinite budget to invest in a possible solution. The main constraints as well as the preferences from the management team of the company should be investigated.

Research design: To find an answer to this question, interviews with the stakeholders should be conducted. Constraints and preferences should be noticed and weights will be assigned to all these constraints and preferences. After that, a multicriteria list will be drawn up according to the findings on both research questions 3.1 and 3.2, which will help to make a decision about which structured approach fits best eventually.

RQ 6: Which structured approach fits best for the order picking process at the company?

The next step is to decide which strategy fits best in order to improve the order picking process at the company, in terms of waste and numbers of mistakes. In the meantime, much information is collected about needs and constraints. This important research question provides the answer to which structured approach fits best eventually.

Research design: The answer to this research question can be found by evaluating the answers of research question 5.1. It is important to consider all the information which is collected in the research. Also, it is useful to have a meeting with the management team when formulating a final answer to this question. Then, the management team can evaluate the selection procedure and give their opinion about whether they want to see an implementation plan for the selected strategy.

RQ 7: How can the selected strategy be implemented?

After the selection of the best standard approach for the company, an implementation plan can be written. This implementation plan will obviously consist of all the steps to take in order to implement the solution.

Research design: The answer to this question will mainly consist of a field study. However, probably a lot of knowledge to answer this question is already investigated on earlier during the research. Here, it is important to consider the constraints and disadvantages of the selected strategy. Otherwise, the solution will not function optimal.

A report with the main findings of the research will be presented eventually. This contains the conducted research as well as the argumentation of the main conclusions on the findings. Also, an implementation plan for the eventual chosen solution will be presented, suited for the company.

2.8 Short summary of chapter 2

Chapter 2 has provided insight in the background interest of the research and partly in the research environment. First, the purpose of the research has been identified. It appeared that the management team of the company wishes to implement an order pick supporting technique within their order picking process. The desire from the management team originates from the wish to reduce the number of mistakes and to increase the speed in which the orders are picked.

The theoretical perspective elaborates on waste of motion, and to a lesser extent reduction of number of mistakes. The main knowledge conducted from this theoretical perspective, is that all activities executed within the order picking process, should add value for the customer. The further design of the research in search for the eventual solution is established with the outcome of the theoretical perspective in mind. Also, the properties of batch picking have been elaborated in in this chapter. There has already been provided insight in batch picking, because this will be part of the end solution. Eventually, the research has been classified into separate phases with each of them having a different purpose. This enables a structured research and eventually a proper solution the core problem.

3 Analysis of the order picking process at the company

The first phase of the problem solving approach provides insight in the current order picking processes at the company. The answers to multiple research questions will be provided in this phase of the problem solving approach. This chapter contributes to the identification of the value stream, which has been described in the theoretical perspective.

3.1 The current order picking process.

This section describes how the current order picking process at the company is structured. It is useful to understand how the current order picking process is structured, as well as the layout of the warehouse. This ensures that the chance of a misfit of the eventual solution will be reduced. The warehouse consists of various functions and all these sections will be elaborated on.

3.1.1 Structure of the current order picking process

Section 2.1.1 finds an answer to research question 1.1*: "How is the current order picking process structured?"* This is already partly investigated in the problem identification phase. Here, the following structure of order picking activities is identified. The various sections within the warehouse are shortly elaborated on below figure 4.

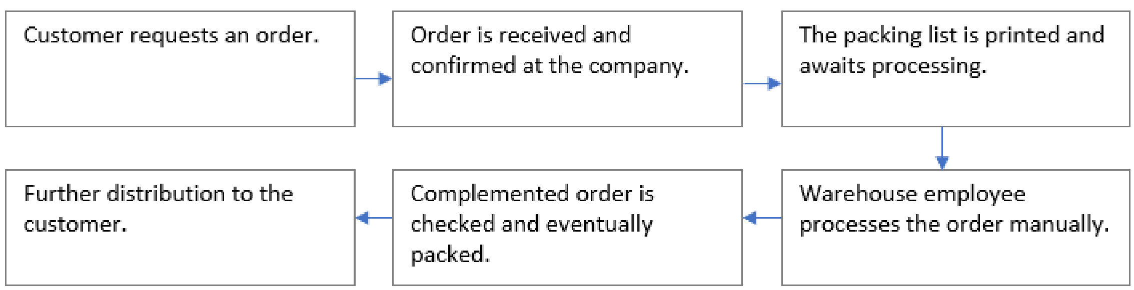

Figure 4: Order picking process at the company

Several product storage sections.

The warehouse is categorized according to the product types in the warehouse. For example, the specific cables and wires are stored in another section than electrotechnical components. The cables and wires are cut off according to the preferences of a customer within a specific order. Another order picker collects the piece of cable or wire, and puts it together with the other components of the order.

At the beginning of the research, the company already started to register the products with a high turnover rate in their WMS system. In the meanwhile of the research, the company is still busy with providing all products of their own unique location code. It is expected that the availability of unique location codes is essential for the eventual implementation of a solution. Most of the well-known order picking technologies thrive on such location codes. For the rest of the research, it is assumed that eventually all the products in the warehouse will be registered in the WMS system of the company.

Figure 5: Example of a storage location in the warehouse

Mapping the layout of the warehouse.

According to the real layout of the warehouse, a general map has been designed. This map is depicted in the figure below. Important to mention is the fact that the scale of this map is not precise. It just provides a general overview of storage of products and other warehouse activities. The various sections will be elaborated on below figure 6.

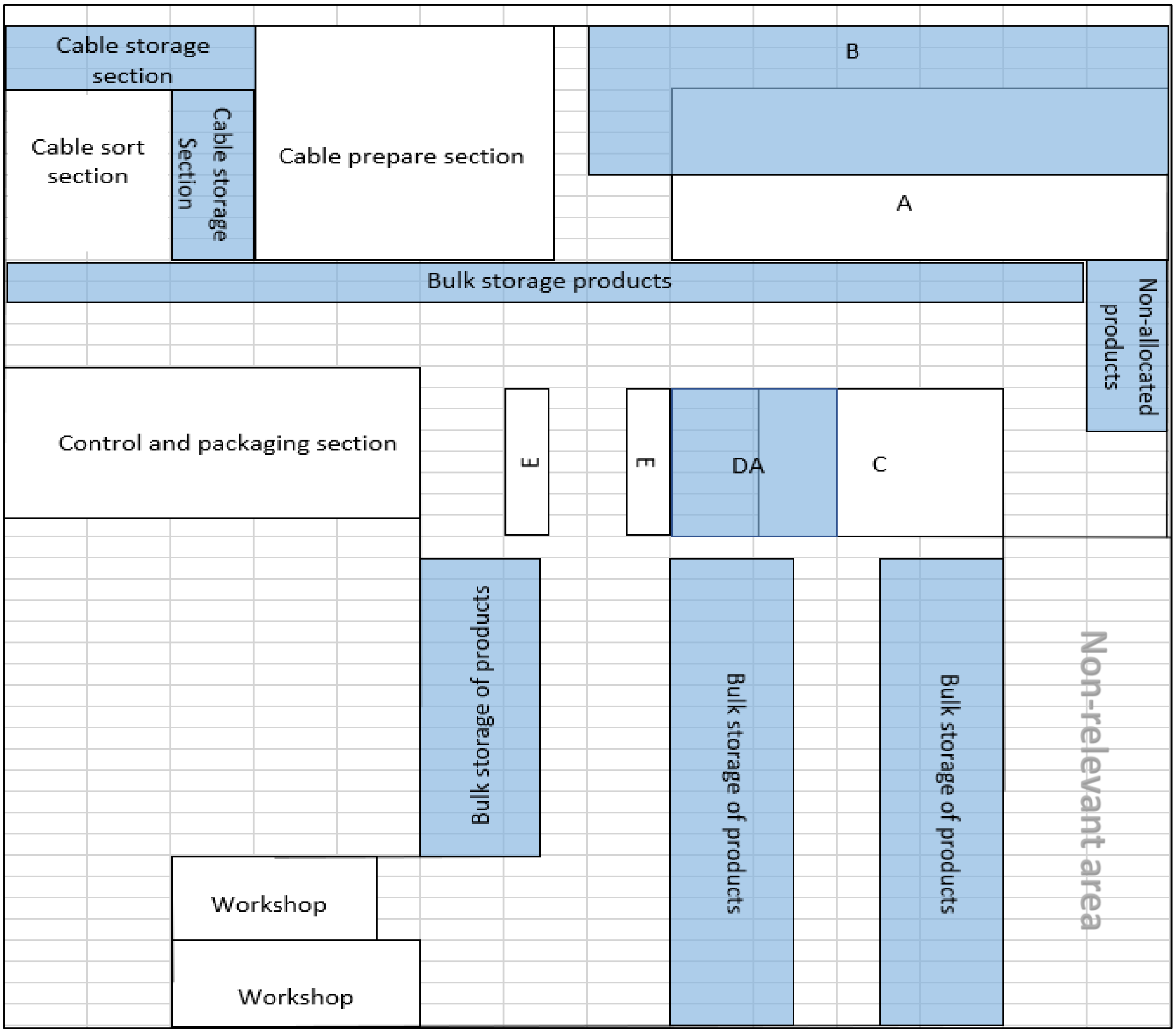

Figure 6: General overview of warehouse layout

- Product storage on height: ■
- Product storage on the ground: □
- Product storage in indicated section: A

The blue colored sections in the map are the sections where products are stored on height. The *bulk storage of products* sections are the sections where products are stored but not directly used. It is just the stocking of products. These products vary from parts of fuse boxes to cables to electrotechnical components. In the *A* and *E* sections products with a relatively high turnover rate are stored. These products need to be picked frequently and these locations enable order pickers to reach for the products easily. The products in the *C* section are picked medium frequently and the *DA* and B sections are equipped with products which are sold less frequent.

The *cable prepare section* is the section where the requested type of cable by a customer is cut to the requested length. If this is done, the warehouse employee places the cable in a specific bin, where another order picker adds this cable to the rest of the order. Such a same strategy holds for the *workshop section*. Here, the customized fuse boxes are developed according to the request of a customer. When the box is finished, the fuse box must be checked first. There are a few people within the company who have permission to execute these checks. When the check is executed properly, the fuse box is stored in the *control and packing* section. Then, the order picker can add the fuse box to the corresponding order.

