Increasing warehouse efficiency by digitalizing warehouse processes using mobile devices

A design study in the steel industry

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Master Thesis in Engineering Logistics

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Lund 2024

ABSTRACT

Title	Increasing warehouse efficiency by digitalizing warehouse processes using mobile devices – A design study in the steel industry
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Problem description	Heine + Beisswenger does not or only partly document material movement in parts of their warehouse which causes a lack of efficiency due to increased search times. Therefore, the case company is interested in implementing digitalized processes to increase warehouse efficiency.
Purpose	The purpose of the master thesis is to investigate opportunities to increase warehouse efficiency by digitalizing warehouse processes using mobile devices.
Research objectives	**RO1:** *Describe the current process of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.* **RO2:** *Identify the performance of the current material and information flow between the incoming goods, the storage as well as the retrieval of the goods.* **RO3:** *Determine the parts of the material and information flow between the incoming goods, the storage as well as the retrieval of the goods that can be improved through digitalization by using mobile devices.* **RO4:** *Propose digitalized solutions which improve the efficiency of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.*
Methodology	The methodology to fulfill the purpose of the thesis has been design science research, accomplished in the following six steps: (1) Identify the problem, (2) frame it, (3) develop a conceptual framework to solve it, (4) theorize the findings, (5) validate them and (6) communicate the gained knowledge.
Conclusion/Findings	The thesis provides multiple design propositions about implementing handheld scanners as well as mobile printers into the current warehouse processes which leads to efficiency increases. It also provides a financial overview that gives a hint about potential savings that could be realized when following the design propositions.
Keywords	Warehousing, Digitalization, Efficiency, Mobile Devices, Design Science Research

ACKNOWLEDGEMENTS

The thesis would have not been possible without the invaluable support and guidance of my supervisor, Joakim Kembro. I am sincerely grateful for his expertise, encouragement, and constructive feedback. Further, I would also like to thank Viktor Leife that has acted as my opponent during the process of writing the thesis.

Moreover, I am very grateful to Heine + Beisswenger and Andreas Schebesta, who initiated this project and has been my supervisor at the company throughout the thesis. Thank you for your expertise, guidance as well as all the information you have shared which helped me a lot finishing the thesis successfully. Finally, I would like to thank all the employees at Heine + Beisswenger that have helped me by providing data and insight in their daily work.

Søren Castor

Lund, June 2024

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ABBREVIATIONS

AGV	Autonomous Guided Vehicle
AS/RS	Automated Storage & Retrieval System
EU	European Union
SME	Small and medium-sized enterprises
CAD	Computer-Aided Design
CIMO	Context, Intervention, Mechanism, Output
QR	Quick Response
OEM	Original Equipment Manufacturer
ERP	Enterprise-Resource-Planning
RO	Resource Objective
WIFI	Wireless Fidelity
WMS	Warehouse Management System
2D	Two-dimensional

1. INTRODUCTION

In the first section of the master thesis the reader will be provided with some background information. This consists of digitalization as well as the case company. Furthermore, the problem formulation, the purpose of the master thesis and the research objectives will be described. In the end the focus and the delimitations will be discussed as well as the disposition about what can be expected in the following chapters is described.

1.1 Background

As the most significant technological trend faced globally, digitalization will affect and is already affecting not only individuals but entire nations as well as businesses across the globe (Leviäkangas, 2016). Digitalization can be defined as improving processes with digital solutions (Kimachia, 2023). The core component of digitalization is the networking of people, machines, processes, and systems that are digitally connected and communicate with each other via numerous interfaces (Engels, 2017). Adopting digital technologies in organizations or in the operation environment causes changes and challenges for companies which further among others will be identified in this research project (Parviainen, 2017). The need for digital transformation was recognized by industrialists as well as governments worldwide after the first publication of the term "Industrie 4.0" back in 2011 (Ghobakhloo, 2018; Nascimento et al., 2019). Since then, Industry 4.0 is progressing exponentially and is transforming the manufacturing as well as the connected supply chain industry (Ghobakhloo, 2020; Lasi et al., 2014).

However, even though no one would disagree that digitalization will have a lasting impact in the future of many industries across the world, a lot of companies still lack behind. Especially small and medium-sized enterprises (SMEs) have a lot of catching up to do and are facing major challenges implementing digitalization in comparison to big enterprises (BDI & PwC, 2015). As per definition SMEs have fewer than 250 employees and do not exceed an annual turnover of 50 million euros, and/or an annual balance sheet of 43 million euros (European Commission, 2003). Considering for example that the digitalization level of German SMEs in some regions are only rated on a high level in 20.9% and are rated on a (very) low level of digitalization in 27.5% of the cases, even though Germany is one of the leading industrial nations worldwide, underlines that there is still a lot of room for improvement (BDI & PwC, 2015). The fact that SMEs according to the European Commission represent 99% of the businesses in the EU shows how important it is that micro, small and medium-sized businesses catch up on digitalization (European Commission, 2024). Therefore, it is in the interest of all Europeans to push digitalization for all enterprises in order to achieve competitiveness and to strengthen the economy sustainably.

As warehouse management plays a crucial role in efficient steel supply chains, warehouses are one important area of potential improvement through digitalization (Zäpfel & Wasner, 2006). The purpose of a warehouse is to store goods for commercial reasons (van Geest et al., 2021). However, this is not the only function nowadays. In general, warehouses are a fundamental component of any supply chain. Buffering the material flow alongside the supply chain to contain changeability which could be caused by factors such as product seasonality, consolidation of products from different suppliers for combining deliveries to customers as well as value adding processes as labeling or product customization are all major roles of warehousing. Since the market competition is constantly evolving, continuous improvement in the design and operation of production-distribution networks is required. This consequently requires higher performance from warehouses which can be achieved through digitalizing warehouse activities. (Gu et al., 2007)

As warehouse activities are getting digitalized, the traditional warehouse is turning into a smart warehouse. New technologies are influencing the manufacturing processes as well as the warehouse processes and the digital transformation of organizations (Catal & Tekinerdogan, 2019). As technological change in the steel industry, in contrast to other industries such as the automotive industry, is progressing more slowly (Gajdzik & Wolniak, 2021), mobile devices such as handheld scanners and mobile printers can be a good foundation for digitalizing warehouse processes to improve efficiency which means avoiding waste of time, labour, or money (Cambridge, 2024).

1.2 Case Company

Heine + Beisswenger is a middle-sized company in Fellbach (Germany) which offers materials and services for the steel industry. With 620 employees in twelve locations, Heine + Beisswenger offers one of the most comprehensive ranges of materials with more than 55,000 tons in stock. To be able to offer an extensive range of processing services the company has a large machine park of a wide range of machine technologies like sawing machines, chipping machines and machines for chamfering. The sawing of steel and other materials is one important service Heine + Beisswenger is providing for their customers as they are cutting more than 17,5 million pieces every year. In addition, the company has its own fleet of 50 trucks which delivers to around 5,000 regular customers with the partial support of external haulage companies. All in all, the material turnover per year is as high as 250,000 tons which means that Heine + Beisswenger is handling a material turnover of 1,000 tons per day. (Heine + Beisswenger, 2024a)

Since the company is part of the steel industry their warehousing processes differ from usual warehouse processes in terms of material handling. Most of their products that are processed, stored, or retrieved in the warehouse are steel bars with a length of three to six meters with different diameters. The bars therefore can only be moved by cranes or forklifts in their warehouse. Heine + Beisswenger does already have a high rack warehouse in their warehouse facility in Fellbach and is therefore, at least in that part of the warehouse, fully digitalized. However, some storage areas are still not digitalized which the company wants to change in order to make the processes more efficient. This will firstly be done only in the warehouse of Fellbach, which is the headquarter of Heine + Beisswenger. If the project is going to be successful and running without any problems, the storage areas of the other warehouse locations will also be digitalized in the near future.

In Figure 1 a rough layout of the warehouse can be seen. The edged red squares are the storage areas that Heine + Beisswenger wants to be digitalized. This is partly inside of the warehouse but also outside. These areas now have either a rack storage system which can store multiple bars at once or are completely empty and do not have any equipment to store the bars such as the floor storage (light blue) and the outdoor storage (green area). The rest of the warehouse is either storage area which does not want to be digitalized yet (grey area), machines were the steel bars are processed (orange area), the high rack warehouse which already is digitalized (dark blue area) and the preparation zone were the steel bars are either prepared to be stored in the high rack warehouse or are prepared to be shipped to customers (white area).

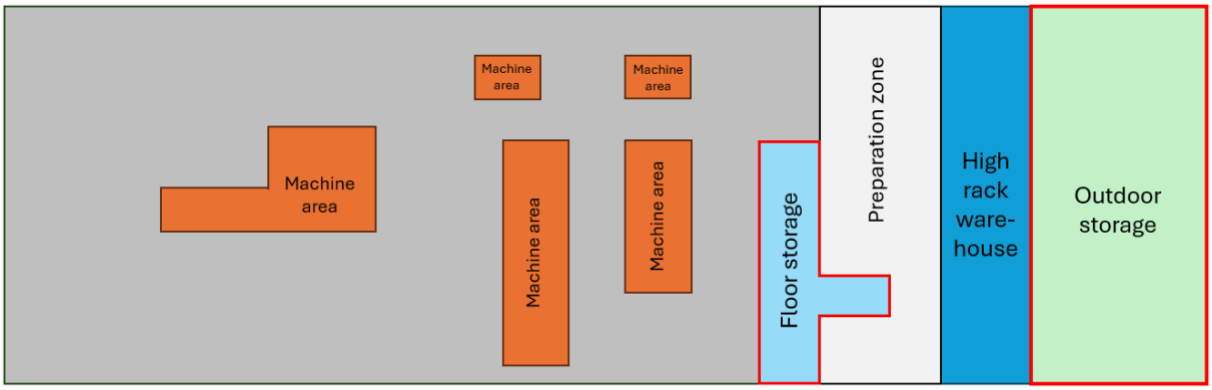


Figure 1: Rough layout of the warehouse.

1.3 Problem formulation

As previously described Heine + Beisswenger is mostly processing steel bars which are between three to six meters long with different diameters. This means that their products weight up to multiple tons and therefore cannot be stored and handled like it is usually done in warehouses where smaller and lighter products are handled.

The problem area can be found in some parts of the storage area of the warehouse where the processes are still not fully digitalized which causes a lack of efficiency. Delivered steel bars find their way in the storage areas of the warehouse. These storage areas are now marked with colors and measure for example 15m*25m. In those areas the places are divided by poles which are as high as 2.3m and measure up to 1.3m to the next pole, as it can be seen in the picture below which shows an example of what such a storage area looks like. Once the warehouse worker has placed the steel bar in one of the colored areas the process is documented at the goods receipt station. However, since the steel bars are piled up in the areas, it often happens that steel bars on top of the pile need to be moved to pick a steel bar in the bottom of the pile. These movements of the goods are not documented which leads to inefficiency in the picking processes since the warehouse workers often need to search for the steel bars because they were moved to pick other steel bars in the storage area. The only restriction of moving the steel bars when picking up steel bars below them, is that the moved steel bar still needs to be placed in the documented colored area. This, however, is still very inefficient because the warehouse workers need a lot of time to find the right products. Figure 2 shows an exemplary rack storage area of the warehouse.

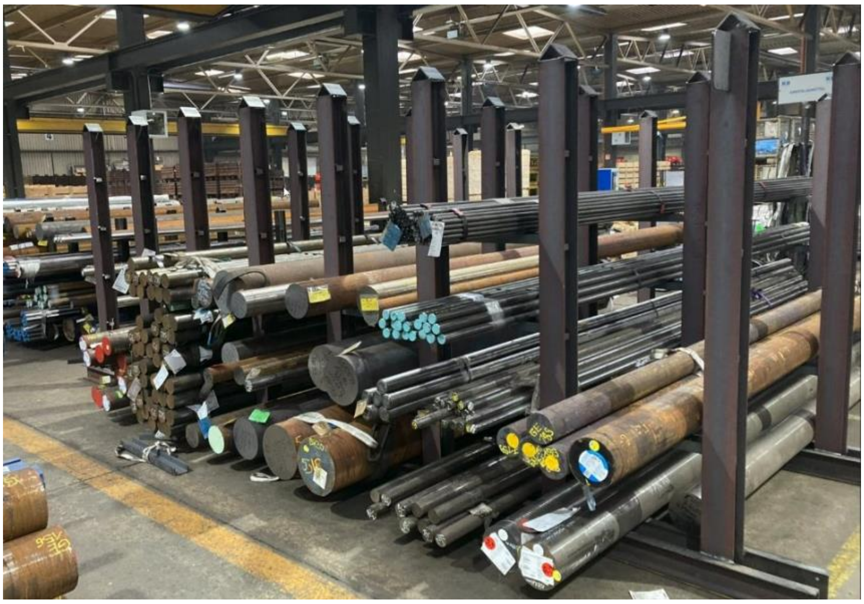


Figure 2: Rack storage area.

The same problem can be found in another part of the warehouse where the products are not stored in racks but on top of each other in wooden boxes, as it can be seen in Figure 3. In that area the products are also placed randomly in an area of roughly 15*25m and are only marked with a number on a colored note. Here the picking process is as inefficient as previously described as it also takes a lot of time to find the right product.


Figure 3: Storage area.

Therefore, the case company is interested in investigating how those processes can be digitalized to maximize the efficiency of those processes.

1.4 Purpose and research objectives

The purpose of the master thesis is to investigate opportunities to increase warehouse efficiency by digitalizing warehouse processes using mobile devices. To successfully achieve the purpose of the master thesis as well as providing Heine + Beisswenger with design propositions of how to digitalize the processes of the designated storage areas, the following four research objectives (RO1, RO2, RO3 and RO4) have been formulated:

RO1: *Describe the current process of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.*

This objective will help understanding how the current material and information flow of the whole process is working. To accomplish the objective, data will be collected through observations as well as unstructured interviews and secondary data, which has already been gathered previously by the company. Those methods will provide the necessary information which is needed to describe how and where material or information flows.

RO2: *Identify the performance of the current material and information flow between the incoming goods, the storage as well as the retrieval of the goods.*

After understanding how and where material and information flows, this objective will provide understanding about the performance of the material flow as well as the information flow. This research objective will provide information about how long such processes take in total, but also how long intermediate steps take in order to analyze further at which point of the process waste can be identified. This as well will be done by using secondary data and by carrying out observations and unstructured interviews.

RO3: *Determine the parts of the material and information flow between the incoming goods, the storage as well as the retrieval of the goods that can be improved through digitalization by using mobile devices.*

This research objective is done to determine which parts of the current material and information flows can be improved through digitalization. It will be done through analyzing the performance of the second research objective and is the necessary step to fulfill the fourth research objective. Together with the results of the first and second objectives, parts of the processes that can be improved will be identified through observations, unstructured interviews, literature review as well as experiments with the handheld scanners and mobile printers are carried out in order to analyze the current processes which is the foundation for RO4.

RO4: *Propose digitalized solutions which improve the efficiency of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.*

The fourth objective will provide propositions of how digitalization of those processes will improve their overall efficiency. For this, the previous objectives will be used as well as literature review which will help accomplishing this last objective. The objective will be done by providing a design proposition for Heine + Beisswenger to successfully perform the digitalization of those processes.

Based on the four research objectives as well as the literature review, a conceptual framework has been created, as it can be seen in Figure 4. The conceptual framework will support towards delivering the design proposition and to fulfill the purpose of the master thesis. Further descriptions can be found in chapter 3.4.

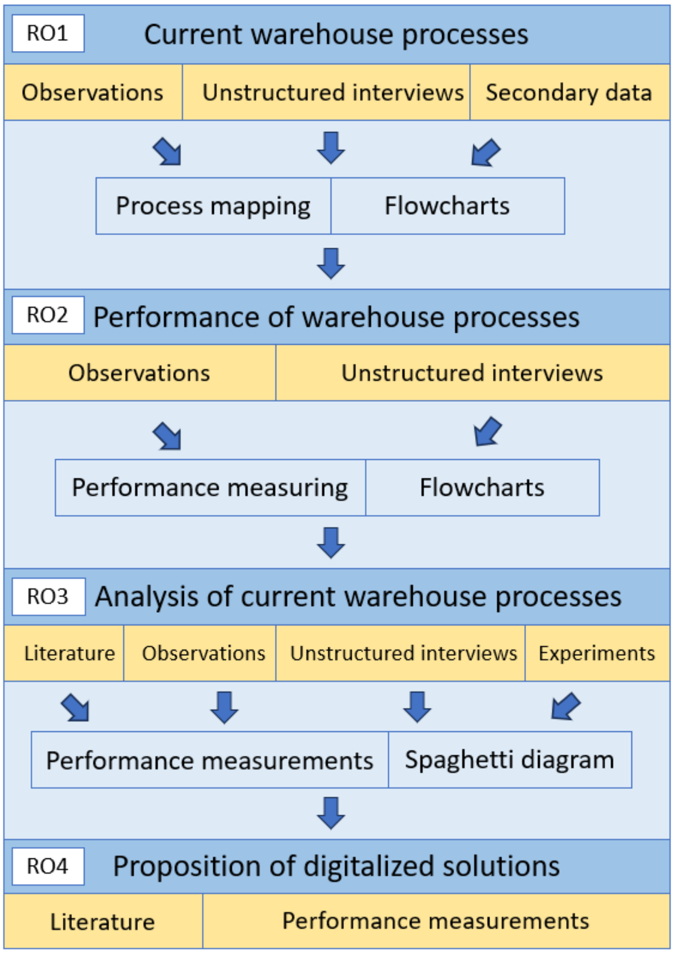


Figure 4: Research approach of this master thesis.

1.5 Focus and delimitations

Since the case company is part of the steel industry and handles mostly steel bars which are three to six meters long, the focus will be on long goods logistics in the steel industry and is therefore delimited from warehouse structures that do not handle long goods but small loads. Inside of the warehouse the focus is on intralogistics processes, which means that the production processes are not in the scope of the thesis. To successfully fulfill the purpose of the thesis only the processes of incoming goods, storage and picking are in focus. Within those processes the material flow from the incoming goods to the storage area to picking is in focus as well as the information flow in between all those three processes. For the digitalization of the storage area the focus is on mobile devices such as scanners and printer which are investigated whether they can help to increase the efficiency of the processes and therefore minimize the search time and create transparency. Only scanners and printers will be investigated since those are part of the accompanied project. The scope can also be seen in Figure 5.

The data gathering from literature as well as Heine + Beisswenger, which would be secondary data, observations as well as unstructured interviews and experiments, focuses on material and information flow within those warehouse processes for long goods logistics. Additionally, literature review will focus specifically on how to increase the efficiency through digitalization using handheld scanners and mobile printers and on design propositions of digitalized processes.

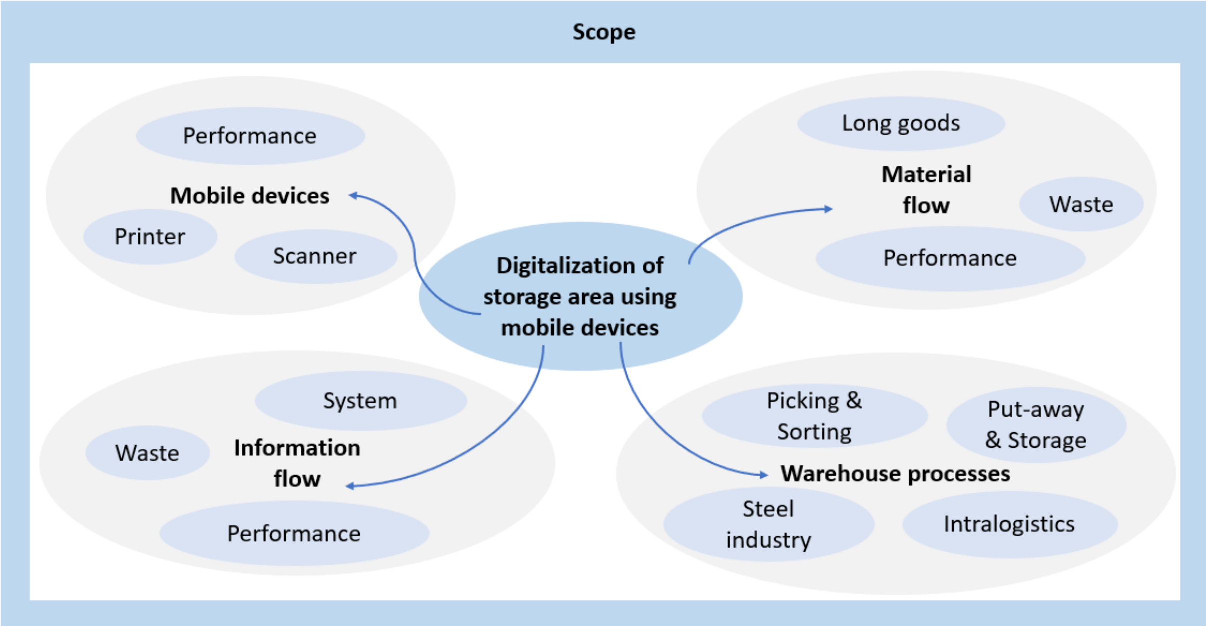


Figure 5: Scope of the thesis.