High shelfs.

The company possesses a warehouse which has a lot of space in height. Storing products on these high shelfs is of course very cost-efficient, but it involves additional order picking techniques. It is necessary to make use of forklifts to pick the items from these shelfs. Obviously, it costs more time to pick these products.

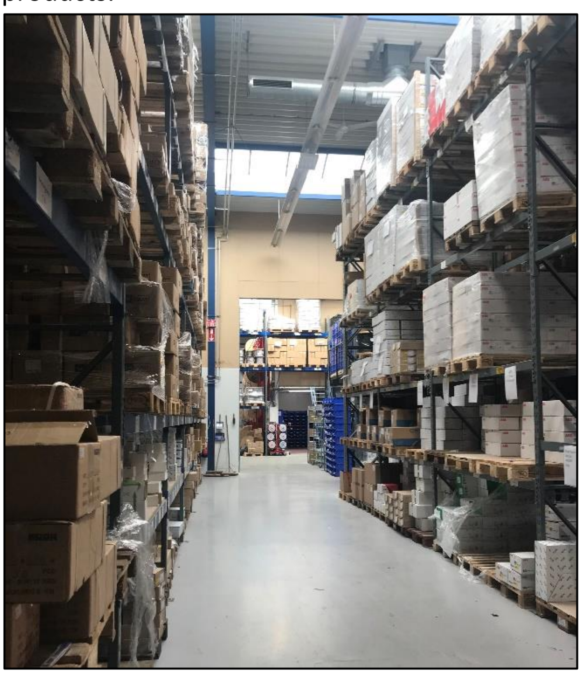

Figure 7: Bulk storage of product shelfs.

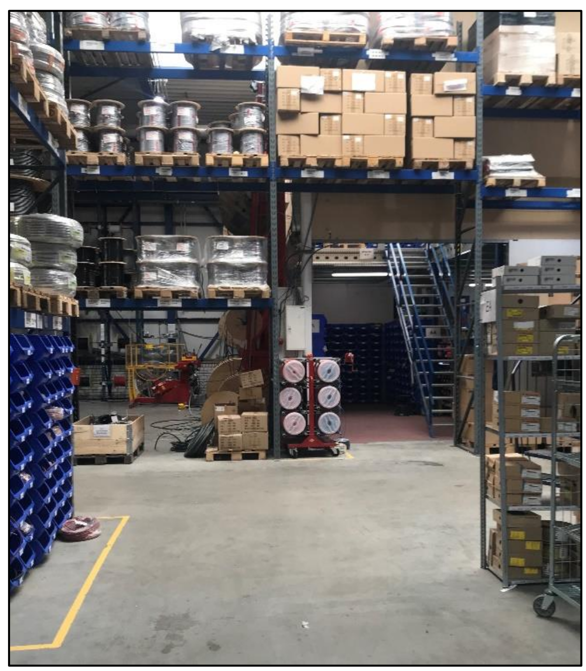

Figure 8: Bulk storage of products shelfs..

As mentioned before, the company stores the products with a low turnover rate at another section on a higher level. When the company notices that these products start to have a better turnover rate, the products will be allocated somewhere else.

Figure 9: Storage of products in the E section.

Figure 10: Storage of products in the E section.

Fuse box development.

The company develops its own specific fuse boxes. The parts of these fuse boxes are mainly obtained from Schneider Electric. However, after development and customization to the customers' preferences, the fuse boxes are sold on behalf of the company itself. The fuse boxes of the company are known as reliable and of good quality. Within the warehouse, a separate section is equipped in order to assemble these fuse boxes. When a fuse box is fully assembled to the wishes of a customer, the boxes are checked by the management team and then the box will pass on to the packaging stage.

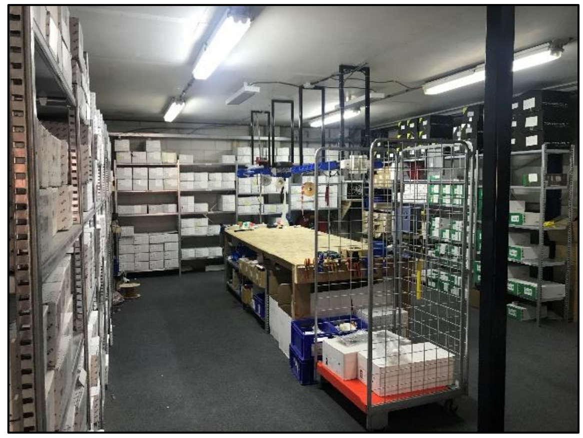

Figure 11: Workshop station for the assembly of fuse boxes

Control and packaging station.

Eventually, all the picked orders arrive at the control station of the warehouse. A warehouse employee checks whether the picked order contains all the necessary products or not. Most of the time, mistakes are identified in this phase. When an order is checked, and if necessary revised, the order will be packaged and prepared for delivery to the customer.

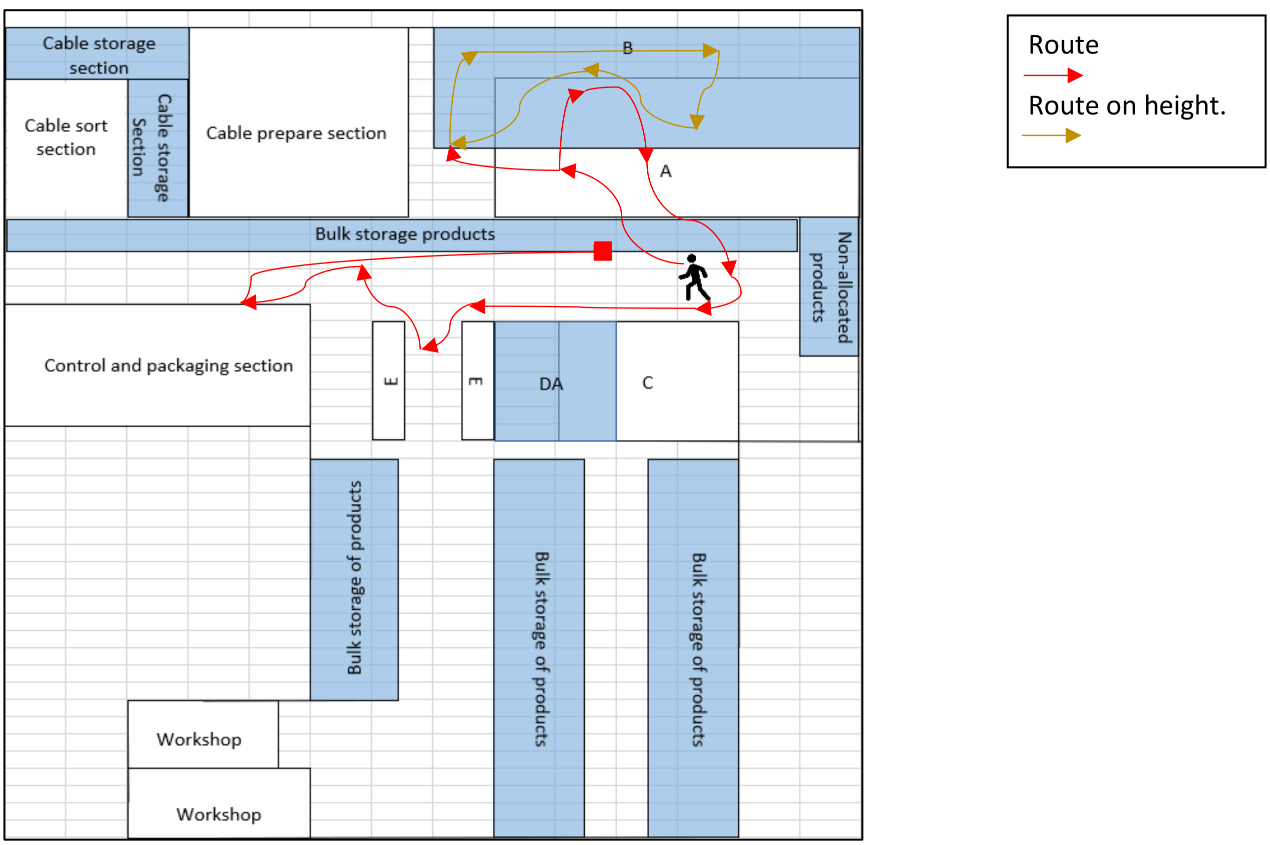

Figure 12: Example of order pick route

3.1.2 Stakeholders within the order picking process

This section describes the main stakeholders within the order picking process of the company. However, it is important to consider stakeholders outside the order picking process as well, who might experience differences in the way orders are picked. This section eventually provides an answer to research question 1.2: *"Which stakeholders are involved in processing an order at the company?".* The stakeholders of the research and the motivation for their interest is described in the table below. Later in the research, the main criteria and preferences of these stakeholders for the implementation of the solution will be discussed.

Stakeholder	**Motivation for interest**
Management team	The management team of the company desires a new strategy for the products of an order to be picked. There is a *high* interest in the eventual solution, because they want the solution to be implemented so that the company can deal with the expected growth over the coming few years.
Warehouse manager	The warehouse manager of the company has a *medium-high* interest in the eventual solution. Eventually, he will have to know how the system will work out and what the critical elements are related to the situation as it is beforehand.
Order pickers	The order pickers are the warehouse employees which eventually pick the different products which complete an order. These employees are essential and will have a *high* interest in the eventual solution. It needs to be considered that the order pickers make use of different tools to pick orders. Some products are stored at such height, that it is needed to make use of a forklift. Other products can be collected just by hand. Order pickers should be able to make use of the eventual solution in both situations.
Customer	An order picking process will not start without the desire of a customer for some specific product(s). Therefore, the customer should be mentioned as an important stakeholder as well. The customers provide the main rewards for the company. In terms of money, but also, for example, in promotion. When a customer experiences a good delivery of desired products, there is a better chance that a customer recommends the services of the company to another potential customer. The customer has a *medium* interest in how the eventual solution will be implemented and what structural consequences this involves. However, he obviously has a high interest in the consequences in terms of accuracy.