However, the research will also provide valuable knowledge for companies or researchers outside of the scope being interested in increasing efficiency of warehouse processes using mobile devices such as scanners and mobile printers.

1.6 Disposition

This subchapter presents the continued outline of the thesis.

Starting with the methodology chapter, the research strategy and the process which is used for the thesis is being discussed. Moreover, the chapter explains the strategy for the literature review as well as the gathering of the empirical data. Additionally, the data analysis and the research quality are being discussed. In the end, the conceptual framework is being created which describes the whole process for accomplishing the purpose of the thesis.

Next, the Frame of reference is all about building the fundamental for the thesis to deeply understand the content. Therefore, warehouse operations, material flow, information flow, warehouse digitalization as well as handheld scanners and mobile printers are being investigated.

Further, the Empirical findings are used to understand how the material flow processes as well as the performance of these processes are and how the information flow between those processes is. Moreover, this chapter investigates experiments on whether handheld scanners and mobile printers could increase warehouse efficiency.

With the gathered data from chapter four, this analysis identifies possible improvements of the storage processes. This will be made by analyzing the material

flow as well as the information flow of the current processes and by comparing these processes with the experiments that have been carried out.
Through the analysis, design propositions can be presented in the sixth chapter. Moreover, the new processes are being analyzed and the applicability is being discussed.
Lastly, the master thesis will be concluded. This is done in three parts. First, it is being discussed whether the purpose of the thesis together with the research objectives is fulfilled. After that the contribution of the thesis is discussed and lastly, the limitations and the future research for the case company as well as the research field are being discussed to round up the thesis.

2. METHODOLOGY

This chapter describes the methodology that has been used to achieve the purpose of the master thesis. As a first step the research design is being discussed. This is mainly describing the research strategy and why the method is used as well as identifying the research process. In the following the different data collection methods are presented. This part is divided into the two-parts literature review and the empirical data gathering. Lastly, it is presented how the data is being analyzed and the research quality is being discussed. Figure 6 describes the outline of this chapter.

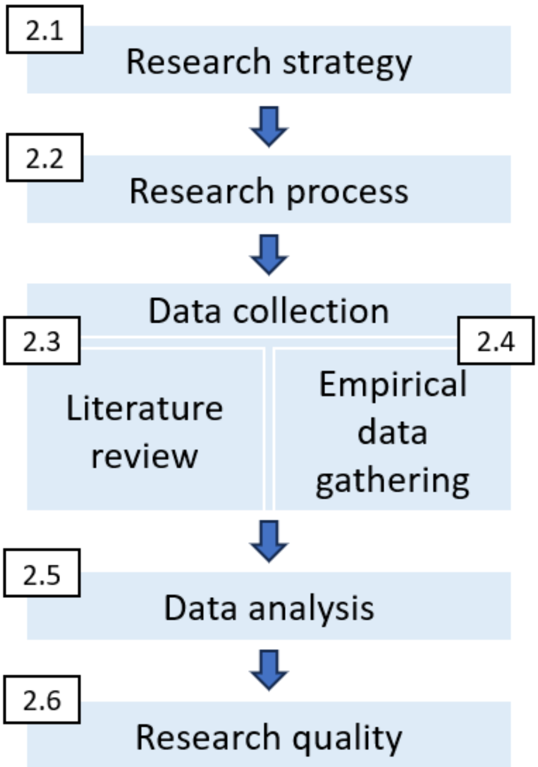


Figure 6: Methodology outline.

2.1 Research strategy

For approaching the defined purpose as well as the research questions of this master thesis, multiple research strategies would be possible. To decide which research strategy fits best to fulfill the purpose of this master thesis, the described matrix of Lukka (2003) is used. Since the research objectives require own observations as well as data gathering, the master thesis can be clearly described as empirical. Further, the thesis is placed in between descriptive and normative. This is because the first two research objectives are descriptive since they describe the current processes and identify the performance of them. However, research objective three seeks to discover which processes can be digitalized and therefore expresses an evaluation which is normative. Research objective four does also fit into normative since a designed system is being proposed. This, as said before, has led to a placement in between descriptive and normative which can be seen in Figure 7.

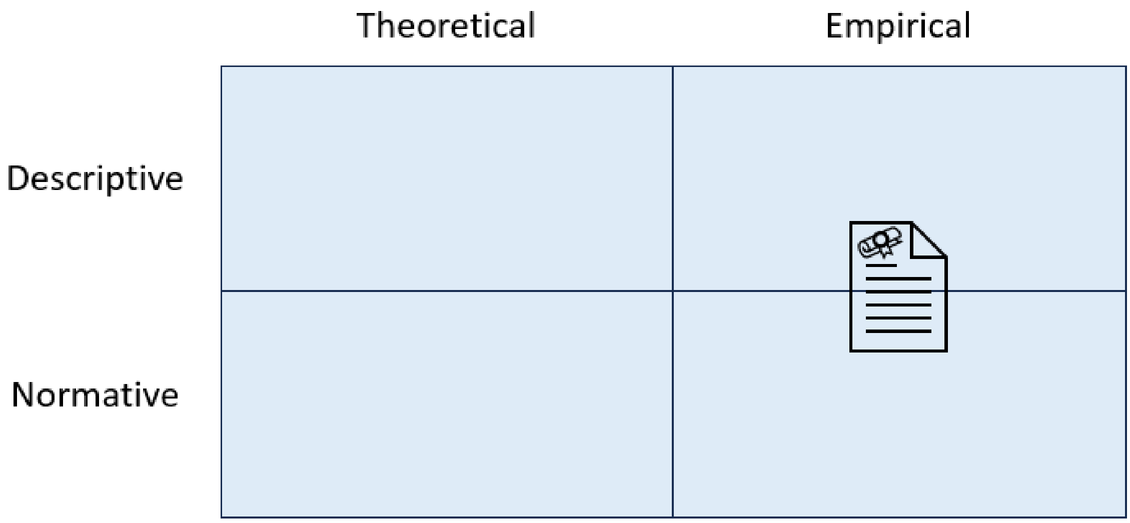


Figure 7: Placement of the purpose and the research objectives of the thesis (Source: Lukka, 2003).

The placement of the master thesis on the empirical side but in between descriptive and normative allows two suitable research strategies, which would be either case research or design research. To decide which one is better, the differences between them need to be discovered.

While case study is based on a current phenomenon, drawn from multiple sources of evidence, design science research through purposeful design and evaluation is a methodology for contributing to theory and practice (Olhager, 2023a). Case research should be used the more that the research questions seek to explain present circumstances or the more that the research questions require an extensive and "in-depth" description of some social phenomenon (Yin, 2009). Design science research on the other hand is driven by field problems or opportunities (van Aken, et al., 2016) and helps linking exploration with explanatory and theory-oriented research (Olhager, 2023a).

Since the purpose of the thesis was driven by a field problem and does not seek to explain present circumstances "in-depth", the research strategy of this thesis will be design science research. The approach of the thesis aims, as inspired by Simon (1996), at knowledge which can be used in a way to design and implement processes in order to achieve desired outcomes in practice. This would be, in the case of this master thesis, the purpose of minimizing the search time in the storage areas of the warehouse by investigating opportunities to increase efficiency of the warehouse processes using scanners as well as mobile printers.

2.2 Research process

To describe the research process properly, the following three steps will be walked through. In the first step, a design research process is developed. This will be done with relevant literature about the field of design science research. The applicability of the design research process will be described in the following. Lastly, the validity of the conceptual framework will be presented.

2.2.1 Development of design research process

Like van Aken et al. (2016), Olhager (2023a) & Simon (1996) have all described similarly, design science is connecting theory with practice. It aims to use the theoretical knowledge (science) in the best way possible to solve a real problem in practice (design). The research process therefore needs to illustrate exactly how this is done and what different parts play a major role in order to connect design and science. Romme & Dimov (2021) have illustrated a design science process for a problem X with its possible solutions in four points, as it can be seen in Figure 8. The created research process is highly inspired by this model because it illustrates the close relation between science and design very well.

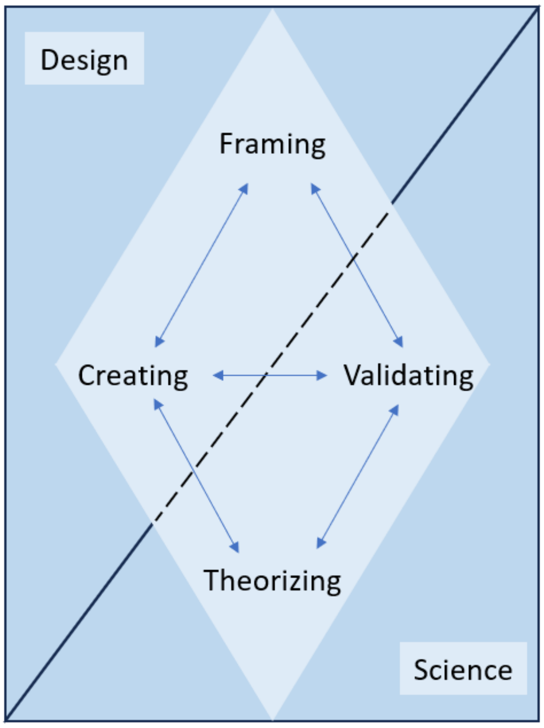


Figure 8: Design research process (Source: Romme & Dimov, 2021).

Framing the problem as well as the process of problem-solving is a key step in any design science project (Dorst, 2015). Therefore, it is the first step of the process and explores the discovering and understanding of the problem (Goffman, 1974). Creating is constructing the artifact which in design science vastly means solution. The development of practical artefacts and solutions which address real-world problems is the fundamental characteristic of the design science methodology, according to

Peffers et al. (2007). March & Smith (1995) have described four different types of artefacts in design science research, namely constructs, models, methods, and instantiations. They are described in Figure 9.

Artefacts	
Constructs	"Conceptualization used to describe problems and specify their solutions"
Models	"Sets of propositions expressing relationships among constructs"
Methods	" Sets of steps to perform a task"
Instantiations	" Realization of an artifact in its environment"

Figure 9: Four types of artefacts (Source: March & Smith, 1995).

The artefacts of the thesis will be designing propositions of how to digitalize the warehouse using handheld scanners and mobile printers in order to increase efficiency of the current warehouse processes.

Framing and creating often go together (Romme & Dimov, 2021). In the design research process, they represent the design part. However, they are closely linked to validating and theorizing which represent the science part of the framework. Validation can be seen as the evaluation of the created artifacts. Methods for validation generally serve to assess whether and why the design artifacts perform as expected (Bevan et al., 2007; Meulman et al., 2018). Lastly, the process where gained knowledge from the validation is used to create more generalized theory is called theorizing (Romme & Dimov, 2021). In short and own words, the problem formulation as well as the problem solving is the design part closely linked to the science part were the problem, the artifact and the theory are validated.

Since the design research process by Romme & Dimov (2021) does not provide clear steps the framework of Peffers et al. (2007) is also taken into consideration. They provide a process model with the following six steps, which also can be seen in Figure 10. The first step describes the motivation of the research. Secondly, objectives of the solution are defined. According to Geerts (2011) defining objectives for solutions means that the criteria that the proposed solution must meet to be considered as successful is specified. Next, the artefact is developed and designed. Fourthly, the artefacts are used to solve the problem. As a next step the efficiency and the effectiveness of the artefact is evaluated which is communicated in the last step.

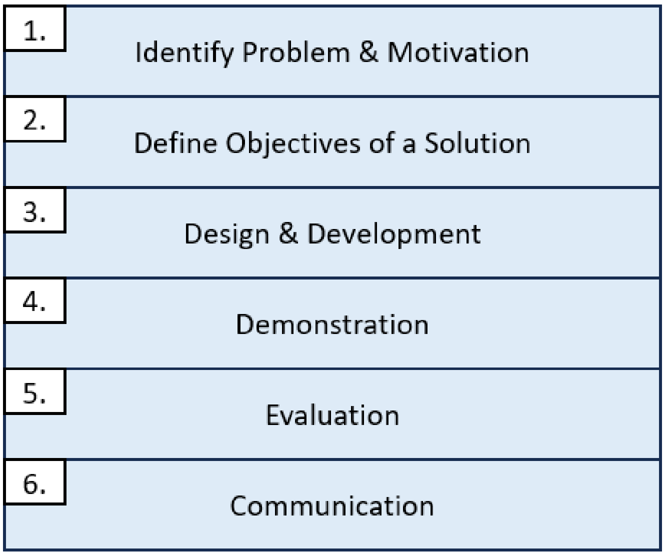


Figure 10: Design research process (Source: Peffers et al., 2007).

Comparing the two research processes it is evident that Romme & Dimov (2021) provide a ambiguous process while Peffers et al. (2007) has clear steps to follow. However, Romme & Dimov (2021) show the interactive processes in an understandable way. For those reasons the two models will be combined as it can be seen in Figure 11. This process will be used in the thesis and will be further described in chapter 2.2.2 (Application of design research process).

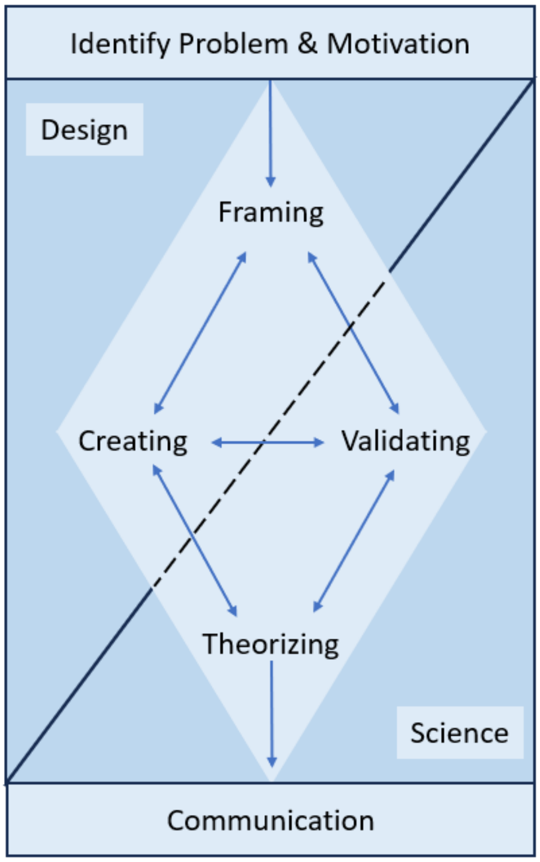


Figure 11: Final design research process (Source: Romme & Dimov, 2021 and Peffers et al., 2007).

2.2.2 Application of design research process

To fulfill the purpose of the thesis, a conceptual framework is used for guidance purposes when creating the design propositions. This consists of all processes needed to develop the digitalization in the warehouse which can be implemented in order to achieve an efficiency increase. In the following section the application of the design research process is described, which is also illustrated in the end of this section in Figure 13.

The first step is to identify the problem as well as the motivation for solving the problem. For this thesis the problem is practical and was found to be in the company Heine + Beisswenger where parts of the warehouse are not digitalization so far. Out of that reason the company lacks efficiency in those processes. This has led to the motivation to solve these problems in order to achieve an efficiency increase which will help the company in the long run. A detailed description of the problem already has been explained in chapter 1.3 (Problem formulation).

As a next step, the design phase as it has been described by Romme & Dimov (2021) as well as Peffers et al. (2007) starts. This phase consists of the two parts framing and creating. Framing specifies on gathering knowledge about the current state of the problem in the company through observations among others, but also on gathering information about the problem in general through a literature review. The importance of framing was found to understand the warehouse operations, the material and information flow as well as the performances of them. Through that the research objectives were fulfilled.

The information which is collected in the framing part is then used in the creating part, which is the next step of the design research process. In this part the conceptual framework was developed to evaluate how to digitalize the warehouse to achieve an efficiency increase and therefore solve the problem. The created conceptual framework was developed to use as guidance when collecting needed information. To create the conceptual framework in the best way possible the research objectives have been used to develop a framework which is leading to positive outcomes in the end. In order to create design propositions in design science research, the CIMO approach by Denyer et al. (2008) was used. CIMO, as Denyer et al. (2008) has stated, stands for Context (C), Intervention (I), Mechanisms (M) and Outcomes (O). The logic of the prescription is that "If you want to achieve outcome O in context C, use intervention I" (Bunge, 1967; Denyer et al., 2008). This approach was also described by Olhager (2023a), as it can be seen in Figure 12. As explained by Denyer et al. (2008) and Olhager (2023a), the context describes where, when and for whom there is a problem and therefore is the cause. Next, through management intervention, a solution is proposed as well as tasks will be delegated to answer what needs to be done, by whom and how. The mechanisms describe how the solution produces outcomes in the context and lastly, the outcomes define all results, intended as well as unintended. Further in the thesis, the CIMO approach is used to formulate and create multiple design propositions of how to increase the efficiency of the warehouse processes, by answering the questions about where, when and for whom there is a problem as well as describing the outcome of the design propositions.

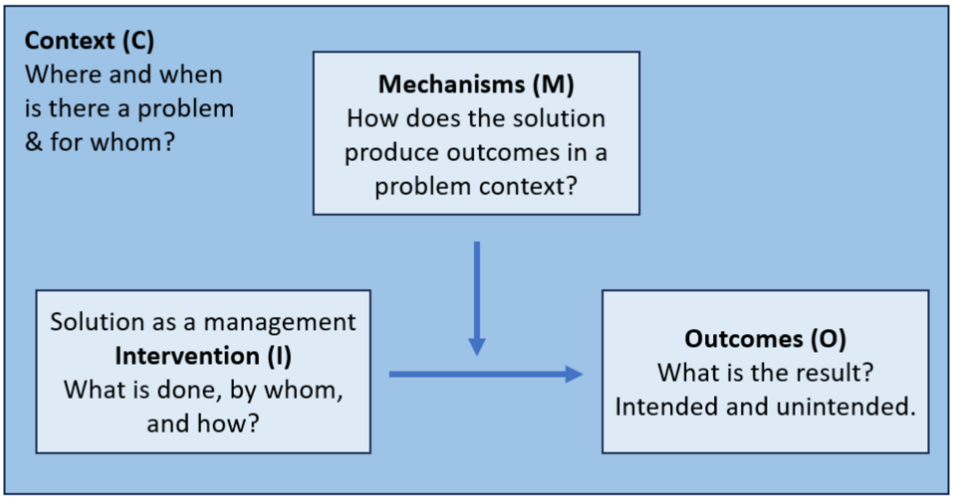


Figure 12: The CIMO approach (Source: Olhager, 2023a and Denyer et al., 2008).

This concludes the design phase and leads to the science phase of the research process. The science phase does also consist of two parts, the validation and theorizing. In the validation part, the conceptual framework is validated, and the performance of the design propositions is evaluated. Validation is done in two steps. Applying the conceptual framework in the warehouse of Heine + Beisswenger as well as testing the performance of the applied framework.

Next, the theorizing phase starts, where the gained knowledge from the previous validation is used to create more generalized theory. Generally, since there are links in between the design and the science phase, whenever there was the need to adjust the framework, it was updated to create design propositions in the best way possible.

Finally, the last step of the design research process is the communication. Here the gained knowledge is communicated and shared with the case company as well as the research field. This leads to sustainable knowledge about the research in the case company but also for the research field where it can be used by others to use or further improve the findings.