Table 1:Overview of the stakeholders

3.2 Measurement of KPI's within the order picking process

The next section describes the determination of the initial values of the main KPI's within the order picking process at the company. These KPI's are the following:

- Number of mistakes.
- Waste of motion.

For both values, the research design is discussed in a separate section. This section tries to find an answer to research question 1.3: *"What are the values of the number of mistakes and the waste of motion?"* There will also be elaborated on the value of customer satisfaction, because this provides a good indication of how the overall service of the company is experienced by the company.

3.2.1 Number of mistakes

Section 3.2.1 describes how the number of mistakes has been analysed and which conclusions can be drawn according to this analysis. But first, a short elaboration on consequences of mistakes within order picking processes will be provided. It might be obvious that mistakes within the order picking process leads to increased costs for the company. Richards (2011) describes the following elements to be involved when picking an order incorrectly:

- Costs of recovering the item.
- Labour of cost of in-handling and checking the item on its return.
- Cost of picking the replacement item.
- Cost of repacking.
- Cost of redelivery.
- Administration costs of handling credit claims.
- Cash flow with reference to non-payment of invoice.

If the error is an under-pick (a requested product is not delivered) then it could result in a lost sale and the associated margin. If it is an over-pick (a non-requested product is delivered), there is the cost of transport to collect the item and labour costs or potentially a loss of margin in persuading the customer to keep the item. The company registers the number of mistakes made in the delivered orders. Each mistake is commented on within their order registration system. However, these mistakes are not classified in a predefined set of categories. In other words, the various mistakes made have not been analysed yet. Data from January 2018 up until April 2018 concerning the mistakes made in deliveries is provided by the company. It is useful to provide insight in how the four types of mistakes are distributed amongst each other. According to the interest of this research, the mistakes have been classified in four separate categories:

1. **Non-delivered products**. This means that an order picker has forgotten one or more product(s).
2. **Delivery of wrong products**. This means that an order picker has picked a wrong product.
3. **Both mistake**s. The above mistakes both occurred in one specific order.
4. **Other mistakes**. This category contains mistakes which are not directly related to order picking. For example, a customer did not receive a product because of a backorder, or a mistake was made in a fuse box which is developed by the company itself.

These four types of categories have been identified because of the interest of the research. For this research, it is not interesting whether the mistake has been made in another phase than the order picking phase. The “other mistakes” category has been identified to store these types of mistakes. The mistakes of “non-delivered products”, “delivery of wrong products” and “both mistakes”, however, are directly related to activities within the order picking process. Figure 13 shows the relative distribution of these types of mistakes. Every order line where a type of mistake occurred has been analysed and this order has been classified.

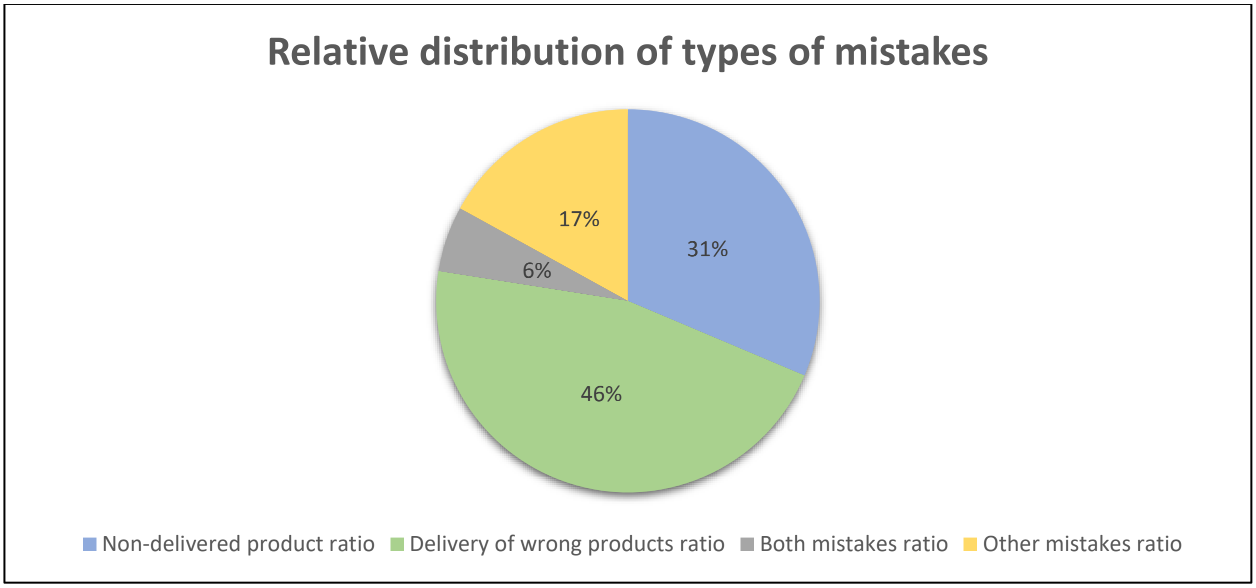

Figure 13: The relative distribution of types of mistakes

The figure reveals that the delivery of wrong products is the most common mistake within the company. In 77% (%delivery of wrong products + %both mistakes) of the total mistakes made, the delivery at the customer contains one or more products who were not supposed to be in this order. This means that there occur mistakes in two phases of the order picking process. The first mistake is made when picking an order. Apparently, an order picker picked a product which was not on the packing list, without noticing it. The company tries to tackle this type of mistake by setting up a control phase for every order before the order is packed and sent out for delivery to the customer. However, the fact that customers receive products which they did not request, reveals that there are mistakes made in the control phase.

Section 2.3.1 describes how the $\%NoMtot$ can be determined: $\%NoMtot = \frac{\#Omc + \#Ouc - \#Omuc}{\#\ total\ orders} * 100\%$

The research on the types of mistakes is executed on order data collected within four months. This data shows that the $\%NoMtot$- ratio for every week is below 1%. Therefore the interest in the answer of the research question has shifted to the distribution in the types of mistakes rather than the relative number of mistakes. The knowledge on which mistake occurs more often than another, might play a role in the selection of eventual solution.

3.2.2 Waste of motion

The function of this section is to describe the waste of motion within the order picking process. In the problem identification phase, it is assumed by the management team that the order pickers fulfil their tasks not as fast as might be possible. Next, the assumption is made that the order pickers do not pick the products for an order efficiently, in terms of distance covered.

It is questionable if the waste of motion really originates from the distance covered by the order pickers. Figure 12 (see page 20) depicts a spaghetti diagram for a single-order pick activity. So, the warehouse employee needed to go through the warehouse to collect items for just one order. Even more, and likewise, spaghetti diagrams have been developed. The main findings of these spaghetti diagrams are the following. It is a fact that the order pickers pick the orders according to their experience. The order pickers basically walk the optimal route for each order individually. Obviously, there are several orders which are not picked the optimal way, but that problem is not as big as expected beforehand. However, there is much room left for improvement in the fact that there is no strategy for batch order picking at this moment. The order picker might walk the optimal route for every route individually, but that does not mean that he covers the least distance necessary for a specific batch of orders. If an order picker combines orders to pick, it is expected that the waste of motion will decrease significantly. The properties and features of batch picking have been discussed in section 2.5.

Unnecessary movement for warehouse employees.

The packing list for every requested order is printed at the A section within the warehouse. All packing lists, so also the lists where only cables or only fuse boxes are requested, are printed at that location. The packing lists are not automatically sorted, but printed in the way the orders are requested. When many orders need to be picked in a busy period, for example on Mondays, it takes four to five minutes to sort the printed packing lists. Then, one warehouse employee needs to transfer the packing lists from section A to the fuse box workshop. This route is depicted in the figure below. When many orders are printed, there is often no time to sort the orders. This means that the order picker needs to walk the route to the workshop (depicted below) for just one packing list. This might occur multiple times a day, which means an increase of waste of motion. Also, the theoretical perspective needs to be considered in this analysis. The third step which has been described in this perspective, considers the creation of a flow. This unnecessary movement for warehouse employee has a dramatic impact on the flow of the order-pick activities. Therefore, it is important that a solution will be provided to eliminate this waste of motion.

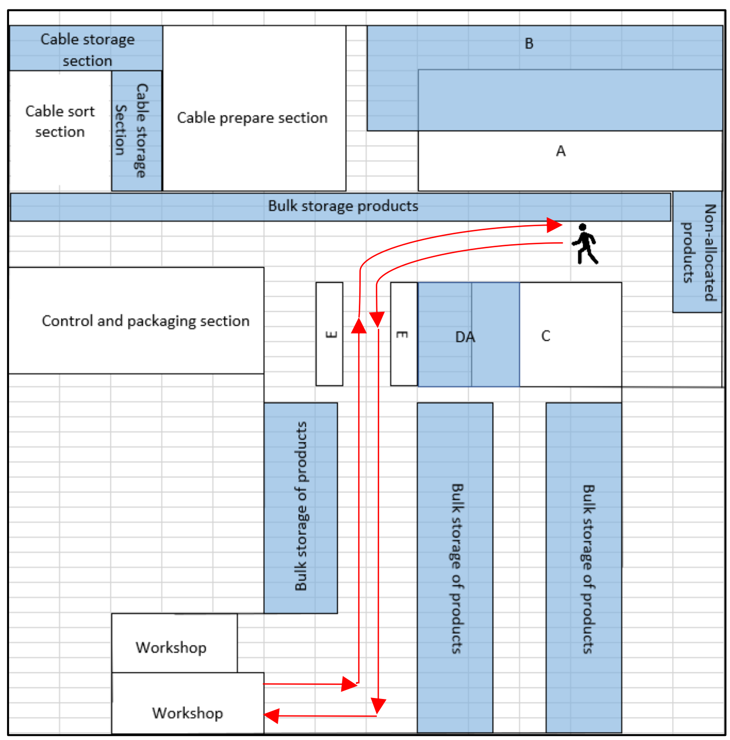

Figure 14: Route from the print section to the fuse box workshop

On a busy Monday, it is not strange for the company to process over 300 orders on one day. All the packing lists for the orders are printed at the same location. Sometimes, the packing list need to be transferred to the workshop. Under these circumstances, the waste of motion can be summarized as follows:

- *Sorting of packing lists*: for 60 packing lists, the employees are busy for approximately 5 minutes to print and sort the packing lists. So, for 300 packing lists this ends up to approximately 25 minutes a day to only print and sort some packing lists.
- *Delivery of fuse box packing lists from the print location to the workshop:* for each of these 60 packing lists, the warehouse employee needs approximately 2 minutes to deliver the concerning packing lists at the workshop. This means a total of 10 minutes for 300 packing lists. Combined with the sorting activities, more than half an hour a day is spend on the printing, sorting and delivery activities of packing lists.

3.3 Short summary of chapter 3

Chapter 3 provides an analysis of the order-pick process within the company. First, the different departments within the warehouse have been explained, as well as the main activities in these departments. Next, the stakeholders related to the order-pick process have been identified. It turns out that there are four major stakeholders, namely: the management team of the company, the warehouse manager, the warehouse employees and the customer of the company. Furthermore, insight has been created in the different types of mistakes which exist in the order-pick process as well as the relative occurrence of these mistakes. Last, the waste of motion within the order-pick process on different levels has been identified.

4 Criteria involved in an eventual solution

Now, phase 3 of the research will be introduced. This chapter provides the main criteria and preferences which an eventual solution needs to fulfil with regard to the order picking activities within the company. This list has been conducted and elaborated on by the main stakeholders, which are identified in the previous section of this report. The chapter eventually finds an answer to research question 3.1: "*What are the main criteria for a new order picking strategy at the company, according to the stakeholders?"* Short interviews with the stakeholders related to the order picking processes are conducted in order to draw up the eventual list of main criteria and preferences. Below, these criteria and preferences are shortly elaborated on.

4.1 Explanation of the main criteria and preferences

The eventual solution should involve a decrease in the number of mistakes of order picking activities.

As discussed in section 3.2.1, there is a relatively low number of mistakes with regard to the total number of fulfilled orders in the researched time period. However, each wrong delivery may consequence dissatisfied customers, with the danger of a decreased envisioned company reputation. Although the rate of mistakes is already relatively low, the eventual solution should contribute to an even more accurate order picking process.

The eventual solution should increase the speed in which the order picking activities are executed.

The management team of the company thinks that there is still much room for improvement left in terms of speed in which the order picking activities are executed. The company is doing its business very well and it is expected that the company will continue growing over the next few years. Therefore it is important to increase the speed of the time needed to fulfil the main order picking activities, in order to keep up with the requested orders in the future.

The eventual solution enables the order pickers to have their hands free while picking the products for an order.

The management notices difficulties for order pickers when these order pickers carry a packing list. It involves unnecessary actions from order pickers and it does not allow them to pick two or more products at a time. Also, physical package lists contain the danger of being lost while picking orders, or somewhere else in the warehouse processes.

The eventual solution must be integrative with already existing WMS and ERP systems within the company.

The past few months, the company has been busy with applying barcodes for every specific product in the warehouse. This enables the order picker to have a better overview of the layout of the warehouse and knowledge of where a specific type of product is stored. The locations of the products are already registered in the WMS and ERP systems of the company as well, so it is important that the accompanied technologies of the solution are ready to be implemented in the already existing technologies within the company.

The eventual solution must be able to be adapted or supplemented, with regard to the growth potential of the company.

As mentioned before, the company has been growing over the past few years and it is expected that this growth will continue. Therefore, the eventual solution should contain the possibility to be extended or supplemented in order to keep up with the growth of the company.

The eventual solution should enable flexible workforce to fit in the order picking activities.

The company experiences some seasonal demand throughout the year, which means that in several periods in a year demand is relatively high compared to another period. It will not be cost-effective to appoint too much employees throughout the whole year. Flexible workforce can provide a proper solution for these fluctuations in demand. When the company is expecting a rise in customer orders, flexible workforce can be requested at employment agencies. However, the flexible workforce should be able to pick orders directly, without an intense training period.

Batch order picking is part of the eventual solution.

This criterion is highly related to criterion 2, where the increased speed of the order picking activities is mentioned. When picking orders in batches, order pickers generally cover less distance and thus execute their tasks faster. The management team of the company wants this to be implemented, because it is expected that this will increase speed of the order picking activities in this specific research environment.

4.2 Overview main criteria and preferences

For such research goals, it is common that criteria lists contain different types of weights for each criteria. This enables the importance of each criteria and possible feature of the solution to be distinguished. However, the management team mentions that it is equally important that all elements of the table below are present in the eventual solution. Every criteria would be assigned weight 1, so it would not make sense to mention it for each criteria. It is interesting to relate the criteria, which are mentioned in section 4.1, to the relative distribution of types of mistakes, which is described in section 3.2.1. There is concluded that out of all the orders which contain a mistake, 77% of these orders contain products which are not requested by the customer. From this we can conclude that the order picking accuracy is an important part of the eventual solution. Therefore, the criteria "*The eventual solution should involve a decrease in the number of mistakes of order picking activities"* is rewritten as "*The eventual solution should involve an increase in order picking accuracy."* Table 2 below represents the most important features which should be involved in the eventual solution.

Description of criterion
The eventual solution should involve an increase in order picking accuracy.
The eventual solution should increase the speed in which the order picking activities are executed.
The eventual solution enables the order pickers to have their hands free while picking the products for an order.
Batch order picking is part of the eventual solution.
The eventual solution must be integrative with already existing WMS and ERP systems within the company.
The eventual solution must be able to be adapted or supplemented, with regard to the growth potential of the company.
The eventual solution should enable flexible workforce to fit in the order picking activities.

Table 2: Final table of main criteria and preferences

5 Analysis of potential order picking strategies for the company.

Chapter 4 describes phase 4 of the research. An overview of the main criteria and preferences of the main stakeholders related to the order picking process is provided in the previous chapter. In this chapter, potential strategies which might eventually fulfil main criteria and preferences will be discussed, as well as the additional conditions for applying these strategies within the research environment.

5.1 Potential strategies which fulfil main criteria and preferences

Section 5.1 tries to find an answer to research question 4.1: *“Which supporting techniques for order picking are known, according to literature?”* In order to find an adequate answer to this research question, extensive research has been executed on a lot of order pick supporting techniques. However, many techniques found in literature and online articles, appeared to be such inadequate that they are not mentioned in this report. This may, for example, be originated from a stuck development of the technique. Also, within this section, an answer is provided to research question 4.2: “*How are the supporting techniques found to improve the order picking process?*” The multiple techniques which eventually might contribute to fulfilling main criteria and preferences of the management team, will be individually elaborated on below.

5.1.1 Pick-by-voice

Voice picking ensures order pickers in a warehouse to work efficient and it reduces the chance of making mistakes. The right information is provided step-by-step via headphones. With voice picking, order pickers do not have to go through the warehouse with a packing list anymore. It is an order picking solution which also requires feedback from the order picker whether he has picked the right collection of items, so that the eventual picked amount can be adjusted if the initial amount was wrong. According to Brown (2015) there are seven main benefits of voice picking solutions.

The first mentioned benefit is the increased accuracy of the order picking activities at the company. Customers place a premium on fast service, but that does not count anymore when the customer receives the wrong products very fast. Errors in orders consequences costs in time and money, but also costs in damaged customer satisfaction. The second mentioned benefit of implementing voice picking is an increased productivity. Often, order picking activities are involved with scanners of packing lists, which means that the order picker does not have his hands free. This limits both employee and operational productivity.

Voice picking solutions provide scalability through simple and cost-effective worker and workflow additions, which provides operations to handle demand while avoiding a wasteful investment. The market of voice picking solutions is increasing and there is a wide variety of systems which support large vocabularies of thousands of words, which enable companies to expand their business without large implications for the company. This connects with the fourth benefit mentioned by Brown, which is the rapid adoption of automation. With voice, management teams leverage support capabilities to quickly scale up new, part-tie or seasonal workers to meet and exceed corporate productivity targets. For example, when a lot of orders need to be picked at a specific day, voice picking enables an easy helping hand for a temporary employee. They will be able to pick orders, with no specific knowledge of the company or products. Another benefit is management visibility. Voice picking solutions provide easy access to the right information. This might not only lead to faster management decisions, it also provides employees on the floor by providing real-time information, from which the order pickers can improve their order picking activities. Dashboards might provide real-time visibility into individual worker, group, zone, site and company-wide productivity levels and daily progress. This enables the management team to make rapid operational decisions. Solution flexibility may be the biggest benefit of voice picking solutions. Generally, voice picking solutions can be easily configurated with other already integrated enterprise software systems, like WMS or ERP systems. The last benefit Brown mentions, is the benefit of multilingual capabilities. Business which eventually employ non-native employees, are able to offer voice picking solutions in all the world's leading languages.

The benefits of voice picking systems which are described by Brown (2015) are supported by Douglas (2013). However, she mentions some additional benefits as well. For example, she mentions increased happiness of employees as well. Employees thrive when they are equipped with the best possible solutions for their main activities. On the other hand, job satisfaction declines when they have to use outdated technologies. Also, voice picking solutions provide easier and faster communication between (a group of) employees in the warehouse.

5.1.2 Pick-by-light

In a high-density order picking warehouse where there are multiple picking locations that require pickers to be fast and accurate, a light-directed system can be implemented to enhance the capabilities of the employees. The basic system will include lights above the shelfs where the employee picks the products from. An order picker will scan the barcode of the next product to pick. Then, the light of the location where the product is stored will light up. Another light above the shelf will indicate the quantity to pick. The order picker will select the item or items for the order and confirms the picking activities by pressing the lighted indicator.

Murray (2018) elaborates on the main benefits of "pick-by-light" systems. The first mentioned benefit is the missing out of language requirements. The light indicators are universally and will not involve issues in a misunderstanding of language. This allows companies to have a completely diverse warehouse staff without warrying about issues concerning understanding the systems voice or any language skill issues. It also allows companies to use temporary labour during busy seasons to perform picking operations with limited training requirements.