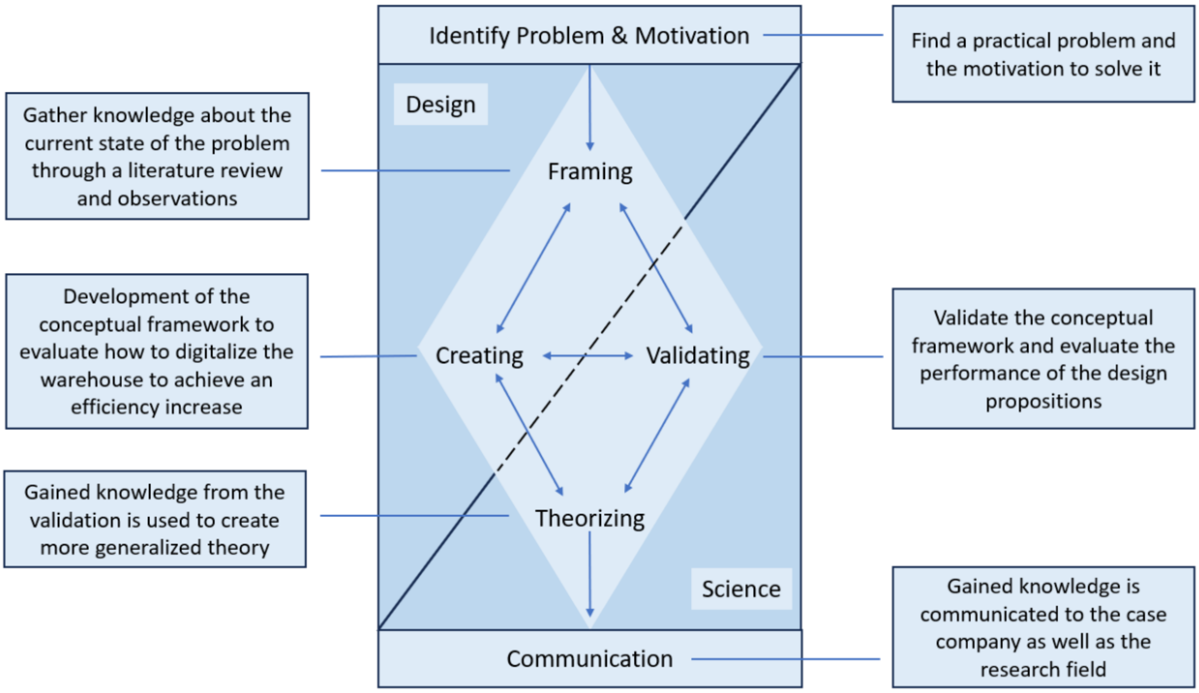


Figure 13: Research process of the thesis (Source: Romme & Dimov, 2021 and Peffers et al., 2007).

2.2.3 Research approach

The research approach of this master thesis, as it can be seen in Figure 14, was created with the intention to use it as a structured guideline to fulfill the purpose of the thesis. It serves as a guideline for answering the research objectives, recording the empirical data as well as analyzing the data and therefore is a predecessor of the conceptual framework. By following the research approach, the end goal of the master thesis, which is to propose a digitalized process in order to increase the efficiency, will be developed structurally.

The first part of the research approach starts with the first research objective. Here the goal is to get an overview of the current warehouse processes. This is done by mapping the warehouse layout to understand the spatial circumstances. Moreover, the warehouse processes are recorded to know the material flow as well as the information flow of the warehouse. The upper part of the research approach, marked in Figure 14 as the empirical part, plays a major role in building a foundation in order to be able to answer the following research objectives.

Once the data is collected and the current processes of the warehouse are mapped and therefore understood, the empirical part of the research approach is done, and the analytical part can start. The second research objective, which is to identify the current performance of the warehouse processes, is the starting point of the analytical part. With the help of the collected data of the empirical part and the data of the first research objective, the performance can be mapped. Mainly the performances of picking, storing, and the allocation of the material as well as the information flow is tracked in this step. This is done to be able to progress to the third research objective, which is to analyze the current warehouse processes. During this step the previously collected performance data about the material and the information flow is analyzed. Through analyzing the data, it is possible to identify process waste, which is the major goal of the third research objective. The identification of waste makes it possible to understand where there is a need for improvement as well as the impact such improvements could make. To further progress and to fulfill the purpose of the master thesis, the warehouse processes are linked with digitalization. Simultaneously the warehouse processes are analyzed to identify the optimal processes connected to digitalized solutions. By putting everything together the fourth and last research objective can be tackled. This is to create a digitalized solution which will improve the efficiency of the warehouse processes using mobile devices. For the last research objective all previous collected data and knowledge is used.

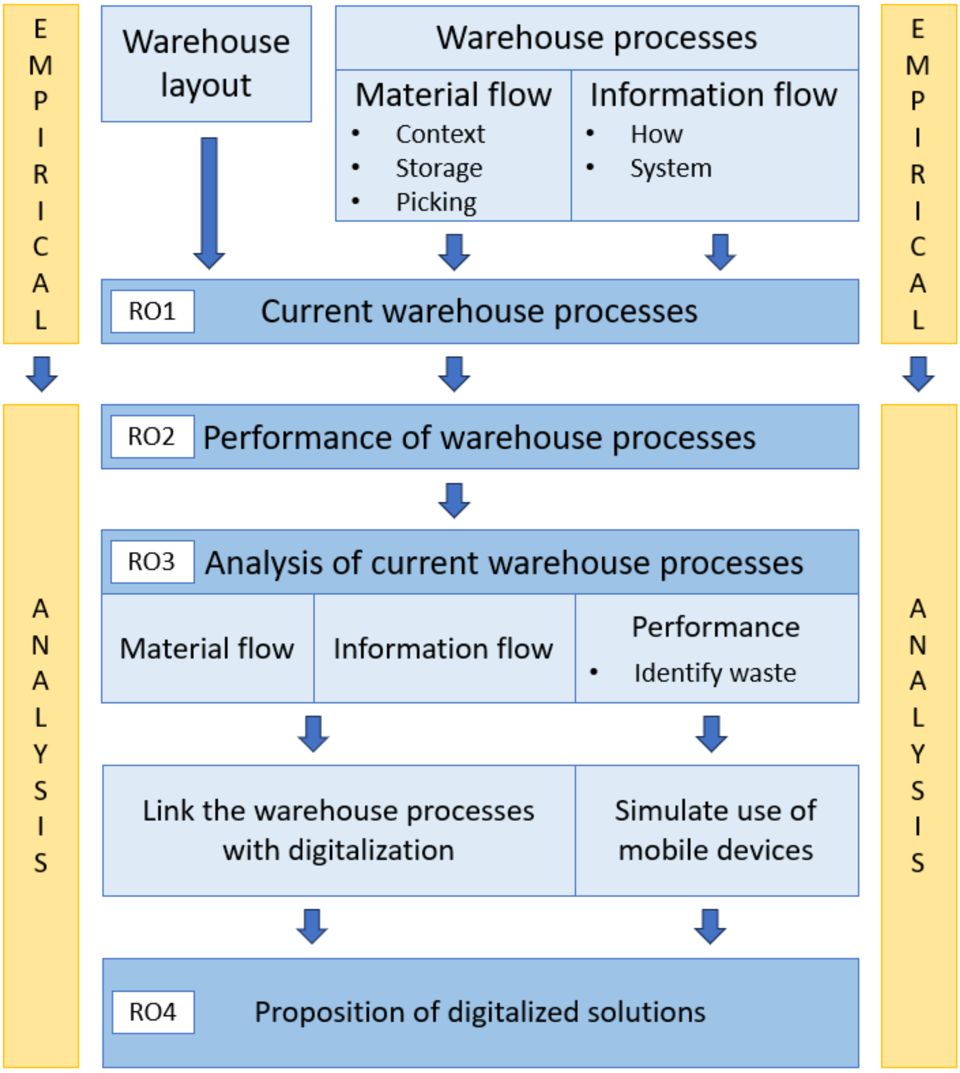


Figure 14: Research approach.

2.3 Literature review

A literature review, as stated by Fink (2020) and Xiao & Watson (2017), is a systematic method to identify, evaluate, and synthesize existing work produced by researchers, scholars, and practitioners. The purpose when conducting a literature review is to gain and summarize a deeper understanding of the subject (Rowley & Slack, 2004). This can be achieved by focusing on high-quality original research which will provide accurate results (Fink, 2020). The conducted literature will be used as a foundation when creating the conceptual framework, which is suggested by Hevner et al. (2004).

The conducted literature review consists of academic journals, articles as well as books. The data bases which primarily have been used were *Google Scholar*, the database *LubSearch* which is Lund University´s library, and *ScienceDirect*. During the literature review key terms such as *warehouse digitalization*, *storage area*, *material flow* or *information flow* were among others searched in the databases mentioned above together with the term *literature review*. It was preferred to pick the most cited articles and books as well as newer once. Through the literature review the theoretical foundation of the thesis was created, always connected to the scope of the thesis. This can be seen in Figure 15.

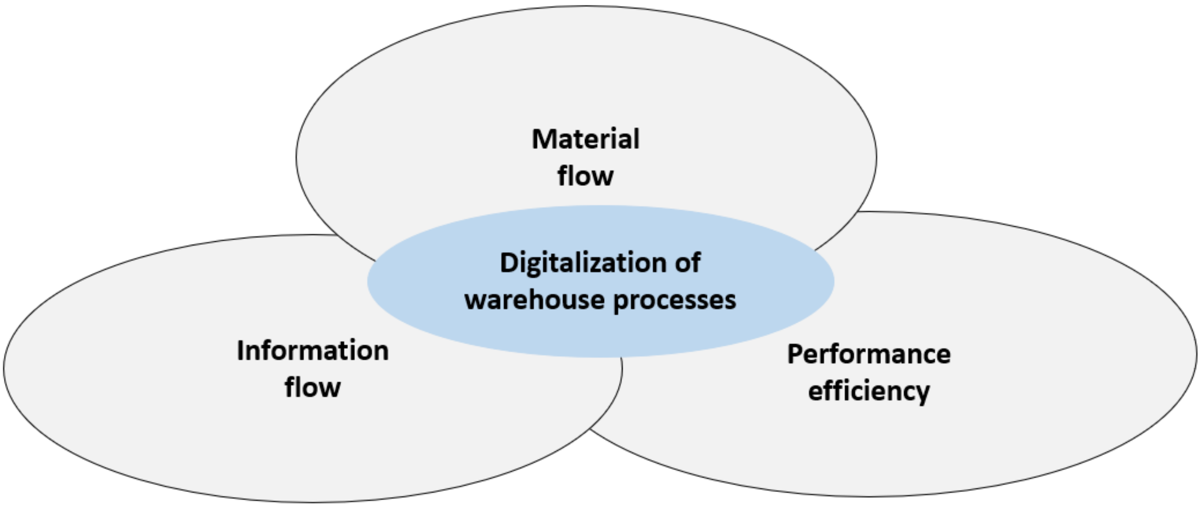


Figure 15: Literature review overview.

2.4 Empirical data gathering

There are many ways to gather data for writing a research paper. In operational management it is common to do interviews, observations, surveys, and content analysis of documents to gather information (Voss et al., 2002; Olhager, 2023b). Since the purpose of the master thesis is to increase the efficiency through digitalization in the warehouse, data about the processes needs to be conducted. This could be done in several ways. However, in order to fulfill the purpose in an efficient way, observations combined with unstructured interviews and experiments of the warehouse processes will play a major role in collecting data. To be able to conduct data through observations and unstructured interviews, there is a need of constant access to the warehouse of Heine + Beisswenger. This is ensured and therefore can be realized. Moreover, secondary data will be used due to time limitations of the thesis. The above-mentioned possibilities to gather empirical data, will be explained in the following subchapters.

2.4.1 Observations, Unstructured Interviews & Experiments

This study relies mainly on three different data collection methods, namely observations, unstructured interviews as well as experiments. The reason for choosing those three data collection methods will be further explained in this section.

An observation is a technique to collect information regarding areas that involve behavior and occurrences in natural situations (Olhager, 2023b; Rosenbaum, 2002). Denscombe (2010) describes that there are two different types of observation methods. Namely structured observations and participant observations. While a structured observation is when one observes the situation from the sideline, are participant observations when one observes by actively participating. The advantages of both methods are that they allow a direct data collection, and one does not rely on what people say they do but on what they are doing. Moreover, the collection of substantial amounts of data can be done in a relatively short time span, which makes observations time efficient. For the thesis both methods, the structured as well as the participant observation, will be used. The reason for using both methods, is that some observations can only be done in a structured way because direct participation is not possible out of safety reasons. Whenever it is possible to directly participate, the participant observation will be done. The overall purpose of the observations is to gain relevant data of the processes in the warehouse to be able to provide design propositions to Heine + Beisswenger on how to digitalize the warehouse to increase efficiency.

The structured observations will be combined with unstructured interviews. The method of combining those two methods is inspired by Engelhardt et al. (2017) who has done data collection through observations combined with semi-structured interviews. As described by George (2023) and Doody & Noonan (2013), there are different types of interviews. The most common ones are structured, semi-structured, unstructured and focus group interviews. Focus group interviews differ from the other interview methods since the questions are presented to a group instead of one individual. Structured interviews are interviews where the questions are predetermined in their topic as well as their order. If the interviewer has only predetermined some questions but other questions aren´t planned, the interviewer is conducting a semi-structured interview. Whereas unstructured interviews are a data collection method where none of the questions are predetermined. Since unstructured interviews are known for being very informal and flexible, they can be a particularly useful exploratory research tool.

For the thesis, as previously mentioned, unstructured interviews will be combined with observations. Since observations are the main data collection method but they only provide data of what can be observed (Denscombe, 2010), another method needs to be picked which makes it possible to gather more information around the observations and therefore can support the observations in the best way. Unstructured interviews are the most flexible compared to other forms of interviews (George, 2023; Doody & Noonan, 2013), and therefore they work best for fulfilling the purpose of recording the processes. Whenever questions arise during the observations unstructured questions can be asked to support the observation in the depth of the understanding of the recorded processes. Therefore, the combination of observations as well as unstructured interviews was chosen.

The data collection is complete by experiments. Bevans (2023) describes experiments as where you manipulate one or more independent variables and in the following measure their effect on one or more dependent variables. This is controlled by the experimenter who ensures that subjects receive different treatments to be comparable, as Rosenbaum (2002) describes. The reason for choosing experiments was that to be able to provide design propositions which increases the efficiency of the current warehouse processes, better use of the processes needs to be simulated which furthermore can be compared to the current processes. As Eekels & Roozenburg (1991) have stated that simulations are often supported by experiments, data about the use of handheld scanners and mobile printers was gathered through experiments. This has been done simultaneously during the observations and unstructured interviews where the processes and their times were recorded. Through carrying out those experiments, the times on how long processes would need when using handheld scanners as well as mobile printers can be measured and therefore waste can be identified. The data gathering through those experiments is a crucial part of the thesis, since the experiments will deliver important data that will influence the purpose of the thesis. Therefore, it is necessary to carry out the experiments carefully so as not to gain any distorted impressions. The exact execution of the experiments is described in detail later in the thesis in chapter four.

All those steps of gathering information were necessary to fulfill the purpose of the thesis successfully. Table 1 keeps track of all observations that have been done in combination with unstructured interviews and the experiments as well as the purpose of them.

Table 1: Summary of all conducted observations/unstructured interviews and experiments as well as their purpose.

Purpose	Date	Attendees	Data collection method
Tour of the warehouse	*30.01.24*	*Warehouse manager*	*Observation* *Unstructured interview*

Mapping of the relevant space in the warehouse	*13. /14. /15.2.24*	*Warehouse manager*	*Observation*
Recording of the process material storage	*25.3 – 29.3.24* *08.4 – 12.04.24*	*Warehouse employee*	*Observation* *Unstructured interview* *Experiments*
Recording of the process material picking	*25.3 – 29.3.24* *08.4 – 12.04.24*	*Warehouse employee*	*Observation* *Unstructured interview* *Experiments*
Recording of the process material allocation	*25.3 – 29.3.24* *08.4 – 12.04.24*	*Warehouse employee*	*Observation* *Unstructured interview* *Experiments*
Recording of the information flow process	*25.3 – 29.3.24* *08.4 – 12.04.24*	*Warehouse employee*	*Observation* *Unstructured interview* *Experiments*

To successfully fulfill the purpose of the thesis, data was gathered with the help of the previously described data collection methods. Table 1 provides information about each collection of data with their purpose, the date, the attendee as well as the data collection method that have been used for the respective data collection.

To gather a first impression of the warehouse a tour of the warehouse together with the warehouse manager has been carried out. This was done in the beginning of the project and helped a lot to understand the context of the project with all its difficulties. Throughout the tour I have observed the processes as well as asked questions about them to get a good overview of the project.

In order to get a detailed overview of the warehouse, the warehouse has been mapped. This was carried out independently but with the supervision of the warehouse manager. The mapping was done on paper first and was then converted into a 2D model. Both, the tour as well as the mapping of the warehouse have been used as a groundwork to ensure that the work that needs to be done can be realized in the best way possible.

Furthermore, to collect all necessary data to answer the research objectives, data about the material storage, picking, allocation as well as about the information flow needed to be recorded. For that, a combination of the data collection methods observation, unstructured interviews, and experiments was used. This was done to fully understand the current processes of the warehouse and to be able to describe them as well as measure the performance of the current processes, which was needed in order to answer the research objectives one and two. To be able to answer the research objectives three and four, subsequently experiments have been carried out to identify possible waste and thus improvements in efficiency for the recorded processes. The recording of the process's material storage, picking, allocation as well as the information flow was done together with the warehouse employees who handle the processes on a daily basis. By that, I have followed them during their different working steps, made notes about them to map the processes, I have asked questions about unclear parts to better understand to processes, I have measured the performance of those processes as well as used exemplary handheld scanners and mobile printers to carry out experiments about the time it would take to run through those processes in the possible future by using those mobile devices. This has led to a significant amount of data that further was analyzed to propose propositions to increase warehouse efficiency. The explicit description of those processes as well as the data that has been gathered can be seen further in chapter 4 of the thesis.

2.4.2 Secondary data

Data, as described by Saunders et al. (2007), which has been previously collected for other purposes but is now used for a different reason can be named as secondary data. One common type of secondary data, which was used during the thesis, is internal company data. During the data gathering process of the thesis, secondary data has only played a minor role. However, as the thesis is carried out with time limitations, secondary data was used to save time which made it possible to fulfill the purpose of the thesis in time. In the following three sections the secondary data that has been used is described.

<u>Ground plan</u>

The first secondary data that was provided by the case company and used during the thesis was the ground plan of the warehouse. This was used to gather the exact measurements of the facility during the 2D mapping of the warehouse layout. By using the data of the ground plan, a layout has been created that supports the thesis by providing a good overview of the current state of the warehouse that will help the reader to understand the processes more easily. During the process of creating the layout for the thesis, time was saved by using the ground plan, since measuring the facility in detail would have costed valuable time. In the following, the layout moreover was used to be able to use further tools such as the spaghetti diagram, where the walking path during the picking process could be identified and illustrated.

<u>ViFlow</u>

ViFlow is the internal website of the case company that provides multiple descriptions of the processes that are done to run the daily business. Among that, the processes that are used during the thesis are described. The data that has been gathered throughout using the ViFlow supported the observations that have been carried out in connection with the unstructured interviews to describe the processes of the material flow as well as the information flow. This helped to understand the processes even more clearly and supported the illustrations of the processes in form of flowcharts. Moreover, the usage of the data of the ViFlow saved time since it was possible to recheck processes around the scope where no observations have been done for.

Key figures
To be able to calculate the financial impact of the design propositions, key business figures as well as logistical key figures needed to be shared by the case company. This allowed illustrating the impact the design propositions would have on the warehouse processes.

2.5 Data analysis

As data analysis influences the quality and strengthen the validity of an empirical study, data must be analyzed properly and is therefore an important step in the research process (Ngulube, 2023; Abulela & Harwell, 2020). Therefore, a data analysis framework has been developed, as it can be seen in Figure 16.

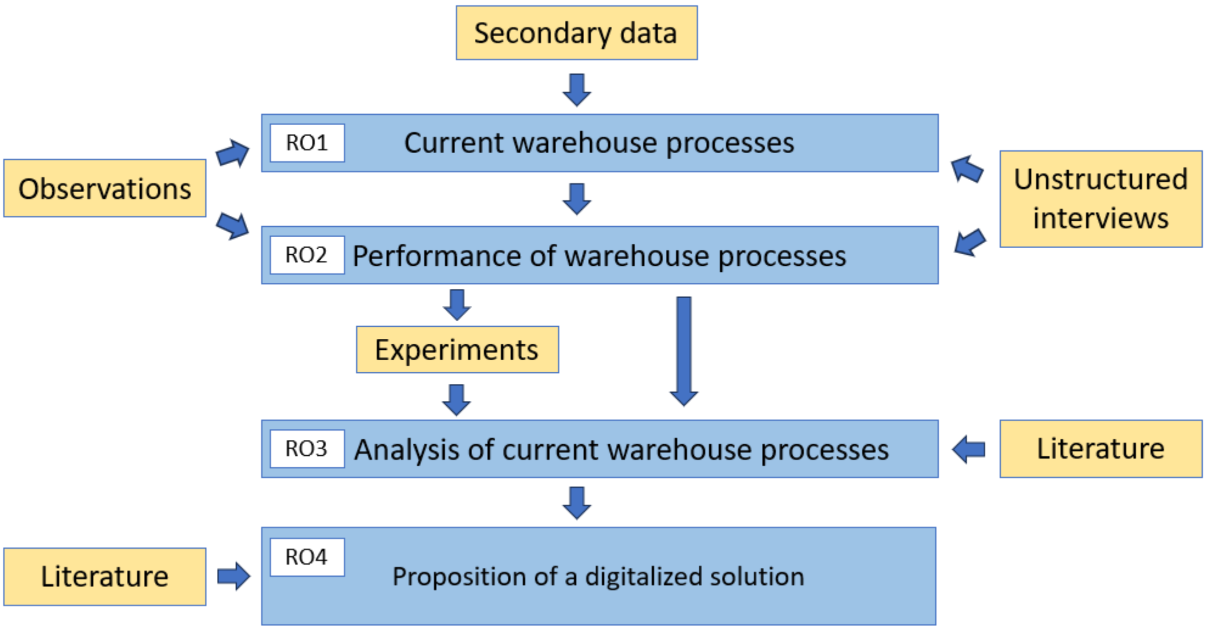


Figure 16: Data analysis framework.

This framework was created to describe how the gathered data has been used to successfully achieve the purpose of the thesis as well as to illustrate during what parts of the research objectives the data gathering methods were used. Those objectives form the guideline to be able to provide design propositions in the end of the thesis. In order to answer those research questions data needs to be collected. The basic pillars of the data analysis of the thesis are the five different types of data, namely observations, unstructured interviews, secondary data, experiments as well as literature.

To be able to describe the current process of the material flow as well as the information flow data is going to be collected through observations, unstructured interviews as well as secondary data. The first research objective provides the foundation for the following objectives and provides the foundation of the whole thesis. Since the purpose of the thesis is to investigate opportunities for increasing efficiency in the warehouse processes, the current performance of those processes needs to be measured. The reason for that is, that there needs to be data of the as-is situation of the processes which are going to be investigated in order for being able to analyze efficiency increases. This data is collected through observations as well as unstructured interviews. Those observations and unstructured interviews are gathered with different warehouse employees. This is done out of the same reason that observations or experiments are done multiple times, to get an average time of the processes. Therefore, multiple warehouse employees are accompanied throughout the data gathering process in order to ensure the most realistic data collection as well as being able to analyze the data in the best way possible. To be able to move from the second research objective to the third research objective, which is the analysis of the current warehouse processes and therefore investigates the parts of the material flow and the information flow which can be improved through digitalization, experiments are going to be executed. Those play a major role in the analysis of the thesis, since they provide the data for possible improvements. In order to be able to analyze the data properly, it is necessary to gather multiple observations as well as experiments to accommodate all possible scenarios. Together with the data that has been collected during the second research objective, the gathered data of the experiments is going to be analyzed for the description of the third research objective. Furthermore, data that is used for the analysis of the current warehouse processes is gathered through literature review.

After collecting the necessary data, the analysis can be performed. There are different ways to analyze data in the research process. Creswell & Clarke (2007) and Denscombe (2010) describe five main stages of data analysis, which can be seen in Figure 17. The data analysis of the thesis was influenced by the process and will therefore be connected to the framework of Creswell & Clarke (2007) and Denscombe (2010).

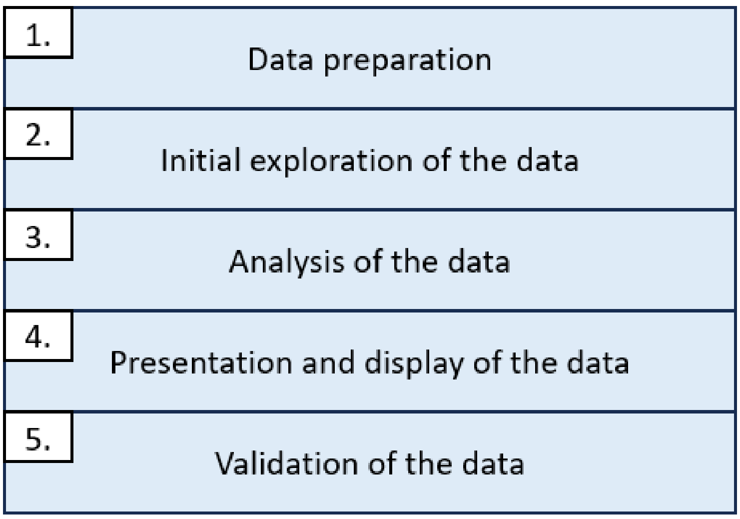


Figure 17: The five main stages of data analysis (Source: Creswell & Clarke, 2007 and Denscombe, 2010).

The first stage of data analysis provided by Creswell & Clarke (2007) and Denscombe (2010) describes the preparation of data. Moreover, at this stage cataloging of interviews or in the case of this master thesis observations and transcribing of visual data will be done. In the second stage one is looking for obvious recurrent themes or issues and notes to the data can be added.

Looking at the research objectives of the thesis as well as the data that is collected for answering those objectives, those two steps describe the first two research objectives where data was collected to describe the current warehouse processes as well as the performance of those processes.

Thirdly, the data is analyzed by comparing the categories and themes. Moreover, one will look for concepts or more abstract categories that encapsulate the categories. In the fourth step the data will be presented and displayed using visual models, figures, and tables. The points can be illustrated by quotes and pictures. In the last step, the data is validated by the members, comparison with alternative explanations, and triangulation of the data and methods.

The analysis of the thesis was influenced by this process. To support the analysis a framework was created that illustrates the process that was run through, as it can be seen in Figure 18.

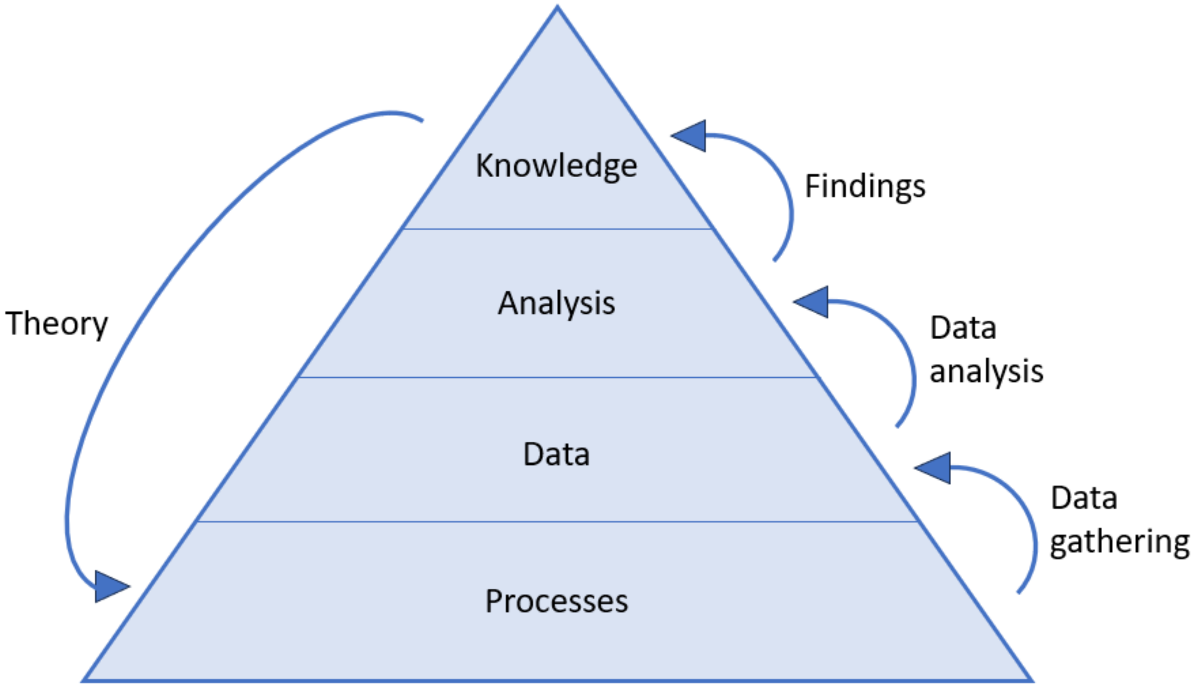


Figure 18: Overview of the analysis flow.

This was done to provide transparency about the analysis process.

The foundation of the analysis was each respective process that was about to be analyzed. Data about the processes have been gathered during observations and unstructured interviews. Additionally, experiments have been carried out, to gather data for potential improvements. Next, the collected data has been analyzed through comparing as well as analyzing the current times with the times of the experiments which simulated the use of mobile devices such as scanners and mobile printers during the current processes. As the data that has been collected by observations as well as unstructured interviews provided information about the current process and the data of the experiments provided information about how the processes would perform when introducing handheld scanners as well as mobile printers, the comparison of those two different sets of data allowed to identify waste. During the analysis different tools such as the spaghetti diagram, process mapping, flowcharts, and performance measurements have been used to illustrate the analysis or the data preparation for the analysis more easily. And lastly, the findings of the analysis are formulated, which could identify potential waste and therefore could provide potential efficiency increases. Those formulated findings aim to provide theory that can be added to the analyzed processes. Furthermore, this will allow being able to propose design propositions for the current process that could increase efficiency, which answers the fourth research objective.

2.6 Research quality

Research has shown that there is a lack of consensus in design research projects on how to evaluate and discuss their quality (Prochner & Godin, 2022). Since the research quality overall is of great importance (Bryman & Bell, 2017) Prochner & Godin (2022) have provided a framework for discussing and positioning design research projects in terms of their quality. The framework illustrated in Table 2 shows research quality indicators and their respective categories inspired by Prochner & Godin (2022) that does overlap and therefore is supported by previous research that has been done on research quality such as by Guba & Lincoln (1989), Gibbert, Ruigrok & Wicki (2008) as well as Yin (2009). This research has been further used to provide research quality throughout the thesis and will be described in the following.

Table 2: Framework of research quality indicators and their categories (Source: Prochner & Godin, 2022).

Categories	Indicators
Traceability	- **Recoverability and transparency**
Interconnectivity	- **Internal validity** - **Credibility**
Applicability	- **External validity** - **Transferability**
Impartiality	- **Objectivity** - **Confirmability** - **Contextualization in theory and research**
Reasonableness	- **Reliability**

The first category of the framework by Prochner & Godin (2022) is traceability which helps the reader to understand what has been done throughout the research. To ensure the first category of the research quality, the thesis focused on providing transparency throughout the project. This has been done by having detailed descriptions of the different steps from start to end, to ensure the understanding of the reader. As Johnson et al. (2020) mentioned, it is important to have a clear purpose, which has been used to explain to the reader why the research was done. Moreover, through having a clear methodology the reader has full transparency about how the research has been done. Additionally, the focus was on describing the key parts of the thesis which was gathering data through observations, unstructured interviews, and experiments as well as the analysis and the conclusions of it explicitly. Frameworks, such as the conceptual framework were created to have further transparency about the approach of the thesis.

The category of interconnectivity groups the indicators internal validity as well as credibility. To ensure internal validity throughout the thesis research frameworks have been developed from extant literature, as Gibbert et al. (2008) and Yin (2009) described. Another principle that was used to ensure internal validity was to use figurers as well as tables to summarize the findings and conclusions within the thesis. Moreover, when evaluating the research impact on either existing knowledge or by solving a problem some measure of credibility about what has been investigated must be guaranteed, as mentioned by Erlandson et al., (1993) and Halldórsson & Aastrup (2003). This has been ensured throughout the research as the data that has been gathered was recorded multiple times in order to avoid or uncover exceptions and therefore gather realistic data, but the data was also presented to the manager of logistics to verify and thus ensure credibility of the data collection.

The category of applicability groups the indicators external validity and transferability which evaluate the extent to which the research outcome can be applied outside of the original research context, as described by Gibbert et al. (2008), Yin (2009) and Guba & Lincoln (1989). As Prochner & Godin (2022) stated that impact is centrally important in design research projects, it was important to ensure that the collected research data and therefore the conclusions drawn from the data cannot only be used for research or companies within the steel industry but also be used in other contexts or serve as information or inspiration to further research on increasing warehouse efficiency using mobile devices. This has been done by describing the problem at the case company in detail to make it easy to compare the situation to other companies as well as by describing the development to the design propositions clearly in order to ensure knowledge transferability to other studies or companies.

Moreover, the category of impartiality groups indicators related to the researcher´s bias, as stated by Prochner & Godin (2022) and Guba & Lincoln (1989). Even though Prochner & Godin (2022) have found that mostly concerns about objectivity of design research projects are low, it was important to establish impartiality. This was done by conducting a wide and detailed literature research, thoroughly describing why research choices have been made as well as why the findings make sense and by demonstrating through transparent descriptions of all decisions as well as data collections biasness cannot be identified of the reader.

The last category of the framework by Prochner & Godin (2022) is reasonableness which addresses that recreation of the measurement techniques produce the same results, as also stated by Gibbert et al. (2008) and Guba & Lincoln (1989). This is ensured by thoroughly explaining and describing the research process, which was supported by frameworks that have been created. Moreover, particularly describing about how data has been collected, with whom and where, enables recreation. This was also supported by creating documentation sheets and using them throughout the observation for every single observation which provides a structured way to facilitate traceability.

3. FRAME OF REFERENCE

The goal of this chapter is to provide a theoretical background of the thesis. In individual cases this will be beyond the literature review and will provide information of the warehouse of Heine + Beisswenger. However, this information is properly supported by literature review. As a first step of this chapter the warehouse processes will be explained. This is done by giving theoretical background about the material flow as well as the information flow. Since the purpose of the thesis is to minimize the search time in the storage area of the warehouse through digitalizing warehouse processes, warehouse digitalization will be explained in the second step of this chapter. Next, to be able to rate the warehouse processes the performance needs to be identified. Therefore, the third section of this chapter will talk about performance efficiency. As a last step, the conceptual framework will be explained. This framework is used as a guideline throughout the thesis from start to finish. The outline of the chapter can be seen below in Figure 19.

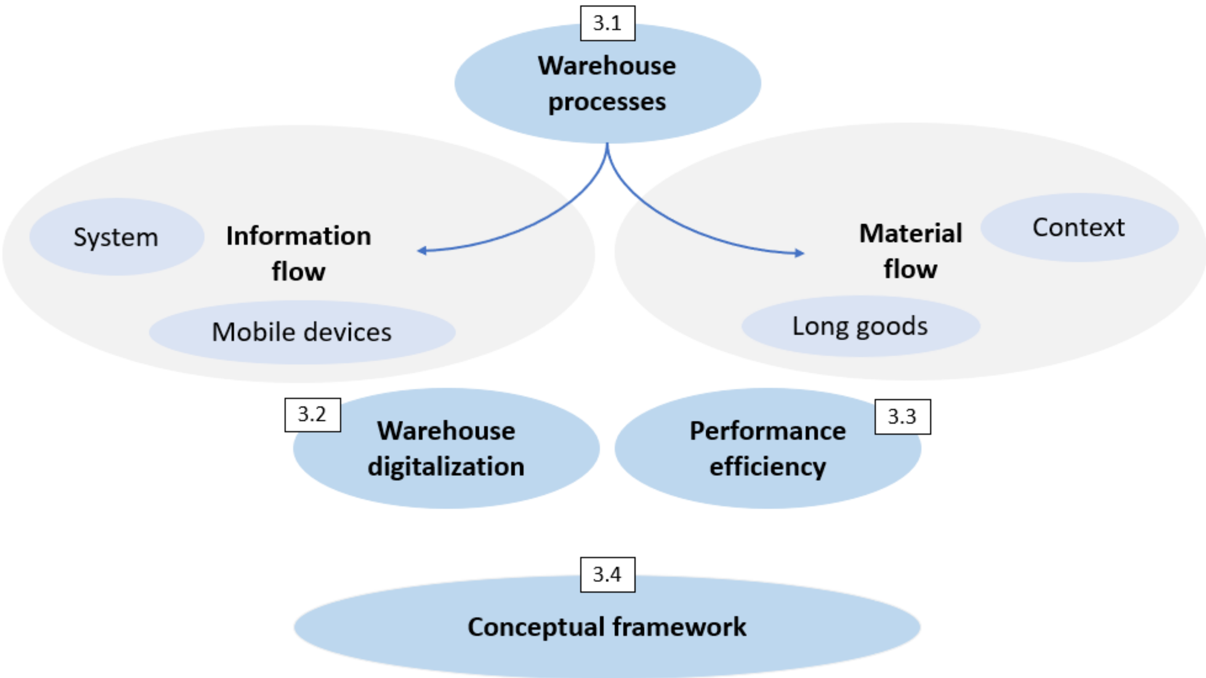


Figure 19: Outline of the Frame of Reference.

3.1 Warehouse processes

A warehouse is the place in the supply chain where the product briefly pauses, for example, to match supply and demand or to consolidate a range of products (Bartholdi & Hackman, 2016; Faber et al., 2013). Warehouse processes can differ from warehouse to warehouse according to the material, which is handled, and the state of the warehouse, but the operations mostly follow similar structures, as stated by Kembro et al. (2018) and can be seen in the figure below. The processes start by receiving the material and is followed by put-away/storage, picking and sorting as well as packing and shipping. Lastly, warehouse operations also include returns. However, as it can be seen in Figure 20, the processes of packing and shipping as well as the returns are not part of the scope of the thesis and are therefore disregarded in the following.

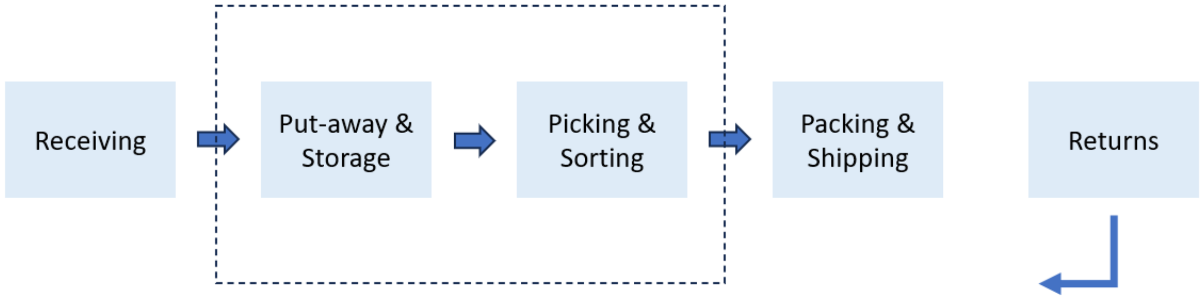


Figure 20: Warehouse operations (Source: Kembro et al., 2018).

3.1.1 Material flow

Meyers & Stewart (2002) have defined material flow as a structured and organized movement of material from point X to point Y taking the efficient use of space as well as cost savings such as energy and human resources into account. Since it is considered that the flow is the most important parameter of a production system (Meyers & Steward, 2002), the optimizations of it will directly impact the costs of an organization (Alvarado-Iniesta et al., 2013). Therefore, to achieve efficient processes, as Alvarado-Iniesta et al. (2013) has stated, it is necessary to have mechanisms to coordinate the development of production activities. The planning of the material flow of a company organizes and optimizes the flow of materials in order to optimize operations, which in the end results in minimized flow costs and therefore minimized overall costs. However, the material flow is a complex process and cannot be optimized without planning. It is likely that the optimization of the material flow occurs in different areas of the organization, which makes it more difficult to implement. For example, optimizing material flow of material coming from the warehouse to various production lines, will also include the information flow and therefore other parts of the organization. Since both, material as well as information flow, often come together, the information flow is also explained further in chapter 3.1.2. But first, to understand the material flow better, the following sub-headings describe the context of the material in general and is supported by the actual material that is handled by Heine + Beisswenger. Moreover, the material storage processes such as receiving, put-away and storing, as well as the storage areas are described. Lastly, the material picking, and allocation are explained.

Material & warehouse context

To understand the context of the material and therefore parts of the logistical processes which are described in this master thesis, this sub-heading provides all relevant information about the material of Heine + Beisswenger. Moreover, it explains warehouse layouts in general, in order to provide basic knowledge which will help to understand further parts of the thesis when it comes to the warehouse layout of Heine + Beisswenger.

<u>Material context</u>

In the forwarding industry, all consignments with an edge length of more than 2.4m are referred to as long goods (Bito, 2021). Because of the length of over 2.4m, Stepanyuk et al. (2021) stated, that the transportation as well as the picking of long goods poses a considerable challenge. This can also be confirmed by observations which have been done to understand the material flow, as it can be seen in the fourth chapter. Overall, as it is also described on the website of Heine + Beisswenger (2024b), the material which is mostly handled in the warehouses of Heine + Beisswenger is steel. Additionally, material such as aluminum, brass, and copper are also part of the material segment. Those materials are handled in bars and measure a minimum length of three meters to a maximum of six meters with diameters of a view millimeters up to a few centimeters. Based on the length as well as the diameter of the steel bars one bunch can weight up to multiple tons. The different shapes of the material, which is individually chosen by the customers, can be seen in Figure 21 - Figure 24. Those pictures show a variety of different material, such as edged or round material, thin and thick material as well as hollowed material. Depending on the customer and the weight of the bars, the material is tied together in a bundle or is handled as a single bar.

Figure 21: Six-meter-long steel bar bundles.

Figure 22: Round single steel bars.