The second mentioned benefit by Brown, is that the system provides real-time feedback on order picking and the productivity of the operator. These reports can be used by the management team to identify and analyse main picking issues. Although it is obvious, it is important to mention the benefit of an increased order picking efficiency, in terms of speed and accuracy. Also, pick-by-light systems are generally known to be easily integrated within existing technologies like ERP- and WMS-systems.

5.1.3 Pick-by-light in combination with put-to-light

Put-to-light, which is also known as sort-light, enables order pickers to pick products for multiple orders at once: batch picking. Light-technologies provide information about where an order picker should store the product he just has picked. Eventually, the order picker carriers a picking device which contains multiple boxes where all individual orders are stored. Renowned international companies like SSI Schäfer and PCData provide solutions which are developed according to a combination of pick-by-light and put-to-light. Further elaboration on pick-by-light in combination with put-to-light will be executed according to the solution of PCData. Later in the report, a comparison will be made with the solution of SSI Schäfer in order to distinguish which company provides the solutions which fits best in the research environment.

PCData offers a solution called "PickCart". PickCart is an innovative solution for multi-order picking. It is designed in order to decrease the time needed to pick an order. This is possible because of the route-optimizing software which is integrated within the solution. According to PCData, it is guaranteed that the order pickers do not experience any waste of motion (PCData, 2018). However, it is necessary to mention that this is an assumption done by the company itself and not scientifically proven and confirmed by some other party. On the other hand, reviews from companies which already introduced solutions from PCData are very positive about the integrated routing software.

The solutions allows order pickers to pick orders in batches. The *sort-while-pick* strategy is the common strategy for this solution. Figure 15 on the right shows what the picking device of the PickCart solution looks like. The modularity of these picking carts are a big advantage. The carts are modifiable to the warehouse of the customer. So, when the paths in a specific warehouse are very narrow, it is possible to adjust the picking devices. It is also possible to determine the number of orders to pick in one batch. According to PCData (2018), the flexible display technology ensures the possibility to make the order picking activities more accurate. The display technology is adjustable to the number of orders to pick in one batch as well. PCData reveals the following main elements of this solution:

Figure 15: PickCart

1. Processing multiple orders at once.
2. Efficient route-optimisation software.
3. Flexible assembly system, with the possibility to apply these on multiple pick devices.
4. User-friendly software.
5. Increased order picking accuracy.
6. Feedback from order picking data to ERP and WMS systems.
7. The system is easy to understand and to learn.

A similar system like PCData offers, is offered by SSI Schäfer. Little information is provided via their website, but after some phone calls the system has been explained clearly. The system is highly comparable to the system of PCData. However, the main difference is that the picking devices of PCData are developed by themselves, while the picking devices of Schäfer are developed by a third party. The advantage of picking devices developed by a company itself, is that it is completely aligned to the whole product. An advantage of developing these picking carts by an extern company, is that there is more specific specialized expertise on the construction of these carts. The additional conditions to implement such solutions in the research environment will be discussed in section 6.2.4.

5.1.4 Pick-by-vision

Obviously, errors have a strong influence on the quality of delivery and the relationship between clients and suppliers. Thus, zero-defect picking is one major goal. Flexibility and fine motor skills of human beings are need because the product range, and thus the variety of items, steadily increases while the size of the orders decreases. It will not be useful to make use of robots in order picking, due to inflexibility. Because humans are highly flexible, they are often the best solution for order picking (Schwerdtfeger et al, 2009). All order picking systems which make use of head-mounted displays (HDMs) are considered as pick-by-vision systems. These systems primarily provide information through the visual sense. Schwerdtfeger et al. (2009) define two pick-by-vision systems:

- The systems which do not make use of tracking technologies to estimate the users position mainly present textual information in the form of a list of items or images etc. These systems are called pick-by-vison (2D) systems.
- Other systems, which make use of tracking and augmented reality, are called pick-by-vision (AR) systems.

The use of such pick-by-vision (AR) systems will be illustrated according to the example of Picavi. Picavi is the first company in the world to have developed order picking with smart glasses into a market-ready solution (Picavi.com, 2018). Nowadays, however, there are various other companies which offer this type of pick-by-vision technologies. For example, Samsung has developed such a system as well. The solution of Picavi has been used to illustrate the use of the pick-by-vision solution. This provides a good insight in how such solutions work. With pick-by-vision, the order picker wears a Google glass or smart glass which indicates where the order picker should pick the next item for the order or batch.

Figure 16: order picker wears smart glasses of Picavi

Figure 17: The order picker sees which shelf to visit next

As depicted in the picture above, this system shows what percentage of the order is fulfilled yet and what the next product to pick will be. When the order picker has arrived to the indicated shelf, he needs to verify the correctness of the shelf via the smart glasses. The glasses scan the barcode of the shelf and give a confirmation whether the order picker has arrived to the correct shelf or not. After this confirmation, the smart glasses indicate how much products the order picker should pick from that specific shelf. Obviously, the smart glasses also warns the order picker when he is in front of the wrong shelf. Then, there occurs the danger of picking a wrong item. After this warning, the right shelf is mentioned again. This checking system makes it hardly impossible to make mistakes. However, when the allocation of products in the warehouse changes, this should obviously be updated in the ERP systems as well. Otherwise, there will still occur mistakes within the order picking process.

Figure 18: Confirmation of the shelf

Figure 19: Number of items to pick from confirmed shelf

5.2 Short summary of chapter 5

Chapter 5 consists of an elaboration on the researched techniques, which might eventually be adequate for supporting the order-pick process at the company. These techniques are selected from an even longer list of possible techniques. However, these have been found inadequate for the company in an earlier stage of the research. The eventually researched techniques are called "*pick-by-voice*", "*pick-by-light", "pick-by-light"* in combination with *"put-to-light"* and *"pick-by-vision".* The next chapter will elaborate more on the fitness of the investigated techniques within the existing research environment.

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6 Fitness of the techniques within the existing research environment

The initial purpose of phase 5 of the research was to analyze the benefits of the order pick supporting techniques found in the previous chapter. Due to time issues and unnecessary investments, however, it is not possible to execute test periods with several techniques in order to determine which is eventually the most beneficial. Therefore, the purpose of phase 5 is redesigned and it now delivers an answer to research question 5: "*What are the main constraints when implementing the strategies found?*". For example, redesign of activities or important accompanied adjustments within the other picking process for each solution are mentioned in this chapter.

6.1 Pick-by-voice

The pick-by-voice solution requires few big adjustments within the warehouse. Of course, the software of the solution must be integrated within the already existing technologies within the company, but that will not cause many big problems.

Batch picking is possible with voice picking. There are companies in the order-pick-solution market which provide some flexibility in batch picking. However, this flexibility seems relatively low when compared to other investigated solutions. Also, when an order picker has eventually picked an order for a batch, there is a lack of indication about which products should be added to which order. Therefore, voice-picking will receive a low score on the batch picking element in the main criteria list. This will be further explained in chapter 5 of the report.

6.2 Pick-by-light

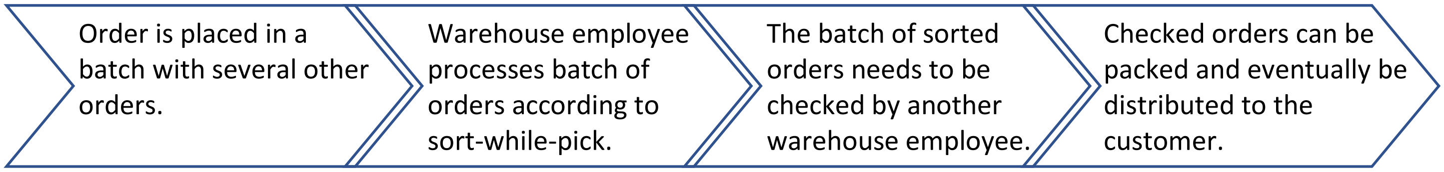
The pick-by-light solution is basically a basic version of the pick-by-light solution in combination with put-to-light. It requires more actions because there is no indication for the order picker where he needs to put the products he just picked. So, the risk remains that order pickers store the products in the wrong order bin and the order pick activities are executed relatively slow. For the rest is it basically the same as the pick-by-light solution in combination with put-by-light.

6.3 Pick-by-light in combination with put-to-light

The implementation of a pick-by-light in combination with a put-to-light solution consequences adjustments in the current order picking process. Because this is solution has a high potential, it needs to be considered what the main consequences will be.

These types of solutions are very easy to implement for assembly lines. However, the structure of the concerning warehouse of the company is different. The warehouse consists of multiple sections which also have different layouts. Therefore, there might be picking devices from PickCart which are not useable throughout the whole warehouse. There are two options for the layout of the PickCart. The first option is to request PickCart devices which are compatible for the smallest section in the warehouse. Then, the order picker is sure that he can pick orders with the pick device throughout the whole warehouse. The second option is to request PickCart devices with various sizes. This eventually enables order pickers to pick bigger batches or orders. It is also necessary that all components in the warehouse have their own unique registration code. This must be registered in the WMS-system of the company. The whole registration and calculation of the optimal routes is based on the data in the WMS-system.

In section 4.2.1, the consequences of several batch picking strategies are extensively described. Because the pick-by-light in combination with a put-to-light solution enables a *sort-while-pick* strategy, the order pick process at the company will look as follows:



6.4 Pick-by-vision

The pick-by-vision solution is very comparable to the pick-by-voice solution. It requires a few medium adjustments in the warehouse as well. However, the pick-by-vision solution has a higher chance of hindering the order picker. The screen with little text in the corner of the eye may be experienced as annoying. The batch-picking element of order picking is also not regular for this solution.

6.5 Short summary of chapter 6

Chapter 6 describes what changes to the current warehouse layout and operations should be made, in order to make every described solution work. This part of the research will also be taken into account in the quantification of fitness of all technique, which will be explained in chapter 8.

7 The application of batch picking within the research environment

Applying batch picking might involve several rigorous adjustments within the warehouse activities of the company. Also, the current conditions in the warehouse should be considered. The management team of the company, however, wishes to implement this strategy for the order picking activities. Therefore, the main implications and limitations for implementing batch picking within the research environment will be discussed in this chapter.

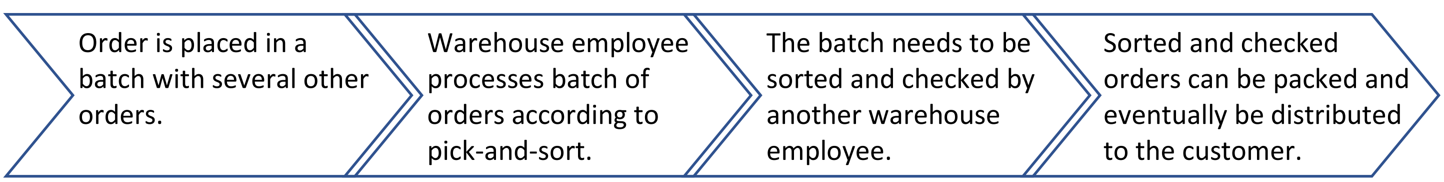
Number of orders collected within one batch.

The savings algorithm (see section 4.1) implies that it will be advantageous to collect all outstanding orders in one batch. However, this is of course not the case in practice. For both *pick-and-sort* and *sort-while-pick* batch picking, the number of possible orders for each batch depends on the following factors:

- If batch picking will be implemented, a pick device will be used as well. Obviously, this pick device has a maximum capacity. The accumulated order lines of the orders within a batch must not exceed the capacity of the pick device.
- There must be a considerable advantage in time, according to the savings algorithm, for the batch to be collected compared to individual order picking. If adding one other order does not contribute to the overall savings, it is better to add that specific order up to another batch.

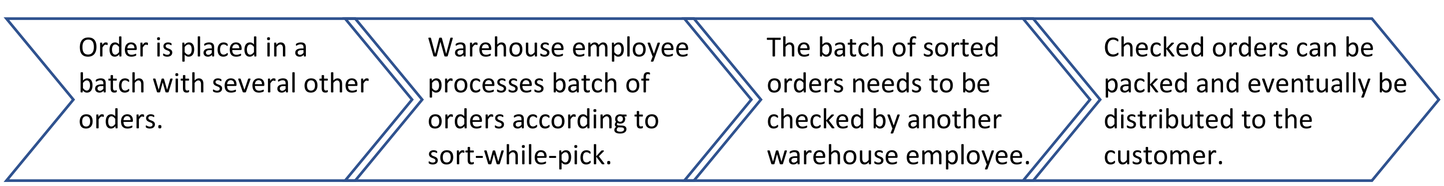
Rearrangement of activities within the order picking process.

Implementing a batch picking strategy involves some rearrangement of activities as well. When applying a *pick-and-sort* batch picking strategy, the overall pick-rate within the warehouse will increase. However, after these batch of orders is collected, these increased rate of orders needs to be sorted. In the current research environment, there is one warehouse employee who checks the picked orders according to the packing list. There will occur a new series of activities when the *pick-and-sort* batch picking strategy will be implemented. After the order is confirmed at the company, the activities within the *pick-and-sort* batch picking strategy will be as depicted below.



Because the arrival rate of orders increases at the employee which checks all the orders, it might be useful to assign two or maybe even three warehouse employees to sort and check all the orders. Because the pick rate per warehouse employee will increase (because of the batch picking), it will be possible to shift one or two order pickers to the sort-and-check station.

When applying a *sort-while-pick* batch picking strategy, the pick-rate will not increase as rigorous as discussed above. However, there will be a slight rearrangement of activities within the order picking process when this type of batch picking will be implemented. The series of activities is depicted below.



In the *sort-while-pick* batch picking strategy, the layout from the picking cart plays a role as well. There occurs a risk that the picked components do shuffle when they are placed in the picking cart. Therefore, the position of the employee who checks the picked orders should be preserved.

Configuration with existing technologies related to order picking.

For both batch picking strategies, the optimal composition should be determined before the warehouse employee can start collecting the components. A decision needs to be made between the strategies which are discussed in section 4.1.1. When eventually the seed- or the savings algorithm will be implemented, the existing technologies related to order picking should be considered. Because each incoming order at the company is different, the eventual batch picking system should also be able to distinguish the best batch composition on a real-time basis. The software for the determination of the optimal next batch should therefore be able to be configurated to the existing technologies in the warehouse.

8 Selecting the eventual solution

This chapter provides insight in how the eventual decision on the possible solutions is made. First, all the main pros and cons of the possible solutions will be shortly discussed. These pros and cons consist of all elements which are not captured in the main criteria and preferences, but which do have and influence on the implementation. Eventually, a table with all the main criteria and preferences and the possible solutions is drawn up, in order to quantify which solution is the best. Also, the vision of the management team on these solutions is requested.

8.1 Additional pros and cons of the possible solutions

The table below shortly discusses the main additional pros and cons of the possible solutions.

Solution	**Pros**	**Cons**
Pick-by-voice	It is not necessary to master the Dutch language fluently. It is possible to obtain the order picker information in another language.	Warehouse employees might get annoyed of hearing the same voice all day. This consequences a negative working atmosphere.
		There occurs a risk of misunderstanding the provided information via the headset.
Pick-by-light	The solution can be eventually extended with the put-to-light solution as well.	It is less comprehensive than the solution with the put-to-light extension.
Pick-by-light & put-to-light	The solution contains the ability to report shortages in stock, and provide immediate feedback to the ERP system real-time.	It is expected that it will take some time to work properly with this solution.
		Relatively high investment costs.
Pick-by-vision		Warehouse employees might get annoyed of the little screen in their vision all day. This consequences a negative working atmosphere.

Table 3: additional pros and cons of the possible solutions

8.2 Determination of the best order pick supporting technique

In this section, the best order pick supporting technique will be determined. In order to do this properly, the fitness of the techniques will be quantified according to the main criteria and preferences which has been identified earlier in this report. Then, these quantified findings will be discussed with the management team. If the management team agrees with the findings, the most adequate order pick support technique has been found.

8.2.1 Quantification of fitness

In order to determine the best order pick supporting technique, the fitness of the techniques, which are described in previous chapters of this report, will be compared to the main criteria and preferences of the stakeholders within the company. In order to determine how good a technique fits a specific criteria, the following scale has been used:

Scale: 1 - 5.	**Times mentioned**
5 = fits very good	4
4 = fits good	16
3 = medium fit	7
2 = does not fit very good	1
1 = does not fit at all	0

Table 4: Scale for determination of fitness

According to the previously described techniques, the table of criteria and preferences has been filled in. This table of criteria and preferences has been developed in chapter 4. The awarded scores are purely based on the information collected during the research, and are all equally important. Therefore, there are no weights assigned to the criteria. The current capabilities as well as the potential of the researched techniques are considered. The value of the scores of each technique for every criterion are determined according to their relative fitness. So, if a solution scores a "5" on a scale of 1 to 5, this means that this solutions is the best fitting solution among the others. However, it is also possible that more than one solution is suitable for a specific criterion on the same level. In this case, the scores will be rewarded equally. So, these scores have been rewarded based on the fitness of the specific criteria, relatively to the researched alternatives. There is, fortunately, no researched option which does not fit a criteria at all (score 1). The quantified results are depicted in the table below.

Criterion \ Solution	Pick by voice	Pick by light	Put to light	Pick by vision
1. The eventual solution should involve an increase in order picking accuracy	4	3	5	5
2. The eventual solution should increase the speed in which the order picking activities are exectued.	4	3	4	3
3. The eventual solution enables the order pickers to have their hands free while picking the products for an order.	4	3	3	4
4. Batch order picking is part of the eventual solution.	2	3	4	4
5. The evental solution must be integrative with already existing WMS and ERP systems within the company.	4	4	4	4
6. The eventual solution must be able t be adapted or supplemented, with regard to the growth potential of the company.	5	4	4	3
7. The eventual solution should enable flexible workforce to fit in the order picking activities	4	4	5	4
8. It is possible to integrate the solution within the research environment with the least additional changes required possible	4	3	3	3
Total score of solution (highest score = overall best fitting solution).	31	27	**32**	30

Table 5: Quantified fitness of techniques according to the main criteria and preferences

As one can see in the table, an eighth criterion has been added to the criteria of chapter 4. Chapter 6 elaborates more on the fitness of the found techniques within the existing research environment. Criterion 5, "*The eventual solution must be integrative with already existing WMS and ERP systems within the company",* only discusses this aspect on technological level. On the other hand, there are also practical issues when implementing such an order pick technique. Therefore, according to the findings within chapter 6, the eighth criterion has been formulated as follows: "*It is possible to integrate the solution within the research environment with the least additional changes required possible.*"

The result of the quantification reveals that the pick-by-light in combination with put-to-light the best fitting order pick supporting technique is for the company. Only 1 criterion would have been fit insufficient according to this table. That means that the reviewed order pick supporting techniques have been selected properly and that they all have been worth reviewing.

8.2.2 Discussion of quantified findings with the management team

The findings of the quantification have been discussed with the management team of the company. The solutions which are described in section 5.1 have been presented to the management team. However, the outcomes of the fitness of the solutions according to the main criteria and preferences have not been revealed to the management team at that moment in time. This provides another check on how sufficient the main criteria and preferences and the investigated solutions fit within the research. According to the presentation it appeared that the management team has a preference for the pick-by-light solution in combination with put-to-light. At the beginning of the research, the management team indicated voice-picking as a solution they would be interested in. However, after the presentation, the pick-by-light solution in combination with put-to-light appeared to be the most convenient solution. This corresponds with the outcomes of the quantified fitness of the solutions according to the main criteria and preferences.

8.2.3 Discussion of quantified findings with the order pickers

The findings of the quantification have as well been discussed with the order pickers in the warehouse. However, they appeared to be less enthusiastic about the solution which has been found. The main concern about this technique is the return of investment. It appears that the solution is very expensive and that it will not be profitable to implement it within the warehouse at this moment. According to the management team, there was no need to add the necessary investment in the list of main criteria and preferences. Also, they mention that the pick-by-light solution in combination with put-to-light might be useful in the future, but that there are some other fundamental order pick issues which must be solved first.