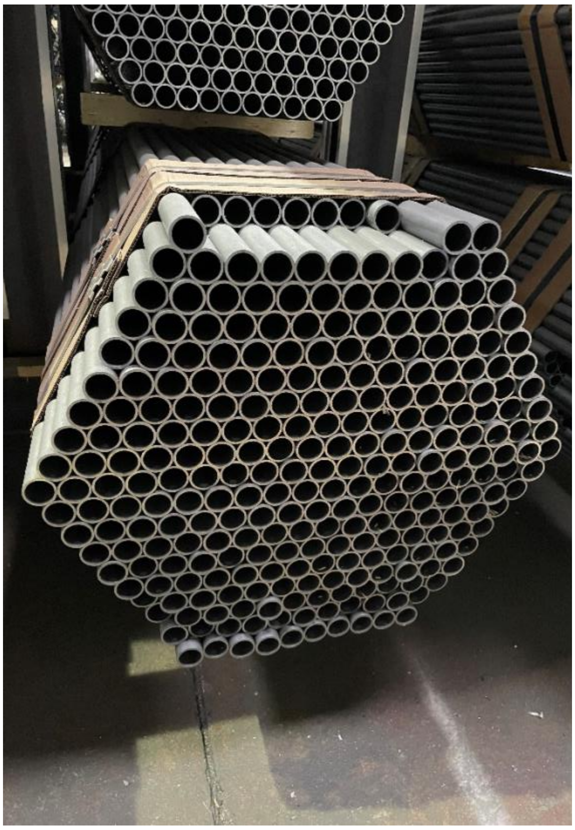


Figure 23: Round hollowed steel bars.

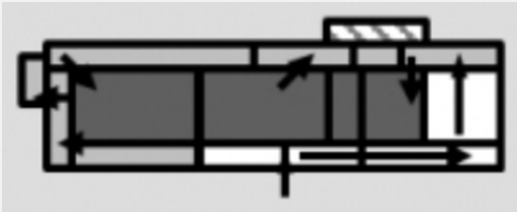
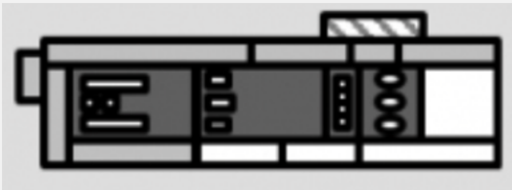
Figure 24: Round steel bars tied into a bundle.

<u>Warehouse layout</u>

The Institute for Integrated Production Hannover (2024b) describes a warehouse layout as the design of the spatial arrangement of objects such as for example machines in a production system. Layout planning involves recording of the production system, as well as considering the production process and local conditions to optimize the use of space. Depending on the objectives, warehouse layout optimization can focus on sustainably reducing costs as well as times ensuring the adaptability, flexibility, and modularity. There are different levels of planning and designing warehouse layouts, as Wiendahl et al. (2015) describe in their book “Factory Planning and Design”. These levels together with their characteristics are described in Table 3.

Table 3: Levels of planning and designing warehouse layouts (Source: Wiendahl et al., 2015).

Levels		**Characteristics**
Factory layout		- Macro display - Arrangement of buildings and functional areas in the factory premises

Rough layout		- Rough representation within the factory buildings of the functional areas - Representation of main transport and main material flow routes
Fine layout		- High level of detail - Precise arrangement of operating resources - Representation of building technology and media supply
Workstation layout		- Micro representation - Fine arrangement of individual operating resources of a workstation

Material handling

Fleischmann & Kopfer (2018) defined material handling as all processes involving the loading and unloading of means of transportation, sorting and the storage as well as the retrieval of materials. They connect individual transport sections as well as external transport with the internal material flow. Transshipment processes must be designed in such a way that undesirable effects, such as additional costs due to transshipment, are kept within acceptable limits.

As all these handling processes are beyond the scope of this master thesis, only the content of the scope is considered. That means that for example the loading and unloading of goods is not taken into account. However, the processes of storing, locating the material, material removal as well as material sorting are part of the scope. Additionally, the transportation options for heavy long goods within the warehouse are considered, as this contributes to the points listed above.

<u>Storage</u>

If goods are required at a later point in time, they are stored in a warehouse and the term storage therefore can be defined as “bridging time” (Schäfer, 2024a).

In case of storing goods in the warehouse, the decision of where and how to store a set of items to ensure optimal operation of the logistic systems must be taken (de Koster et al., 2007). Kovács (2011) has described the dedicated and the shared strategies as the two main families of storage strategies that can be considered in such a decision. In case of the dedicated strategies, the items are always stored in the same slot. In contrast to that, the shared storage strategies do not reserve slots for specific items, which is making them more convenient whenever stock levels change over time. Within the shared storage strategies, the class-based storage strategies are the most important representatives, as stated by (Petersen & Aase, 2004). Those form classes of items as well as partition the warehouse floor into zones, in order to assign each formed class of item to a partitioned zone in the warehouse where the storage within a zone is randomly (Kovács, 2011).

Moreover, there are different storage types in order to categorize warehouse logistics according to their function and structure, as the Institute for Integrated Production Hannover (2024a) has described. A distinction is made between procurement, intermediate and distribution warehouses. However, a clear distinction is not always possible and is depending on the position of the warehouse in the value creation process. Table 4 describes the three different storage types with their respective characteristics.

Table 4: Three storage types (Source: Institute for Integrated Production Hannover, 2024a).

Storage types	Characteristics
Procurement warehouse	- Temporal arrangement: Before production - Serves to provide required goods - Material warehouse - Can usually be geographically assigned to the production site
Intermediate warehouse	- Temporal arrangement: In the production or distribution process - Short-term storage of goods (buffer) - Between two stations or when transferring to another means of transportation - Objective: Timely provision/onward transportation of the right quantities as quickly as possible - Assigned directly to the production line or means of transportation/routes
Distribution warehouse	- Timing: After production - Picking according to customer requirements - Make ready for dispatch - Can be directly at the production site, but also centralized at one location or decentralized at several locations

Additionally, warehouses can be differentiated based on their structure, the way in which storage units are stored and their operating mode (Institute for Integrated Production Hannover, 2024a). Güttler (2023) has explained some examples like the rack storage, high rack storage, floor storage or the open storage, which are further described.

Rack storages provide the possibility to store pallets in racks and therefore into height. Upwards of twelve meters, racks are referred to as ***high racks***. Those can be up to 50 meters high, and they therefore offer the big advantage that the entire storage volume of the warehouse, including the height, can be used even with non-stackable goods. However, within rack storage the problem of crushing of material or in case of the case company, inaccessibility of the material may occur as heavy material is placed on each other. Another option is to use ***floor storage***, where the goods are stored on a free-standing surface with no use of shelving. Items instead are stacked next to each other or on top of each other. This can be done through the help of stackable pallets, crates, or mesh boxes. However, using floor storage comes with some disadvantages such as that it is more difficult to access and locate individual goods than on shelves. Moreover, although it is known which goods are in the blocks, it is not known exactly which pallet is in which position. Therefore, floor storage systems are particularly suitable for storing goods of one type. In comparison to the high-rack storage the full storage volume is not utilized since goods can only be stacked on top of each other to a limited extent. However, floor storage has some advantages such as that goods can be easily loaded and unloaded and therefore, they can be flexibly rearranged at any time. Another type of storage is ***open storage***, where storage areas are without structural weather protection. For those purposes corrosion-resistant shelving can be used. The open storage usually is demarcated by fences, markings, or signage. It is important that the area has a paved floor which makes it accessible for means of transportation. Open storage is particularly suitable for very large, robust, or less valuable goods such as construction and industrial waste and bulk goods.

Retrieval of material

As described in the previous section of floor storage, it is more difficult to access and locate individual goods in floor storage than it is for example in rack storage. Therefore, when using floor storage, the retrieval of the material is an important point to think about. In traditional warehousing employees move around shelves and aisles and physically pick items according to a picking list (Benrqya et al., 2020). To find the materials on the picking list more quickly, employees can use signs, information boards, floor markings or product labels, that are installed in the warehouse (Logistic Express, 2019). However, since digitalization is developing further, it is also possible to use digitalized solutions such as automated storage and retrieval systems, radiofrequency or near field identification as well as barcodes or QR-Codes to ensure that materials can be found quickly and to reduce search times, as stated by Sunol (2023). Those solutions will be explained in the further course of this chapter in the subchapter of digitalization in warehouses.

Picking/Allocation

Since material first needs to be located by a warehouse employee before being able to pick the item, picking is closely connected to the retrieval of material. Order picking is the act of picking inventory either manually or fully automated based on the order which has been made (Schäfer, 2024b). Picking is also often referred to as the most labor-intensive, expensive, and time-consuming operation in manual warehouses (Battini et al., 2015; Kovács, 2011). Therefore, it is common to optimize order picking performances in order to minimize picking times (Kovács, 2011). There are various types of picking, such as manual picking, semi-automated picking, or fully automated picking as Schäfer (2024b) described. Manual picking is based on the principle of person-to-goods, where, as the name suggests, the employee moves to the item to pick it. The semi-automated picking is based on the goods-to-person principle, where the items is moving for example on a delivery conveyor to the person who is picking the item. Lastly, fully automated picking does not require an employee to pick the items, but an automatic logistic solution is picking the items.

Material handling equipment

There are different types of transportation in warehouses. Since the scope of the thesis is on long goods as well as the steel industry, only transportation types that can move heavy and long goods are considered in the following. As Battini et al. (2015) and Kovács (2011) both stated, picking is often referred to as the most labor-intensive, expensive, and time-consuming operation in manual warehouses. Since the goods of the steel industry often weight multiple tons or measure a couple of meters the material handling differs from warehouse of other industries where smaller goods are handled. Therefore, warehouses need special equipment to handle the material in the best way possible in order to keep the time-consumption as low as possible and to be efficient. For those purposes equipment such as overhead cranes, forklifts that are capable to carry heavy and long goods, or chassis on castors can be used. The equipment which is used by Heine + Beisswenger to transport their goods inside and partly outside of the warehouse can be seen in the Figure 25, Figure 26 & Figure 27 below.

Figure 25: Overhead crane in the warehouse of Heine + Beisswenger.

Figure 26: Forklift in the warehouse of Heine + Beisswenger.

Figure 27: Chassis on castors inside of the warehouse of Heine + Beisswenger.

3.1.2 Information flow

In order to be able to improve the performance of the material flow, information sharing is of importance for companies (Kembro & Selviaridis, 2015). As it can be characterized as the enabler of collaboration and improvement, Supply Chain Management has become dependent on information flow (Pereira, 2009). Significant improvements can be achieved when integrating the information flow through suppliers, since Original Equipment Manufacturers (OEM) can concentrate on their core activities while using suppliers' additional resources, capabilities, and skills to achieve lower costs as well as better quality products (Lindquist et al., 2008). However, this also comes with the risk of losing competitive edge since Original Equipment Manufacturers allow their knowledge assets to become public (Kim et al., 2011). Moreover, Madenas et al. (2014) has stated that globalization as well as the rapid pace of technological innovation increased the complexity of information flows in supply chains. Web-based systems, which have been developed through the evolution of technology and the Internet, however, can lead to improved collaboration within the supply chain and therefore can lead to improved performance efficiency. Digital systems, such as Computer Aided Design, Product Data Management, Enterprise Resource Planning or Product Lifecycle Management are used on a daily basis in the manufacturing industry to design, develop, produce, deliver and support products for global markets. The wide range of used systems on the other hand has created a landscape of "Isolated Islands of Information", making it difficult to share information since the information is locked in different repositories (Madenas et al., 2014). Even though some systems allow dynamic and a direct way of data exchange, organizations still need to work hand in hand with the supplier to improve the decision-making process as well as the entire supply chain performance (Fiala, 2005).

To better understand the information flow, types of information systems will be further described as well as mobile devices, as they are part of the scope and will possibly play a major role in the design propositions that are going to be suggested in the end of the thesis.

<u>Types of information systems</u>
There are many different types of information systems. However, in the following only the Enterprise Resource Planning system (ERP) and the Warehouse Management System (WMS) will be described, since they are common and known within warehouses (Kembro et al., 2017).

As stated by Europe's largest software manufacturer SAP (2024a), an Enterprise Resource Planning encompasses all core processes that are necessary to run a company: Finance, human resources, manufacturing, logistics, services, procurement, and others. Therefore, it can also be seen as a management technology that advocates an integrated approach to conduct business (Chang et al., 2008). Considering only the logistical processes since this is in the scope of the thesis, a well-functioning ERP-System is important to be able to deliver the right products and services to customers in time. Because ERP-Systems provide the automation, integration and intelligence that are essential to the efficient handling of all daily business operations, it sometimes is referred to as the “central nervous system of a company” (SAP, 2024a). Sharing information between internal functions, enables companies to improve efficiency of their supply chain (Kembro et al., 2017), which underlines the importance of a well-functioning ERP-System.

Another type of information systems is the Warehouse Management System (WMS), which provides, stores, and reports necessary information to efficiently manage the flow of products within a warehouse, considering the time of receipt to the time of shipping (Faber et al., 2002). WMS is used to gain an overview of task that are completed and incomplete by tracking inventory and managing resources (Kembro et al., 2017). WMS software systems are a key component of supply chain management as they provide real-time insight into a company´s entire inventory, both in warehouses and in transit. Additionally, a WMS provides tools for picking and packing processes, resource utilization, analytics and much more (SAP, 2024b). To perform some of its tasks, WMS need to communicate with other information systems (Faber et al., 2002).

<u>Mobile devices</u>
The information which is provided, stored, and reported by ERP´s or WMS also needs to be connected to the goods in the warehouse (Faber et al., 2002). It is therefore important to be able to uniquely identify the goods in the warehouse (van Geest et al., 2021). Goods in the steel industry can be identified through multiple ways. Either by marking the steel bars with the respective information by pen, by pinning spreadsheets to the steel bar, by printing barcodes and tagging them to the goods, or by using technology such as Radio Frequency Identification (RFID) as Sunol (2023) has stated. Since the thesis accompanies a project investigating whether and how scanners and mobile printers can improve efficiency of the warehouse processes, the focus in the following is on barcodes, handheld scanners which are needed to scan the barcode as well as mobile printers which are needed to print the barcodes.

As Woods (2024) has stated, using spreadsheets and manual data can lead to mistakes when performing inventory counts or other activities such as picking goods and therefore can hinder the efficiency of the warehouse. Using barcodes instead of spreadsheets or manual data makes it possible to identify the goods in the warehouse more efficiently at any time. By scanning the barcodes which can be tagged at every possible warehouse, rack, pallet, container, or even the individual good, mistakes by the warehouse employees can be avoided more often. Moreover, using barcodes will lead to faster order processing speed, reduced operating costs, as well as excellent scalability for future expansions.

Figure 28: Exemplary barcode.

To capture barcodes (Figure 28) in the warehouse, handheld barcode scanners as one exemplary scanner can be seen in Figure 29 can be used. Depending on the requirements, various scan modules such as laser scanners, imagers, or long-range scanners can be chosen for reading the information via code, as the handheld barcode scanner provider Integer Solutions (2024) has stated. Handheld barcode scanners can be used for various applications in the warehouse. They are mainly used to simplify and improve the flow of goods in the warehouse and enable paperless warehouse management. The barcode scanners can be easily integrated into existing work processes and provide a better overview of warehouse management. The scanners are an efficient way of capturing data on all products quickly, accurately, and easily. Barcode scanners for the warehouse are characterized by the fact that they capture one- and two-dimensional barcodes and warehouse shelf labels quickly and reliably, which declines the error rate and therefore are an interesting tool to improve efficiency of general warehouse processes.

Figure 29: Exemplary handheld barcode scanner.

In order to further increase efficiency of the information flow, mobile label printers can be used for labeling goods in the incoming goods area or directly on warehouse shelves, as it is described by the mobile printing provider 4Logistic (2024). This makes it possible to apply barcodes to the goods without having to walk back and forth between the goods and the workstation. The mobile label printers are usually equipped with large rechargeable batteries, which allows printing the labels throughout the day without the need for charging them in between. They usually work via WIFI or Bluetooth. Mobile printers are available in a wide variety of designs or different sizes. Depending on the size of the printer, the label roll only needs to be replaced once a day which can increase the efficiency flow of the process. Figure 30 shows an exemplary mobile printer. Those printers can be attached to the waistband or similar of the warehouse employee and are therefore close to the body and quickly to use. Thanks to their lightweight the warehouse employee is not impaired in his or her way of working.

Figure 30: Exemplary mobile printer.

3.2 Warehouse digitalization

As the operational efficiency determines the logistical operational efficiency, warehouses are crucial components of the logistics industry (Tiwari, 2023). Manual operations in warehouses have been a standard not long ago (Kembro & Norrman, 2021), but since the introduction of Industry 4.0 technologies and a rapid technological advancement in the recent decades, the role of warehouses has changed significantly (Tiwari, 2023). Increasing competition as well as expectations on shorter lead times such as same-day deliveries, high product availability, shorter product life cycles, variation of delivery and return options have paved the way for transforming manual warehouses into smart warehouses (Kembro & Norrman, 2021; Chung, 2021; Jacob et al., 2023). The aim of smart warehouses is to improve overall service quality, productivity, as well as efficiency while lowering costs and failures (Tiwari, 2023).

Considering the scope of the thesis, as it can be seen in the figure below, warehouse digitalization can be implemented differently depending on the industry. As Gajdzik & Wolniak (2021) stated, some industries can implement technological progress faster and easier while for other industries the implementation is often a technical and economical barrier. Industries such as the automotive industry, production of clothing, footwear, or food, are industries where technological progress can be implemented more quickly than in industries where the life cycle of devices is counted in decades which is the case for the steel industry. Therefore, technological change in the steel industry is progressing more slowly. However, since 60-70% of the warehouse costs equates to the process of picking, which is an important part of the scope of the thesis, many warehouses are looking to increase efficiency of such warehouse processes to lower their costs (Chen et al., 2015; Bélanger et al., 2023).

To be able to decrease costs and increase efficiency, technologies such as the previously described information systems or automated material handling can be used (Kembro & Norrman, 2022). Cloud computing, Artificial Intelligence, the Internet of Things, or collaborative robots are additional examples of digitalization and emerging technologies that are making automation more flexible and easier to implement, especially for material handling activities like transportation, picking, placing and sorting (Sgarbossa et al., 2022). Automated storage and retrieval systems (AS/RS), automated guided vehicles (AGVs) and conveyorized sorting systems are examples of equipment that can be used when it comes to automated material handling (Kembro & Norrman, 2022), since there is no need for operators or drivers while having direct control of handling equipment producing movement and storage of loads (Rowley, 2000). Warehouse automation therefore has the advantage of fast processing of goods with a consistent high quality even at peak times (Schäfer, 2024b). Additionally, space can be utilized in the best way possible, service and operating costs can be improved as well as picking errors can be minimized (Kembro & Norrman, 2022). As described by the Institute of Integrated Production Hannover (2024c), the further development of digitalization and intelligent networking is the smart warehouse, in which production facilities and logistics systems organize themselves. With the help of a digital warehouse, it is possible to simulate different scenarios. Sunol (2023) underlines this as he addressed seven promising technologies for warehousing which will play a major role in up to six years as it can be seen in Figure 31.

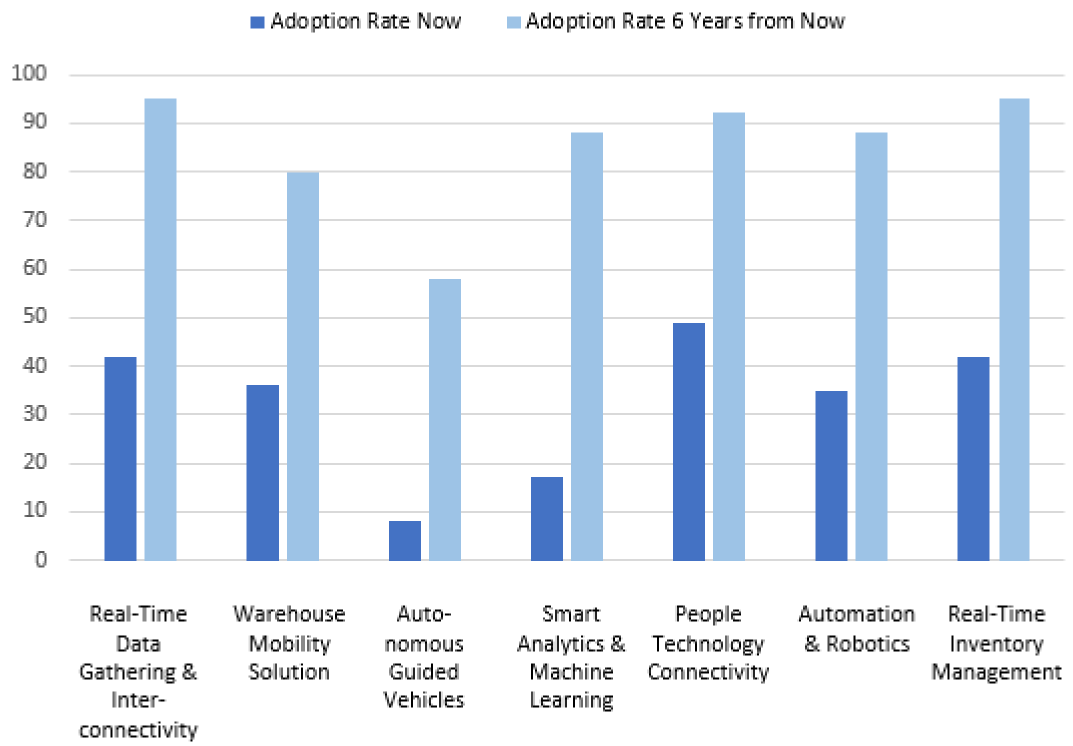


Figure 31: The future of warehouse technology (Source: Sunol, 2023).

To gather a better overview of those technologies, Sunol (2023) has further described those technologies:

Real-Time Data Gathering & Interconnectivity

As warehouse and supply chain systems of the future will be transparent, blockchain has the potential to play a vital role in providing transparency at every level of the supply chain. It offers the power to distribute information quickly and securely, thus making exchange of data in real time for warehouses efficient and transparent.

Warehouse Mobility Solutions

The use of smartphones and mobile devices will play a major role in gaining warehouse efficiency, as those devices reduce walking time and will allow working from distance as well as having access to data no matter of the current location of the employee in the warehouse.

Autonomous Guided Vehicles

Reducing the need for employees can improve efficiency in warehouse processes. Therefore, as being a potential substitute for forklifts for example, AGV´s can revolutionize the way how cargo is transported inside as well as outside of the warehouse.

Smart Analytics and Machine Learning

Customer satisfaction is crucial for every company. Through effectively predicting product demand as well as making better use of the resources, warehouses can play a key role for customer satisfaction. Nowadays interpreting data trends, optimizing warehouse capacity and asset utilization is done by warehouse managers. However, in the future this can be done by predictive analytics and artificial intelligence, which will be a more effective way to optimize the warehouse processes.

The People-Technology Connection

In order to support the efficiency of warehouse employees, warehouse technology can be used. Technologies such as smart glasses, augmented reality, voice-enabled devices such as pick-by-voice or pick-by-light are becoming more popular. The interconnection between people and warehouse technology will be important, as humans still play a crucial role in the future of warehouses.

Automation and Robotics

As it already is part of today, automation and robotics will also remain in the future of the digital warehouse, as they can simply perform multiple tasks with much less time and cost over the long run and therefore increase efficiency. Considering the competition in the markets, automation and robotics are indispensable aspect without warehouses are unlikely to survive in the future.

Real-Time Inventory Management

To survive the heavy pressure of commerce, warehouse managers need efficient inventory management. More visibility as well as control over the inventory will help achieving efficient inventory management. Technologies such as smart sensors, RFID or others, will provide end-to-end visibility of inventory and operational intelligence.

3.3 Performance efficiency

Efficiency in supply chains focuses on delivering quality products to customers at the lowest possible cost by maximizing resources such as material or labor (Jenkins, 2022). Moreover, Jenkins (2022) stated that excellence in this area is important for companies since money can be saved while customer satisfaction is kept. There are different ways on how to improve efficiency in supply chains. They range from increasing supply chain visibility over developing and maintaining strong relationships with quality suppliers to using real-time supply chain data and automating supply chain processes. However, since those ways of improving efficiency contain the whole supply chain, only the scope of the thesis will be considered in the following, which is the warehouse efficiency. To improve the performance of the logistical warehouse processes of a company, warehouse performance measurements are needed (Kusrini et al., 2018). Moreover, Kusrini et al. (2018) has stated that it is necessary to identify Key Performance Indicators (KPIs) in order to improve warehouse performance. Improved warehouse performance will lead to improved quality performance, delivery time, customer satisfaction as well as to reduction of cost in the logistics system (De Marco & Mangano, 2011). To be able to improve warehouse performance, it is important to identify the most important KPIs of the respective warehouse, since every warehouse has different KPIs (Kusrini et al., 2018). Generally, the most important performance measurements of warehouses are related to the time or effort which is required for order picking, where the items are retrieved from the shelves for example, to delivering them to the point where they will be picked up by the appropriate vehicle (Kovács, 2011).

3.4 Conceptual framework

The conceptual framework of this master thesis is used as a structured approach to organize the whole thesis. It is a key component of the project since it ties together and visualizes the research objectives which will be answered to fulfill the purpose of the thesis together with the data gathering approaches as well as the tools, which are taken advantage of, to be able to perform the research seamlessly throughout the thesis. Figure 32 therefore is used as a guide of the whole research process from start to finish.

The conceptual framework ties together Figure 14 and Figure 16 and adds tools which are used to be able to walk through the research process from the beginning until the finish line, which are the propositions of a digitalized solution increasing the efficiency of warehouse processes using mobile devices in the case company Heine + Beisswenger. Starting with the first research objective, the current warehouse processes are described with the help of data gathering methods such as observations, unstructured interviews, and secondary data. Using tools such as process mapping and flowcharts allows structured descriptions of the current warehouse processes which is important since it provides the foundation of the whole project. After providing the first research objective the performance of the current warehouse processes can be recorded. Additionally, experiments are being carried out to identify potential efficiency increases using scanners and mobile printers. Using tools such as performance measuring on documentation sheets and flowcharts, process times can be structurally documented and therefore documented transparently. This step concludes the second research objective and is necessary in order to be able to move on to the analysis of those processes, which is the third research objective. At this point of the research data from literature, observations, and unstructured interviews as well as from the experiments are tied together in order to analyze the performances and to identify waste. Tools such as performance measurements as well as spaghetti diagrams are used during this step and conclude the third research objective. To fulfill the purpose of the thesis, the fourth research objective can be elaborated based on the research data gathered throughout the research objectives one to three. Literature as well as the performance measurements gathered before, are used to design a digitalized solution which could increase the efficiency of warehouse processes in the warehouse of Heine + Beisswenger using scanners as well as mobile printers. Moreover, all gathered data as well as the used tools are utilized in order to provide well elaborated design propositions.

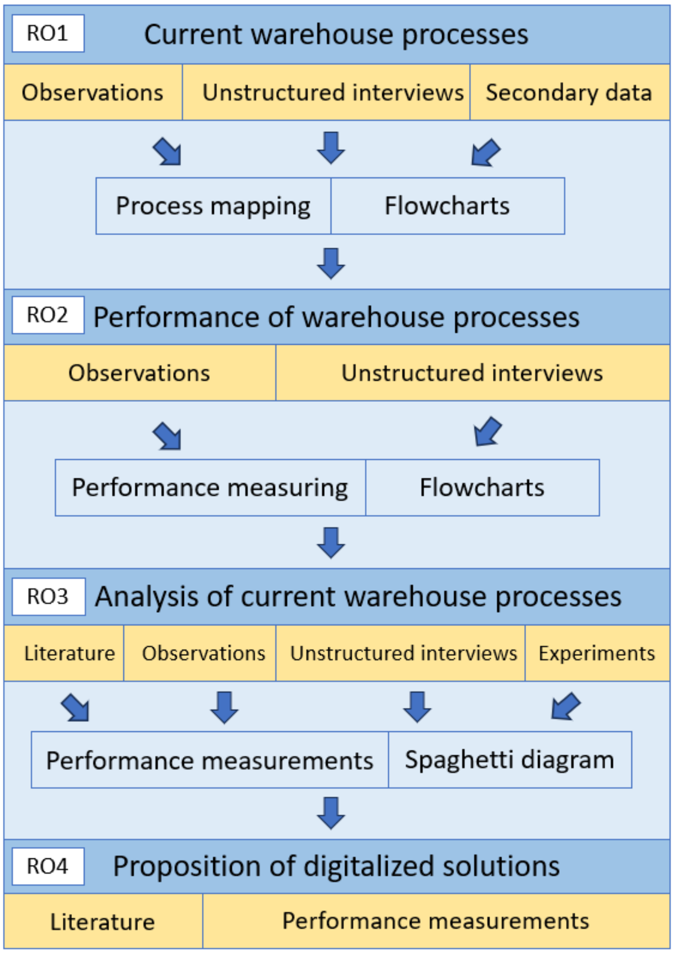


Figure 32: Conceptual framework.

4. EMPIRICAL FINDINGS

This chapter describes the current situation in the warehouse of Heine + Beisswenger. To gather all relevant information observations, unstructured interviews, experiments as well as secondary data was used. The outline of this chapter, which is illustrated in Figure 33, describes the current warehouse processes as a first step. This includes the material flow as well as the information flow in the warehouse. However, only the material flow and information flow of the scope will be considered, which are the processes of incoming goods, storage, and retrieval of the goods. Until that part, the first research objective of the master thesis is done. Next, the state of the current level of digitalization in the warehouse is being described. This is done to understand more about the workflow and provides necessary information for the analysis, which is done in the fifth chapter. Lastly, the performance of the warehouse processes is recorded, which fulfills the second research objective. This last step of the chapter provides crucial information for the following analysis of the thesis.

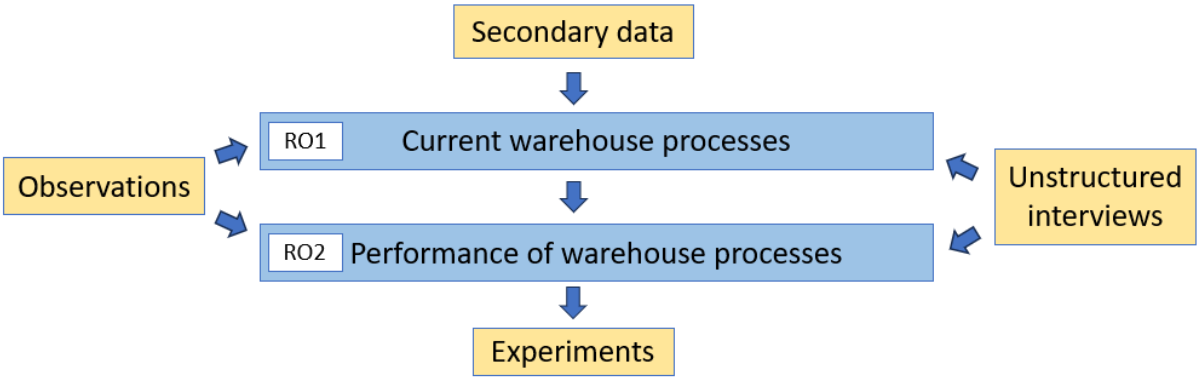


Figure 33: Outline of the chapter empirical findings.

4.1 Current warehouse processes

In the following section of the thesis the current warehouse processes will be described, which at the same time is the first research objective. To successfully fulfill RO1, both, the material flow as well as the information flow of the processes in the warehouse of Heine + Beisswenger will be described. This will help understanding the as-is situation of the warehouse. To accomplish this objective, data will be collected through multiple observations connected with unstructured interviews as well as secondary data, that has already been gathered previously by the company. Again, this will only be done for the areas within the scope of the thesis. Both, the material flow, and the information flow will be described only for the processes of put-away & storage as well as picking & sorting.

4.1.1 Material flow processes

This section describes the material flow of the processes within the warehouse of Heine + Beisswenger. In the first section of the chapter the layout of the warehouse will be illustrated. This step will provide background information about where and what material is stored within the warehouse. The second section of the chapter describes the material handling processes of the scope: 1) Put-away & Storing and 2) Picking & Sorting.

Material & warehouse context

The warehouse of Heine + Beisswenger in Fellbach consist of three major parts, as it can be seen in the rough layout of the warehouse below. The first one is the outdoor storage, the second one is the high rack warehouse, and the last one is the rest of the warehouse, which includes the preparation zone for the high rack warehouse, different storage areas such as floor or rack storage as well as areas for machines. The rough layout of Figure 34 shows only the storage areas which are part of the scope, however, there are more storage areas in the grey colored sections, but they are disregarded in the following since they are not part of the project.

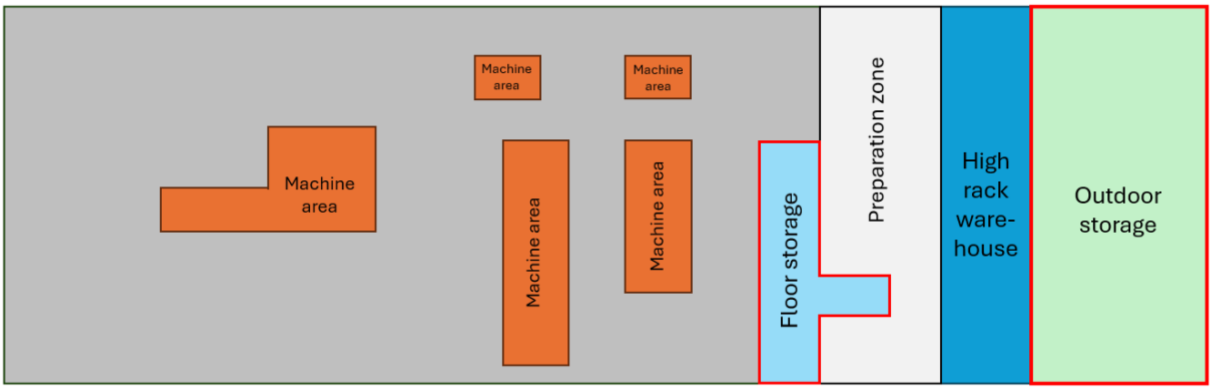


Figure 34: Rough layout of the warehouse.

Since the rough layout of the warehouse has only been created to get a basic overview, a fine layout has been created. This has been done to get a detailed illustration of the actual warehouse with its storage areas, which will help during the process of gathering information about the current warehouse processes. With the help of a computer-aided design (CAD) program, a 2D model of the warehouse was created. To provide the best possible as-is situation of the actual warehouse with the stored material, the areas which are part of the scope can be seen in Figure 35. The layout will be further used for the spaghetti diagram, which is part of the information gathering process of the current performance of the warehouse. In this step, the layout is used to document the walking routes of the warehouse employees during the search times, which is known as the spaghetti diagram. Figure 35 illustrates the storage areas of the warehouse which are being investigated and marked with red.

Figure 35: 2D model of the outdoor & indoor storage area.

Outdoor storage

The outdoor storage area, as it can be seen in Figure 36, has multiple storage areas, which are marked in red. Those function as a free storage area, where the material is stored without protection against the weather. Therefore, the only materials which are stored outdoors, are materials that can rust while not losing value for the customer. This can be seen in Figure 37, where the stored material is rusted. Currently the areas do not follow a structure, which means that there are separate places, but they are not marked and labeled. Out of that reason the structure seems random from an outside point of view. However, there still is a structure as the places are aligned, which makes it possible to drive through the outdoor storage area with enough space to load and unload material. As it also can be seen in the layout below, most of the marked red places are divided in half by a thin black line. This is because they function as two separate places since the places are too wide to be able to reach both ends from both sides with the forks of the forklift. Therefore, the places cannot be loaded and unloaded from both sides but only from one side. The layout also shows that the places on the outer right side as well as the outer left side measure only half of the size of the other places. This is due to the described reason, that the forklift is limited in the reaching distance.

Figure 36: Outdoor storage layout.

Figure 37: Stored materials of the outdoor storage.

Since the outdoor storage has no racks, but all materials that are stored outside are round materials and therefore cannot be stacked onto each other easily, wooden bars are used. This makes it possible to store multiple layers of steel bars on top of each other while keeping a safe storage structure, saving storage area as well as keeping the same materials at the same place. The high rack warehouse of Heine + Beisswenger (Figure 38) limits the outdoor storage area on the left side of the layout and the end of the facility on the right side of the layout.

Figure 38: High rack warehouse of Heine + Beisswenger.

Lane 1 & 2

The detailed layout of Figure 39 shows the first two lanes of the warehouse. In total, the warehouse is divided into six lanes, however not all lanes will be looked at since not every lane is part of the scope of the thesis as they consist of storage area which is not part of the project or machines. The first lane is defined as the preparation zone for the high rack warehouse. All yellow marked areas in the layout below of lane one is floor storage area, where materials are stored to either soon be stored in the high rack warehouse or to be soon delivered to the customers. However, those processes are disregarded because they are not part of the scope as they are already digitalized. The only area of lane one which is part of the scope is the red marked area. This is because the area, as it can be seen in Figure 40, is used as a storage area for small-sawn materials. The rack system in lane one is different from the usual racks in the warehouse, since the materials here are shorter than the usual materials, which measure three to six meters. The small-sawn material can be seen as remaining material which needs to be stored somewhere.

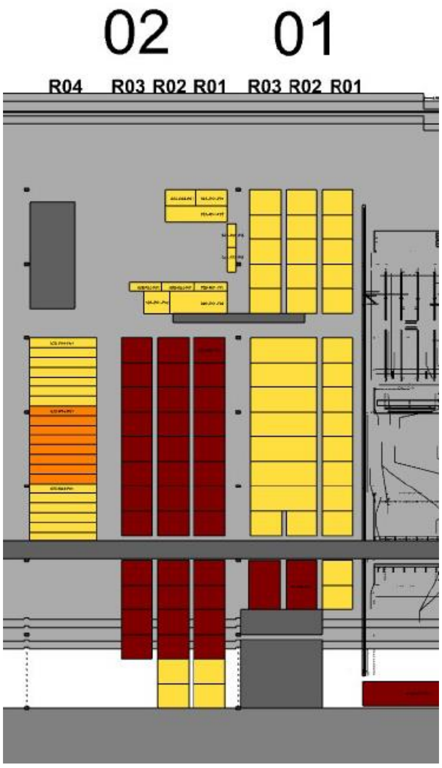


Figure 39: Layout of lane 1 & 2.

Figure 40: Racks for small-sawn material.

The second lane of the warehouse has a much bigger area which is part of the scope. The layout of Figure 39 shows the relevant area marked in red, which function as a floor storage area in the warehouse. As it can be seen in Figure 41, the stored materials in that area are packed into wood, since the material should not be damaged during transportation. This area does follow a structure as two small footpaths divide the area into three rows. The footpaths are needed to load and unload the material with the overhead crane. However, the described structure does not follow a logic of how to find the materials in the best way possible. There are no marks on the floor which could make it easier to find materials quicker, so the only available information the person who is about to pick the material has, is that the material is stored in that area. As the Figure 41 below shows, the wooden boxes are not that big, which makes it possible to store a lot of boxes but at the same time makes it hard to find the right materials quickly. The information sheets on the end of the boxes provide information about the materials, however since there are a lot of boxes and they are all looking equally, the process of picking seems inefficient as it looks like it is hard to locate a specific box when needed.

Figure 41: Floor storage area.

Material handling

After providing information about the material context as well as the context of the warehouse, this section describes the processes of the material flow.

Put-away & Storage

The first material flow that is described, is the process of “Put-away and Storage”. The flowchart in Figure 42 shows all processes that are happening throughout the put-away procedure, however, only the material flow of put-away and storage is described, as this step is part of the scope and therefore marked in light red.

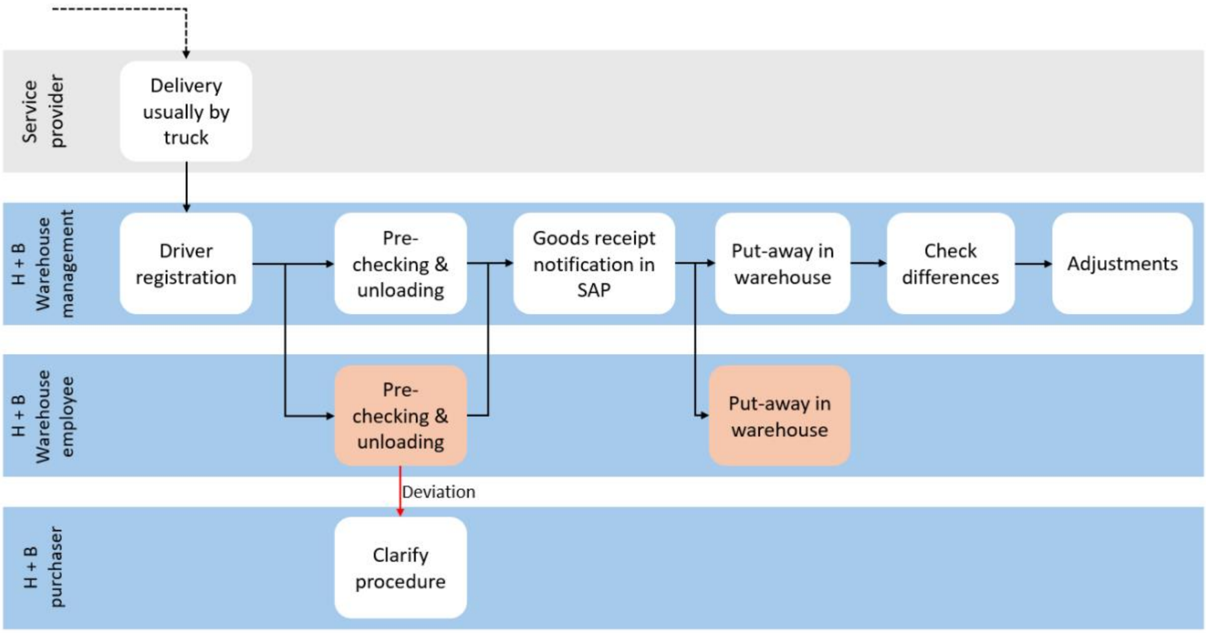


Figure 42: Flowchart of incoming goods processes.