8.3 Determination of optimal batch pick strategy.

Chapter 7 describes the two batch pick strategies which have been investigated in this research. In section 8.2.2, the conclusions is drawn, in collaboration with the management team, that "*pick-by-light"* in combination with "*put-to-light"* will be the best solution for the company. Since there is also interest in the research on which batching strategy is the best, there needs to be drawn a conclusion on that topic as well. The chosen solution, however, implements the *sort-while-pick* strategy. On that point, there is no decision left. The order picker has the ability to store the picked products in the different bins of his pick-device. He receives the data to put which product in which bin from the software of the solution. There exists additional strategies on, for example, batch picking in specific sections of a warehouse. In the recommendations and conclusion in chapter 10, also one recommendation elaborates more on which strategy the company should maintain for their batch picking strategy.

8.4 Short summary of chapter 8

Chapter 8 describes the quantification of fitness of all researched order-pick supporting techniques. This quantification has been executed according to the list of main criteria and preferences. The outcomes of this quantification have been discussed with the management team and the warehouse employees. The pick-by-light solution in combination with put-to-light turns out to be the most adequate order-pick supporting technique for the concerning company.

9 Implementation strategy

Chapter 9 tries to find an answer to research question 7: “*How can the selected strategy be implemented?”*. Because of the discussion of quantified findings with the order pickers, it appears that the solution with pick-to-light in combination with put-to-light should not be implemented yet. The outcomes of the discussion with the order pickers have again been discussed with the management team. They agreed that the solution might be feasible for in the future and that the company is not ready for it at this moment. Therefore, the management team has agreed on the deliverable of an implementation strategy for over the years. This implementation strategy should contain the steps the steps which need to be undertaken in the future in order to be able to implement the solution eventually. The discussion with the order pickers has revealed additional insights for a proper implementation in the future. The first steps of implementation are part of the infrastructure and layout of the warehouse.

Providing all products with unique product locations.

At this moment, products with a high turnover rate are provided with a unique product location. The management team should make the decision whether they want to register all components in the WMS system or only the products with a high turnover rate. It is possible to preserve this level of product registration and allocation, because the chosen solution is partly implementable. There exists a trade-off between the costs of applying the solution to the products with a low turnover rate (but increased efficiency), and the gap in efficiency for picking products with a low turnover rate (but lower investment costs).

Overview of orders within ERP system

The overview of orders within the ERP system is depicted in figure 20 below. The packing lists for all sections within the warehouse are printed at one location: the A section. This has been discussed extensively already. It involves a lot of waste of motion, but it appears to be relatively easy to solve this waste of motion in direct manner.

Figure 20: Initial situation ERP system

The management team is able to request modifications within their ERP systems. In order to reduce the waste of motion, it needs to be visible for each section which packing lists should be printed or not. For example, the orders which only contain a fuse box do not have to be printed at the A section. If this packing list is printed at the fuse box workshop, a warehouse employee does not have to cover the distance from the A section to the fuse box workshop anymore. Also, there is less time needed to sort the different printed packing lists which are printed at the A section. The management team, however, already requested these modifications to the moderator of the ERP system, so this part of the implementation plan will be implemented soon. An indication of the new features of the ERP system is depicted in the figures below.

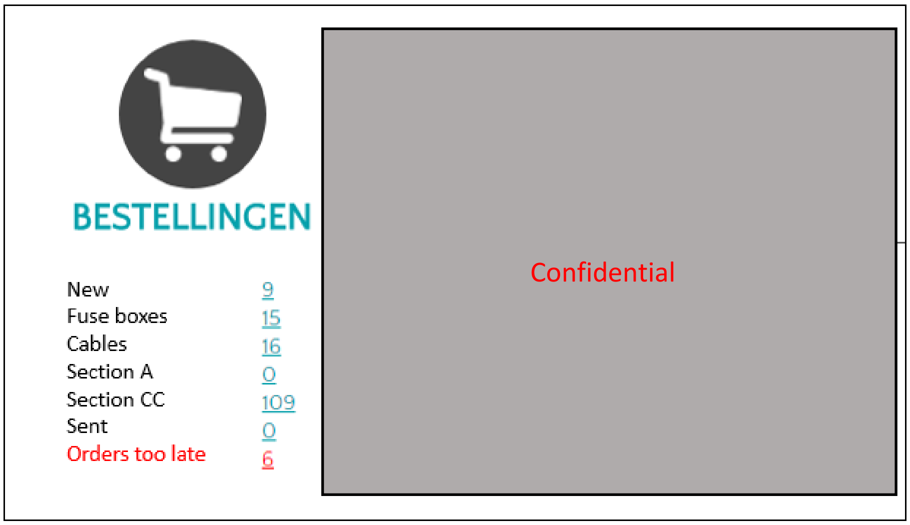
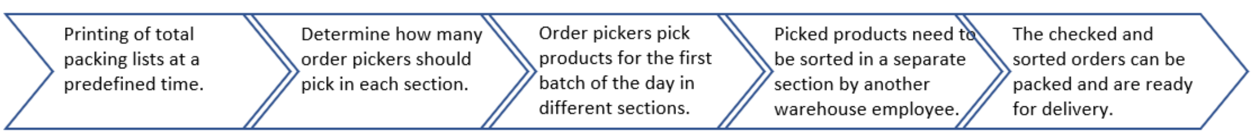


Figure 217: Example of what the ERP system will look like

The packing lists of orders with products stored in different sections can be printed separately. So, as depicted in the figure, the fuse box workshop employees know that there are 15 orders which contain a request for a fuse box. The same counts for the cable section and the other product storage sections within the warehouse. When this additional features are implemented within the ERP system, the packing lists can be printed for each section individually. This means that orders pickers can focus their order pick activities for a specific time slot on one section. When the orders for this section has been fulfilled, the products can be merged with the order requested products from other sections. The activities of order pickers will look as follows:



This is basically a more concrete adaption of the *pick-and-sort* batch picking strategy. More research should be executed on the layout of the warehouse in order to determine whether it is possible to create space to sort all the orders. On Mondays, more than 300 order lines need to be processed. At this moment, there is no space to store all the partly picked orders and merge them at a specific section.

Execute research if it is profitable to store products which are frequently ordered together, in the same section.

There exist research papers which support to arrange the layout of the warehouse such that products which are frequently sold together, are also stored close to each other. De Ruijter et al. (2009) found some interesting results on batch order picking when products, which are ordered together frequently, are stored in the same section. De Ruijter et al. describe the use of “order oriented slotting” (OOS). This strategy deals with the assignment of stock keeping units (SKUs) to storage locations in a warehouse. OOS stores the SKUs in the warehouse in such a way that the total time needed to pick all the orders, is minimized. In the warehouse of the company of the research, the products are stored according to the cube per order index (COI). Turnover-based slotting strategies, like COI, are often implemented in practice. However, critical observations on this slotting strategy reveals that this is not always the best way of slotting, because the assignment of SKUs to locations is based on the assumption that all storage and retrieval transactions are single-command transactions. (Mantel et al, 2007). When a specific order has multiple items and all of these must be picked in one tour, it is far more logical to assign SKUs to locations in such a way that the total travelling time of all tours is minimized.

The interaction frequency heuristic (IFH) is used to determine the efficiency of such a warehouse layout. This heuristic first allocates the singles. The singles are the SKUs that never share an order with other SKUs. They are allocated in such a way that their distance to the print location of packing lists is in line with their individual popularity. Next, it ranks the interaction frequencies in decreasing order (Mantel et al, 2007). There is one important constraint about this OOS strategy. Extensive batching implies longer order sequences that occur less frequently and consequently a slotting such as IFH is much more difficult to implement.

De Ruijter et al. (2009) have conducted research on the effects of applying the IFH strategy on a fictive warehouse. The fictive warehouse contains 7,500 SKUs and 42,000 orders with a total of 275,000 order lines are assumed. In such warehouse circumstances, the computed reductions in order picking time are in favor of the IFH. For single order picking, the IFH appears to involve 10% more reduction in distance covered of picking the orders compared to COI. In batch order picking, the IFH reduces 3,4% more distance than the COI. The following side notes are important when applying these results to the concerning research environment:

- The research environment contains 10,000 SKUs, instead of 7,500 SKUs.
- For comparison the order lines and number of order per month are determined. For the research of De Ruijter et al: 8,400 orders with 55,000 order lines. The data of the research environment: 9,000 orders with 207,000 order lines.

Mantel et al. have conducted research on the deviation of the covered order pick distances when some of the three given values are changing. They sketch different scenarios, with a maximum deviation in percentage of approximately 7,5%. This means that it is definitely not sure that in the given research environment the total distance covered will be reduced significantly when the IFH is used. Especially because there is such a difference in order lines per order, the results of such an implementation in the research environment is not sure.

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10 Conclusions and recommendations

This last chapter consists of the conclusions and recommendations for the company. The chapter provides an answer to the main research question: *What is best order-pick support technique for the company in order to reduce the waste of motion?"* During the research, much knowledge is obtained about the current situation within the company with regard to the distribution of types of mistakes, where the main waste of motion occurs, several order pick supporting techniques and about the fitness of the researched order pick supporting techniques. The research eventually led to four main recommendations, which are elaborated on below.

1. **Execute research on an existing trend within frequently ordered products together.**

Data of the interdependencies of orders is requested at the providers of order data within the company. However, there is no reaction on emails yet. If a significant trend can be detected in combinations of products and orders, it might be profitable for the company to apply changes within the layout of the warehouse. Then, it might be profitable to make use of batch picking in sections, because this will eliminate the waste of motion within the warehouse even more. If there is little to none interdependency within the order compositions, it is better to store the products with a high turnover rate close to each other. This is already the case within the warehouse but it is necessary to keep track of which products do have a high turnover rate, to keep the warehouse layout up-to-date.