As soon as the material is delivered, the warehouse workers unload the truck. Most of the trucks arrive in the morning, therefore the unloading also happens during the morning. The unloading is done with overhead cranes that are installed in each lane of the warehouse, as it can be seen in Figure 43 and Figure 44 below. For that the roof of the truck needs to be opened, because the overhead cranes can mostly only unload and load vertical. If the material is going to be stored in the outside storage area, a forklift will put-away the material after the overhead crane has unloaded the truck. Each material that is unloaded will directly be moved to the designated storage area.

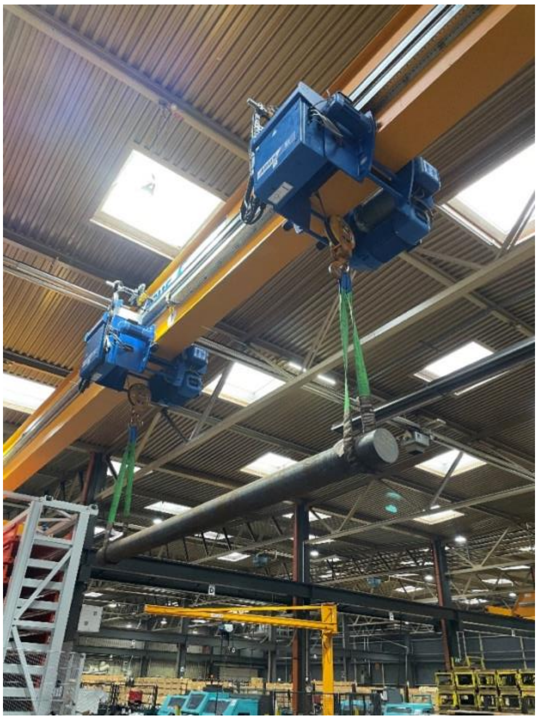


Figure 43: Overhead crane transportation

Figure 44: Unloading of material.

According to the measurements of the material the warehouse employee stores the material in the designated area of the warehouse. Three-meter material for example is always stored in the same racks, because they are built for three-meter material. Six-meter material is also always stored in the same racks out of the same reason as before. Another decision variable on where to store the material is the diameter of the material. As soon as the material for example reaches diameters of 250mm the goods are stored in lane five. Goods with diameters over 400mm are stored in lane six. However, those storage places are always seen as one big area for similar material. Therefore, there is no specific storage place for each material type or whatsoever. After putting away the material, the storage bin card is attached to the material in order to make it easier to find the materials when they are going to be picked. To make it a bit easier to find the material, Heine + Beisswenger uses colored storage bin cards connected to colors in the storage areas, but more on this will be explained in the chapter of the information flow.

Picking & Sorting

The second material flow that is described, is the process of "Picking & Sorting". The flowchart of the whole process of material selection is illustrated in Figure 45. However, as only picking and sorting is part of the scope, this process will be described and is therefore marked in light red.

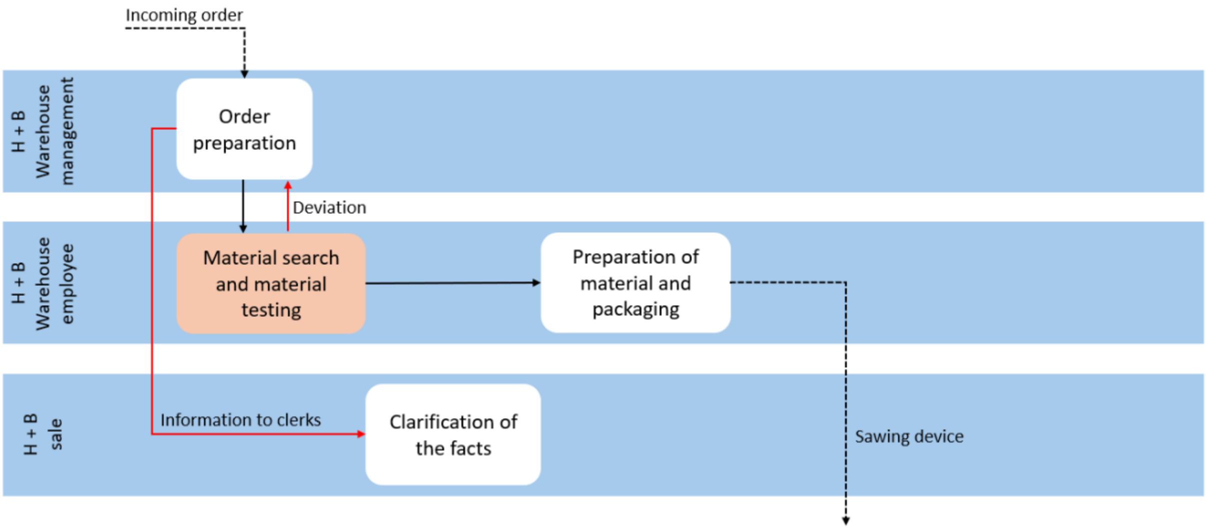


Figure 45: Flowchart of material selection processes.

As soon as an order is placed, the warehouse employee needs to find and pick the right material in the right quantity. The material search is carried out with the help of a "guidance sheet". This sheet, among others, shows the storage location and the quantity for each item. Since, as previously described, there are no fixed storage locations in the warehouse, only storage areas, the warehouse employee must search for the material once they have arrived in the storage area. This is done by using the material number marked on the "guidance sheet". Once the material has been found and the correctness of the quality, batch and dimensions has been checked, the material can be picked. However, this may result in material movements that has nothing to do with the material the warehouse employee was looking for. As the material is often stacked in the floor storage area or in the racks, material may lay underneath other material. In order to remove the correct material, the other material must first be removed and placed in a different location. This is done with forklifts in the outdoor storage area and with the overhead crane in the warehouse. Once the not needed material is placed somewhere else in the storage area, the needed material can be picked, and the moved material will stay in their new storage area.

4.1.2 Information flow processes

This chapter is about the information flow of the processes within the warehouse of Heine + Beisswenger. Since the information flow which is part of the scope partly overlaps with previous or subsequent steps of the warehouse operations, the illustration of the scope was adjusted, as it can be seen in Figure 46. Out of that reason, the first section of the chapter will describe the information flow from the process of receiving to storing the goods while the second section is about the information flow of picking the goods.

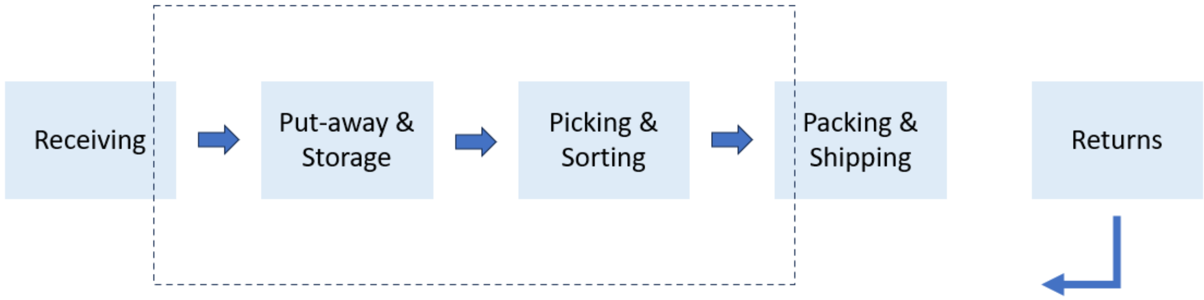


Figure 46: Scope of warehouse operations (Source: Kembro et al., 2018).

<u>Put-away & Storage</u>

The information flow of “Put-away & Storage” starts already in the previous step of the warehouse operations, which is receiving of the goods. Once the goods are delivered by truck, the warehouse employee will take the delivery note to the warehouse management. The warehouse management then stamps the delivery bill. This stamp forms a control table for the warehouse employee so that the warehouse employees can further check the goods of the delivery based on the information on the stamp. If all characteristics of the material match the requested ones, the warehouse employee can put-away the goods into storage. As previously described in the material flow, the warehouse employee decides where the goods are stored based on the length or the diameters of the goods. These areas are marked with different colors. There are eight colors in total (red, blue, white, brown, black, green, orange and yellow). Three-meter material, as an example to understand the colored system, is always stored in the area of red or green. Therefore, the warehouse employee knows the colored area on where to put the material after looking at the material. After storing the material, the employee marks the goods with the respective color. The warehouse employee reports the assigned color to the warehouse management, who can then post the put-away in the WMS of SAP. In this process, the color of the area is assigned an individual number so that the goods can be identified easier in the goods search process. After the goods have been booked into SAP together with the material information, color assignment as well as the number, the warehouse management prepares color slips matching the respective color with the individual number. This is then attached to the previously stored material by the warehouse employee, completing the information flow to the "Put-away & Storage" process. The flowchart in Figure 47 marks the points of the information flow processes that overlap with the scope of the thesis.

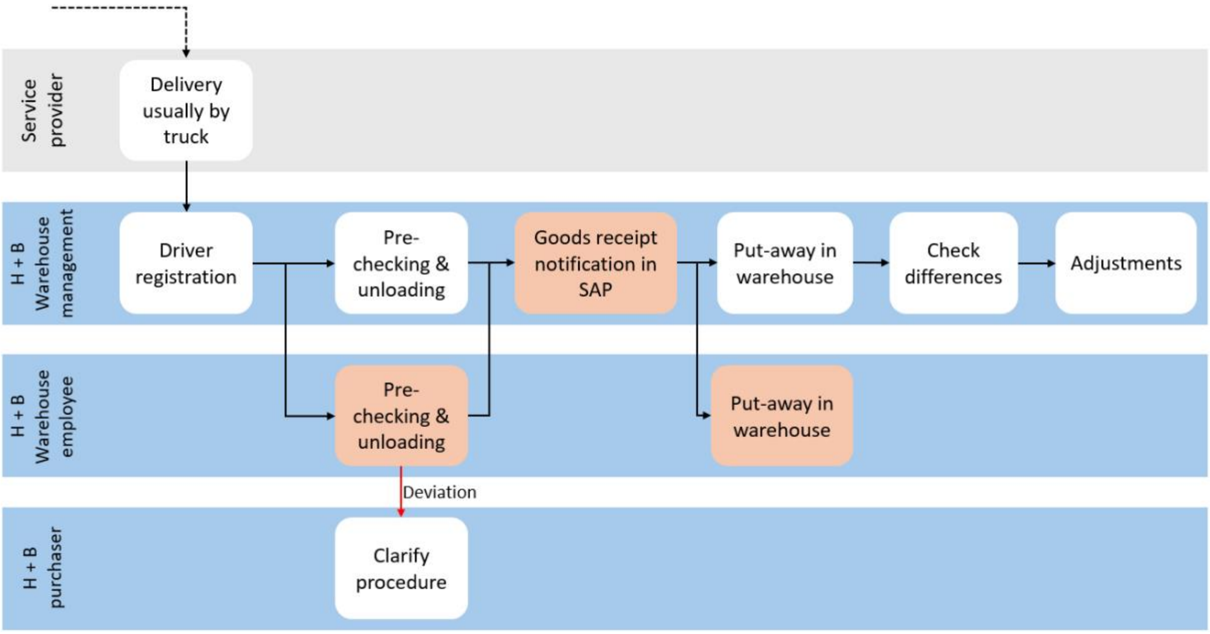
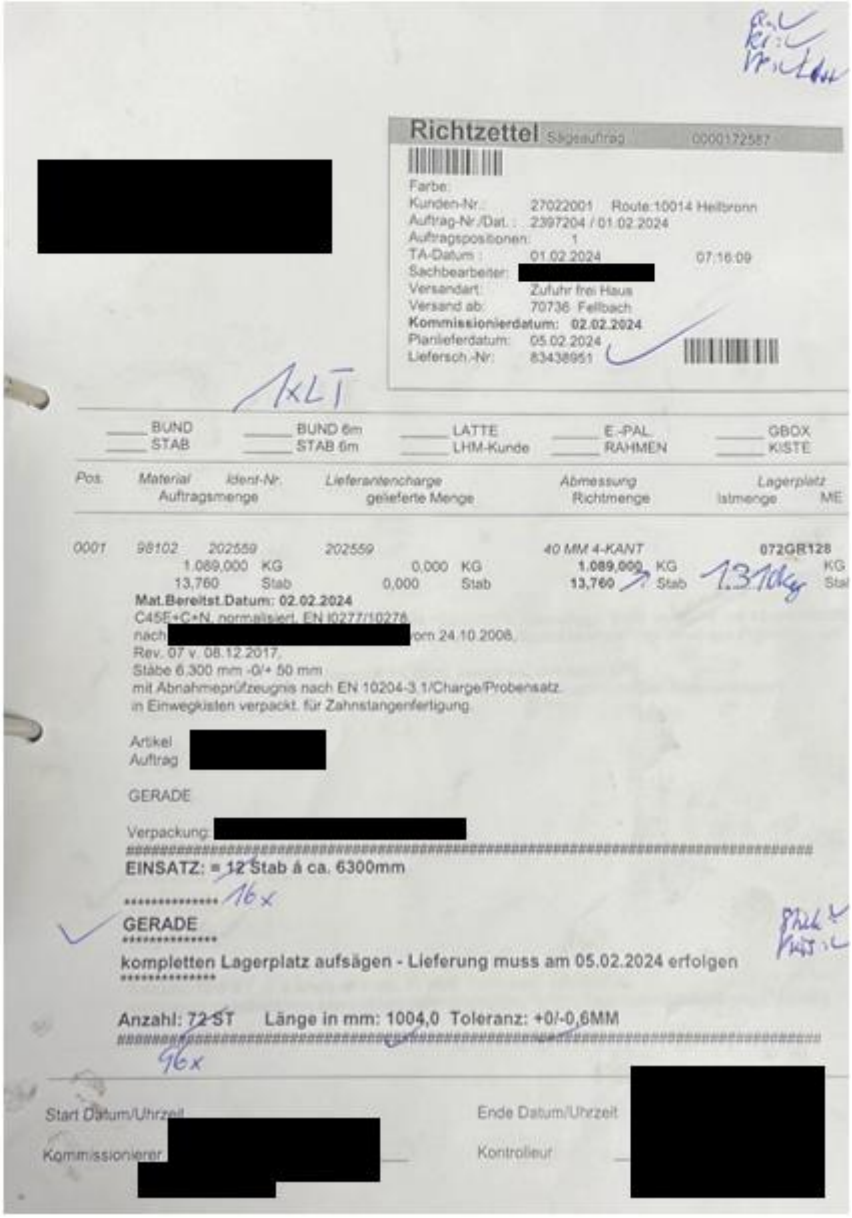


Figure 47: Flowchart of incoming goods processes.

Picking & Sorting

The information flow of "Picking & Sorting" starts with the order preparation by the warehouse management. After the sales department has completed a new order, a guidance sheet and a corresponding label are automatically printed out in the office of the warehouse management, as it can be seen in Figure 48 and Figure 49 below.

Figure 48: Exemplary label of order.



[redacted]

Richtzettel Sägeauftrag 0000172587

Farbe:
Kunden-Nr.: 27022001 Route:10014 Heilbronn
Auftrag-Nr./Dat.: 2397204 / 01.02.2024
Auftragspositionen: 1
TA-Datum: 01.02.2024 07:16:09
Sachbearbeiter: [redacted]
Versandart: Zufuhr frei Haus
Versand ab: 70736 Fellbach
Kommissionierdatum: 02.02.2024
Planlieferdatum: 05.02.2024
Liefersch.-Nr: 83438951

____ BUND ____ BUND 6m ____ LATTE ____ E.-PAL. ____ GBOX
____ STAB ____ STAB 6m ____ LHM-Kunde ____ RAHMEN ____ KISTE

Pos.	Material / Auftragsmenge	Ident-Nr.	Lieferantencharge / gelieferte Menge	Abmessung / Richtmenge	Lagerplatz / Istmenge	ME
0001	98102	202559	202559	40 MM 4-KANT	072GR128	
	1.089,000 KG		0,000 KG	1.089,000 KG		KG
	13,760 Stab		0,000 Stab	13,760 Stab		Stab

Mat.Bereitst.Datum: 02.02.2024
C45E+C+N, normalisiert, EN 10277/10278,
nach [redacted] vom 24.10.2008,
Rev. 07 v. 08.12.2017,
Stäbe 6.300 mm -0/+ 50 mm
mit Abnahmeprüfzeugnis nach EN 10204-3.1/Charge/Probensatz,
in Einwegkisten verpackt, für Zahnstangenfertigung.

Artikel
Auftrag [redacted]

GERADE

Verpackung: [redacted]
\##
EINSATZ: = 12 Stab á ca. 6300mm

****
GERADE
****
kompletten Lagerplatz aufsägen - Lieferung muss am 05.02.2024 erfolgen
****

Anzahl: 72 ST Länge in mm: 1004,0 Toleranz: +0/-0,6MM
\##

Start Datum/Uhrzeit Ende Datum/Uhrzeit [redacted]
Kommissionierer [redacted] Kontrolleur

Figure 49: Exemplary guidance sheet of order.

The warehouse management sorts the new orders by date which they have received during the day and passes them on to the relevant shift manager. The shift manager forwards the information in form of the guidance sheet and label to the warehouse employees, who then search for the material based on the information on the guidance sheet. The guidance sheet, as seen in Figure 49 above, contains information about the storage location, the material, the quantity, the length, the quality, the batch, and the diameter. As soon as the material has been found, it is checked based on the given information. In case of correctness of the material, it can be picked, and the information flow of the process “Picking & Sorting” is done considering the scope of the thesis, as it can also be seen in the flowchart in Figure 50 below.

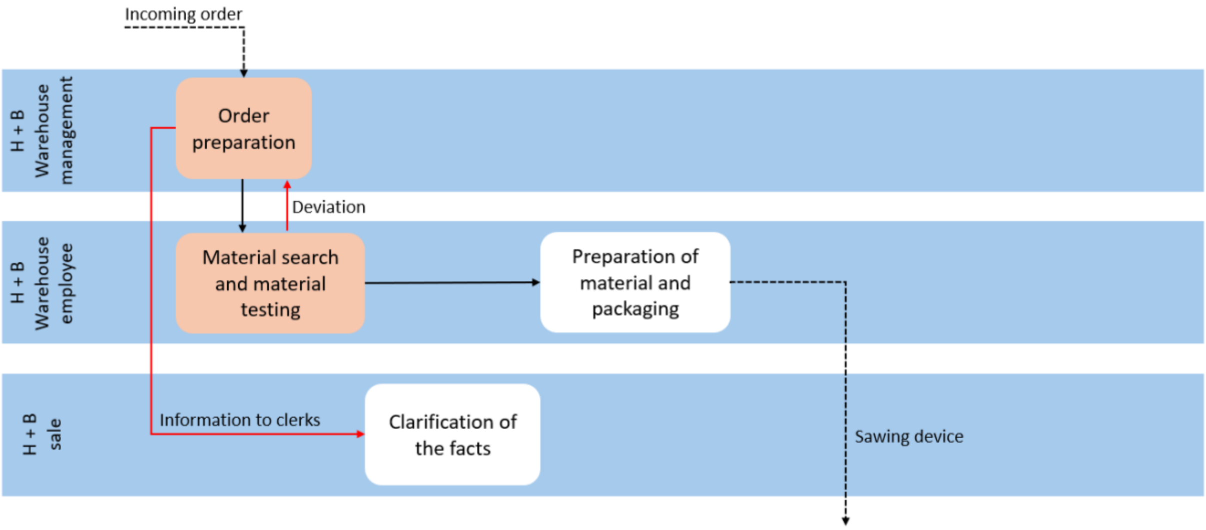


Figure 50: Flowchart of material selection processes.

4.2 Current state of warehouse digitalization

As it was stated in the chapter of warehouse digitalization before, industries, such as the steel industry, progress more slowly on technological change since the life cycle of devices is counted in decades. Therefore, it is no wonder that there is still a long way to go in order to be able to present a fully digitalized warehouse of Heine + Beisswenger. However, there are already some parts which are digitalized.