2. **Evaluate the practical outcomes of the changes within the ERP system.**

The changes within the ERP system will be implemented and are available soon. The outcomes and the decrease of waste of motion should be evaluated by the company, but it is expected that it will involve a lot of increasing efficiency with regard of the unnecessary movement of employees. When this additional features are implemented within the ERP system, the packing lists can be printed for each section individually. This means that orders pickers can focus their order pick activities for a specific time slot on one section. When the orders for this section has been fulfilled, the products can be merged with the order requested products from other sections. There is, however, doubt whether this strategy might be useful for the company. Especially in terms of space needed for a specific section to merge the products from different sections to one order. In periods of a relative easy order flow, the company can try to fulfill orders for each section and them merge them afterwards: the *pick-and-sort* strategy.

3. **Provide all products and components with unique product locations.**

The eventual solution, independent of the pick-by-light solution in combination with put-to-light or another solution, operates the best when all the products in the warehouse al. All the investigated solutions are executive based on the registration of products in the warehouse. The selected order pick supporting technique works most efficient when all products are provided with unique product locations.

4. **Implementation in phases of pick-by-light in combination with put-to-light.**

The way the implementation of the pick-by-light solution in combination with put-to-light will be implemented, depends on the decision which is made with regard to product registration within the WMS system. According to representatives of PCData, the solution is partly implementable. So, it is easy to start with, for example, just two pick carts within a specific section of the warehouse. However, if this solution will be implemented, it should be considered that products, which are not picked via the solution, need to be merged with the other products. This decision can be based upon the results of the experiments in recommendation 2. The batch picking strategy which is involved with this solution is the *sort-while-pick* batching strategy.

What is best order-pick supporting technique for the company in order to reduce the waste of motion and the number of mistakes?"

The best order-pick supporting technique for the company in order to reduce waste of motion, is a pick-by-light solution in combination with put-to-light. It is the solution which fits best according to the list of main criteria and preferences. It is also a very practical solution, since it is partially implementable. It provides adequate soft- and hardware which both will be used to reduce waste of motion and the number of mistakes. The solution also contributes to a value stream with less internal waste and a better flow of order-pick operations. Next to this order-pick supporting technique, there are also other recommendations which will contribute to an even better operation of the solution. These recommendations are:

1. Execute research on an existing trend within frequently ordered products together.
2. Evaluate the practical outcomes of the changes within the ERP system.
3. Provide all products with unique product locations.

The recommendations together with the implementation in phases of the pick-by-light in combination with put-to-light solution, will have an explicit contribution to the order-pick process and it is expected that this will involve a decrease in waste of motion and the number of mistakes.

11 Reflection on the use of theory

A theoretical perspective has been identified in section 2.4 of this report. This theoretical perspective consists the theory of Lean in order to identify value within a value stream. According to this value, the waste within company processes can be determined as well. A reflection on the use of theory within the research will be discussed in this separate chapter. The principles of the identified theoretical perspective, Lean, have been used throughout the research. The structure of how this perspective has been drawn in this theoretical perspective, is basically the way how this research is structured. However, there are some remarks on how the theory has been used as well.

The first step which is described by the theoretical perspective, is to specify value within the operations of the company. However, there has been more focus on the other side of value: waste. In the theoretical perspective, the definition of waste has been identified as well because the reduction of waste is actually the main focus of this research. The next step of the theoretical perspective is to identify the value stream. In this report, the order-pick process as well as the warehouse layout has been analyzed and described extensively. In particular the order-pick process covers the value stream of order picking activities. However, in this part of the research I should have reflected more on the practical value stream related to the theory. This would have helped to have a more convenient support of my assertions. The third step refers to make a flow of all the operational steps within a value stream. This is what the whole research is about. That is also why I have elaborated more on the properties of batch picking. The provided recommendations eventually are all aimed to make the order-pick process flow better. More in-depth theory on the creation of such a flow has not particularly been mentioned, because I decided to use theory which would have practical value (for example the theory of the order-pick supporting techniques) for the research. The fourth step of the theoretical perspective, has not been focused on during the research. I have mentioned an example of how their pull strategy works, but my research did not have an influence on that way of working. The fifth and last step of the theory, was called “perfection”. This refers to the first four steps, which should be executed iterative. This ensures continuous improvement of, in this case, warehouse activities and elimination of waste. The solution which eventually has been chosen as the most adequate, contributes to an iterative process of improving order-pick processes. The system provides feedback data on the execution of order picking activities. Next to that, the system can be extended according to the preferences of the management team.

Concludingly, the theory of lean could have been used more throughout the research. The main goal of lean is to reduce waste within the operations of an organization. And that is indeed what this research is all about. But on the other hand, I should have referred more to theory within my research. That would have provided a more convenient covering of my assertions. It is clear that this research contributes to the reduction of waste within the order-pick processes of the company, but I think that I could have linked more relevant theory to this research.

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12 Appendices

A12.1 Reference list

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A12.2 Systematic literature review on waste of motion within order picking processes

This systematic literature review is executed in order to find an answer to research question 2.1: "*Which methods of Lean exist to reduce waste of motion, according to literature?".* In this systematic literature review, Scopus and Web of Science will be used to search for articles which will contribute to answering this research question.

Number	Criteria	Reason for exclusion
1	Articles before 1988.	The first article considering the Lean principles is published in 1988.
2	Medical topics.	This does not refer to firms.
3	Simulation studies.	Simulations are not related to this research.
4	Articles cited by less than 5 other papers.	The relevance of the article is not confirmed by other articles.
Number	Criteria	Reason for inclusion
1	Articles where "waste of transport" is mentioned in the title and abstract.	There is considerable overlap between "waste of motion" and "waste of transport".
2	Case studies.	The outcomes of the case studies might provide a useful understanding on reduction of waste of motion.

Search string	Scope	Date of search	Date range	# entries
Scopus	*Scopus*	*Scopus*	*Scopus*	*Scopus*
“Lean” AND “waste” AND “motion”	Article title, abstract, keywords.	21/04/2018	1988 - present	71
“Lean” AND “unnecessary movement”	Article title, abstract, keywords.	21/04/2018	1988 - present	14
“Unnecessary movement” AND “value stream mapping”	Article title, abstract, keywords.	21/04/2018	1988 - present	4
“Muda” AND “value stream mapping”	Article title, abstract, keywords.	21/04/2018	1988 - present	11
“Muda” AND “motion”	Article title, abstract, keywords.	21/04/2018	1988 - present	6
Web of Science	*Web of Science*	*Web of Science*	*Web of Science*	*Web of Science*
“Lean” AND “waste” AND “motion”	Topic	21/04/2018	1988 - present	28
“Lean” AND “unnecessary movement”	Topic	21/04/2018	1988 - present	5
“Unnecessary movement” AND “value stream mapping”	Topic	21/04/2018	1988 - present	4
“Muda” AND “value stream mapping”	Topic	21/04/2018	1988 - present	5
“Muda” AND “motion”	Topic	21/04/2018	1988 - present	3
Total number of entries				**151**
Removing duplicates				-36
Selecting based on exclusion criteria				-103
Removed after complete reading				-9
Included after complete reading				+1
Total selected for review				**4**

This systematic literature review yields 5 articles which will be useful in answering the research question. Before defining an answer to this research question, a concept matrix is designed to provide insight in which concept is mentioned by which article.

Journal	Authors (year)	Methodology	Operationalization “methods to reduce waste of motion”	Key finding with regard to “methods to reduce waste of motion”
International journal of operations and production management	(Rawabdeh, 2005)	Study on the definitions of each type of waste and overlapping areas.	“Operators have to stretch, bend, pick-up or walk when such actions could be avoided.”	Receiving and shipping activities of parts or products should be located in standard places.
International journal of quality and reliability management	(Douglas, Antony, & Douglas, 2015)	A combination of observation and a cause-and-effect analysis,	“reduce unnecessary movement of people and materials”	Point-of-use-storage can be used to reduce unnecessary movement of people and material.
Proceedings of the World Congress on Engineering	(Muslimen, Yusof, & Abidin, 2011)	Semi-structured interviews and open-ended questionnaire.	“When reducing the level of inventory, other forms of waste can be reduced.“	“Each type of waste should be reduced individually. Then, another waste can be reduced.”
Institute of Industrial Engineers transactions	(Gopinath & Freiheit, 2012)	Metrics used to monitor the seven traditional non-value adding waste are explored.	“Reducing excessive operator movement between workstations.”	“ Method to reduce waste of motion is different for every single warehouse.”

The systematic literature review is executed in order to provide an answer to the following research question: **“***Which methods of lean exist to reduce waste of motion, according to literature?”* According to the findings from this systematic literature review, there are differences in the matter of usability of the key findings of the articles. The following elaboration tries to provide an answer to research question 2.2: “*How are the methods found in literature applicable to an order picking process?”.* Gopinath and Freiheit (2012) elaborate a little on the different possible layouts of warehouses, which obviously has an influence on how waste of motion can be reduced optimally. Waste of motion might occur on a higher scale in a bigger warehouse, where products do have to cover more distance anyway. Also, products which are consisting of multiple components or which have to pass by multiple departments, are more vulnerable to waste of motion. Therefore, it is necessary to obtain a good understanding of the research environment. Only when a good understanding of the research environment is obtained, the best fitting solution for waste of motion can be found.

Rawabdeh (2005) mentions standardization as the main opponent of waste of motion. He states that “receiving and shipping activities of parts or products should be located in standard places”. Then, nor the product as the warehouse employee does have the opportunity to neglect the standardized process. This vision is partly supported by Douglas, Antony and Douglas (2015). They suggest that point-of-use storage can be used to reduce unnecessary movement of people and material. This mainly concerns that the next stage the product will be in, is already recognized. So, when the product has fully gone through stage *n,* it will be stored at stage *n+1.* Then, *n+1* should be the department where the next action on the product will be undertaken. If this way of working is done for each product and each components, then the waste of motion will be reduced to its minimum. Last, Muslimen, Yusof and Abidin (2011) elaborate on the various types of waste which might all occur within one organization. They state that each type of waste must be reduced individually. According to this reduction, another type of waste will occur. This continuous process can be executed on and on, in order to reduce the maximal waste.