The biggest one is the high rack warehouse. The processes around the high rack warehouse are completely digitalized. Therefore, having the 2D layout in mind, most processes in the preparation zone, which is in lane one as well as directly connected to the high rack warehouse, are fully digitalized. Nevertheless, considering the scope of the thesis, it is more interesting if there already is any digitalization in the processes of the material flow as well as the information flow of put-away and picking. After going through all relevant processes for this project in form of observations as well as unstructured interviews, it is safe to say that the material flow of today is not digitalized. As described before, all material flows are documented by paper and the put-away as well as the picking is not supported by any technology. However, the information flow, is partly digitalized in form of using a WMS provided by SAP. This allows a seamless documentation between the warehouse and the sales department, which is responsible for providing orders for the warehouse. During this documentation relevant information about the warehouse and all stored materials are documented through the WMS, which provides transparency. However, the digitalization in the information flow stops at the point of providing information digitalized via the WMS and still has a lot of possibilities for further improvement.

4.3 Performance efficiency of warehouse processes

This chapter is about measuring the performance of the current warehouse processes of the material flow as well as the information flow, which will answer the second research objective. Moreover, there are also experiments carried out at the same time, which will provide valuable information for the subsequent analysis as well as for the design propositions. To measure the performance observations together with unstructured interviews as well as experiments have been carried out. Since 60-70% of the cost of a warehouse equates to the process of picking (Chen et al., 2015; Bélanger et al., 2023) and this is a major part of the scope, observation plans were created in order to be able to measure those performances of the current warehouse in the best way possible. Figure 51 illustrates an exemplary documentation sheet for the observations of the **material flow**, which is measured in the following:

Legend
Search route: Red
Relocation route: Blue
Return route: Yellow

Outdoor storage area

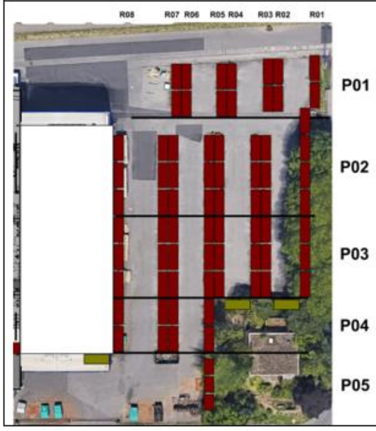
Spaghetti-Diagram	Search time	Rearrangement time	Distance to nearest location with space	Number of materials	Material splitting	Scanning time
						

Figure 51: Exemplary documentation sheet for the outdoor storage area.

In order to understand exactly how the material is searched for, the search path was drawn in the form of a spaghetti diagram. This also includes the return route and the transfer routes, which are drawn in different colors to make it easier to understand how the respective employee moved throughout the process.

At the same time, the **search time** is recorded. This is measured from the station at which the guidance sheet is handed over to the warehouse employee by the respective shift supervisor until the moment the goods are found. If the goods are on top and therefore can be picked directly, the observation is stopped at this point, as the loading of the goods is not of interest to the scope, as digitalization cannot make this step more efficient for Heine +Beisswenger for now. If the goods are not immediately ready to pick, the time it takes to move others out of the way is measured until the target material is ready for picking. This is included because the digitalization of those processes could potentially save **rearrangement time** and the next search process can be accelerated by potentially smart rearrangement of the goods. In addition to the time, this step also measures the distance to the next free space where the employee places the goods. This is done in order to be able to understand how large storage places should be defined when defining them. The number of materials and whether the material is divided up in the transfer process was part of the observation, but did not occur, as the employees only ever transferred materials to places where there was enough space for all the materials to be put-away as a whole. Lastly, the **scanning time** was added to the observation. This part is the experimental part where it is simulated how long the process of documentation of the rearrangement as well as the picking of the material would take with mobile devices such as scanners if there already would be such a digitalized system. Test scanners were used during this experiment in order to simulate the reality as closely as possible. Each time a single material or a bundle of materials was moved, it was simulated to scan the material as well as the storage location to record the time it would take for such a documentation. This was done to be able to analyze further if it would make the processes more efficient or not. Figure 52 shows one of the twenty observations of the material flow that has been done as an example.

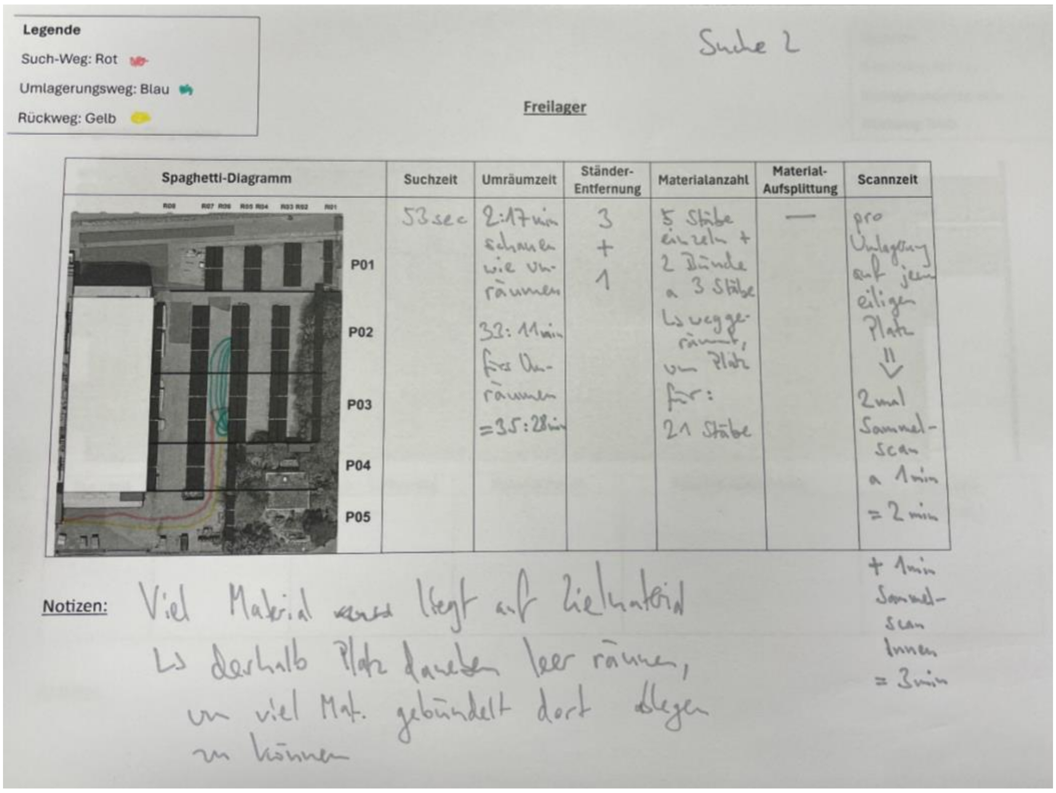


Figure 52: Filled documentation sheet for an observation of the outdoor storage area.

The number of observations was chosen to be as high as twenty in order to have multiple observations with different times to gather information that reflect the reality as closely as possible. During twenty observations of the material flow process, it was more likely to get exceptional cases and not only ordinary cases which would obscure the reality of the actual material flow processes. The observation times were documented in Table 5 in order to have a good overview and to be able to calculate the average performance further in the analysis part of the thesis.

Table 5: Observation times of the picking process.

Search time	Rearrangement time	Distance to nearest location with space	Number of materials	Time for scanning
2:26min	-	-	6	0:30min
2:48min	-	-	1	0:30min
0:53min	35:28min	3 & 1	21	3min
1:05min	-	-	1	0:30min
0:19min	-	-	1	0:30min
11:26min	2:26min	13 & 1	2	1min
0:58min	-	-	1	0:30min
0:46min	-	-	1	0:30min
1:33min	-	-	1	0:30min
0:47min	2:24min	12	2	0:45min
0:39min	-	-	1	0:30min
1:24min	7:16min	3	4	1min
31:40min	-	-	1	0:30min
3:08min	-	-	2	1min
1:40min	-	-	1	0:30min
1:21min	3:54min	10	2	1min
1:37min	-	-	1	0:30min
4:02min	-	-	2	0:30min
0:55min	8:27min	16 & 1	2	1min
1:37min	-	-	1	0:30min
3:33min	**9:59min**			**0:46min**

Next to the time of scanning, the walking distance needs to be observed. This is important for the analysis of the material flow, to be able to identify whether there is a potential efficiency increase in the time of the process. In order to be able to determine the average time of walking, the most common routes have been walked through the warehouse. For each route the shortest time as well as the longest time was measured. The observation times, as they can be seen in Table 6 will provide necessary data for the analysis which will be carried out in chapter five.

Table 6: Recorded walking times.

	Shortest time	Longest time	Average time
Route 1	0:45min	1:45min	1:15min
Route 2	0:05min	0:35min	0:18min
Route 3	0:10min	0:55min	0:33min
			0:42min

In order to observe the **information flow** multiple steps need to be walked through. To understand the process of the observation combined with the unstructured interviews as well as the experiments more easily, the information flow of goods receipt can be seen in Figure 53. The whole information flow process is divided into multiple steps. It starts by pre-checking the goods, continues with the documentation of the material in the WMS and ends with marking the material information in form of a colored slip which provides all the relevant information that needs to be attached to the material in order to be able to find it when needed.

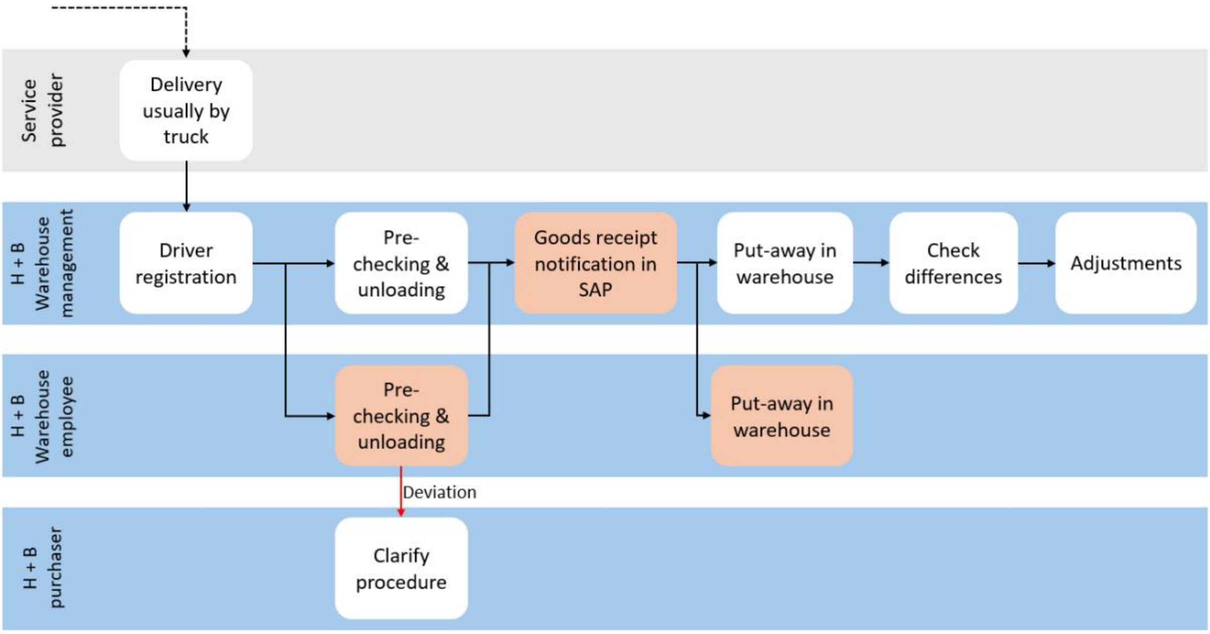


Figure 53: Flowchart of goods receipt.

Therefore, those processes need to be observed in order to carry out experiments to be able to analyze opportunities to increase efficiency of the warehouse processes using mobile devices. To fulfill the purpose of the thesis, it is necessary to track the times the warehouse management needs to document the process of an incoming good into the WMS as well as printing the label. The documentation is divided into the two steps SAP and scanning, as it can be seen in Table 7. SAP, in that case, stands for the time the employee needs to document the information in the WMS, which is provided by SAP, while scanning stands for digitalizing papers and securing of the guidance sheet. The documentation process as a whole was divided into those three steps, since for the analysis it is of interest how long the labeling process takes. This will allow calculations on whether there is an opportunity to increase the efficiency when using mobile printers at the workstation or even directly at the employee when moving through the warehouse.

In contrast to the observations of the material flow, the information flow was observed mostly in the office and therefore no documentation sheet was created. However, a documentation table was created, as it can be seen in Table 7, where all relevant times of the observations are documented. The documentation of the goods receipt is either done single or in bundles. Therefore, the time either was recorded individually or as a total time and afterwards divided by the amount of goods receipt. Like for the material flow, the information flow was observed twenty times. This was done to get more realistic times, as the probability of observing exceptional cases increases the more observations are carried out. The times of the observed processes can be seen in Table 7 below.

Table 7: Information flow observation of goods receipt.

	SAP	Labeling	Scanning	Total Time
Single Goods Receipt	2:05min	0:28min	0:55min	3:28min
Bundle Goods Receipt	2:44min	0:31min	0:51min	4:06min
	2:44min	0:31min	0:51min	4:06min
	2:44min	0:31min	0:51min	4:06min
	2:44min	0:31min	0:51min	4:06min
	2:44min	0:31min	0:51min	4:06min
Single Goods Receipt	6:02min	1min	1:16min	8:22min
Bundle Goods Receipt	3:38min	0:30min	0:38min	4:46min
	3:38min	0:30min	0:38min	4:46min
	3:38min	0:30min	0:38min	4:46min
Single Goods Receipt	4:02min	1min	1:16min	6:18min
Single Goods Receipt	1:24min	0:30min	0:50min	2:44min
Single Goods Receipt	2:06min	0:30min	0:50min	3:26min
Bundle Goods Receipt	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
	1:53min	0:28min	0:57min	3:18min
Average	**2:40min**	**0:32min**	**0:54min**	**4:07min**

After observing the documentation times of the warehouse management, it is furthermore important to observe the time the warehouse employees need to walk from their working station to the office of the warehouse management. Those routes need to be walked to give the reference sheet of the order to the warehouse management and later to pick up the colored slip to attach it to the material. In order to get an overview of how long it takes to walk to the office of the warehouse management, the distance to the closest working station as well as to the furthest working station was measured. Those times are documented in Table 8.

Table 8: Walking distance to working stations.

Furthest working station	2:30min
Closest working station	1:30min
Average walking distance	2:00min

To further be able to compare the non-digitalized process to a digitalized process, the time it would take to print out the label by the warehouse employee itself using a mobile printer and a handheld scanner needed to be documented after recording the time. After scanning the documents, it is only one click on the screen, as it can be seen in Figure 54, and the label is printed. This will roughly take 0:10 minutes.

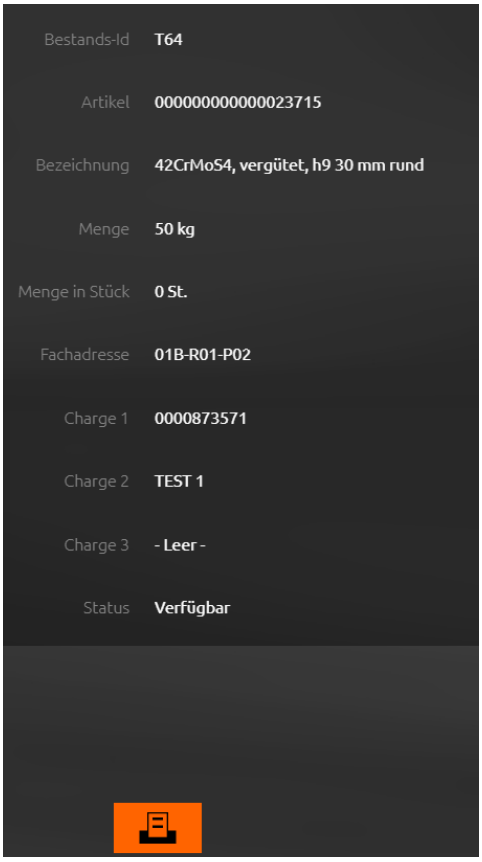


Figure 54: Exemplary printing option of a scanner.

5. ANALYSIS

In this chapter the current warehouse processes will be analyzed. After digitalizing parts of their warehouse in the past, Heine + Beisswenger has achieved improvements in their efficiency. Therefore, they have decided to start a project to further digitalize parts of their warehouse processes, which is accompanied by this thesis. To identify waste and therefore potential efficiency increases of their current warehouse processes, data was gathered which in the following will be analyzed for the processes Put-away and Storage, Picking, as well as Sorting by linking the current processes to digitalization and to furthermore compare those processes to the current ones. Furthermore, conclusions can be drawn by comparing the digitalized processes with the non-digitalized processes. This analysis is the basis for the subsequent design propositions in the sixth chapter. Through analyzing, identifying waste, and comparing the processes with a potential digitalized process, findings are gathered and further reviewed with the assembled theory about the processes as well as digitalization (such as Kovács, 2011; Benrqya et al., 2020; Faber et al., 2002; van Geest et al., 2021; Woods, 2024) which will provide propositions of a digitalized solution using scanners and mobile printers that increases warehouse efficiency when implemented correctly.

This fifth chapter is divided into two parts. In the first part, the current processes Put-away and Storage, Picking, as well as Sorting are analyzed. The analysis of those processes follows the same structure, as it can be seen in Figure 55 below. After that the second part is done, which discusses the limitations of the analysis.

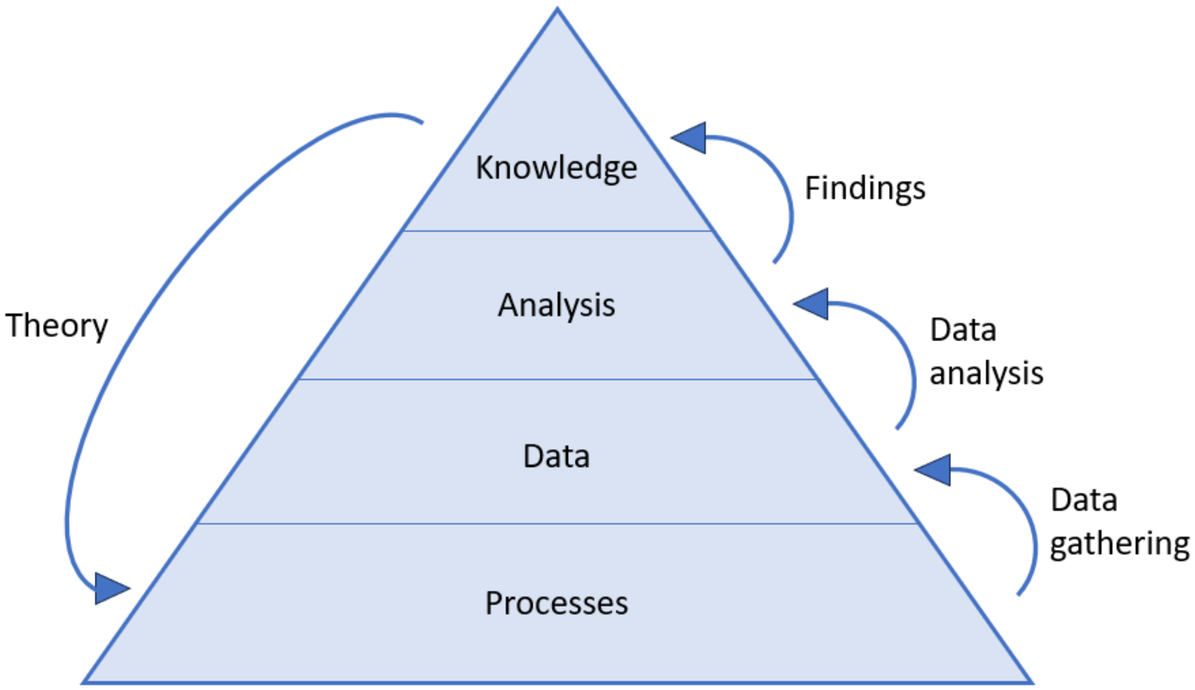


Figure 55: Overview of the analysis flow.

5.1 Analysis of the processes

To be able to analyze the processes Put-away and Storage, Picking, as well as Sorting in the following sections, data was gathered through observations as well as unstructured interviews and experiments. The reason for doing so, was to be able to compare the current process times of a non-digitalized process to a digitalized process using mobile devices such as a handheld scanner and mobile printers, as research has shown that digitalization most likely will make the warehouse processes more efficient (Faber et al., 2015; Woods, 2024; Tiwari, 2023). During the analysis potential waste of the current processes will be investigated and furthermore identified whether or how waste can be avoided by adding handheld scanners and mobile devices to the processes and therefore digitalize the processes.

Put-away & Storage process

In this section the Put-away & Storage process is going to be analyzed. To identify possible waste and therefore room for improvement by using mobile devices, firstly the current process of putting away and storing material is being described and afterwards is compared with how much of an impact there would be when using handheld scanners and mobile printers for the respective process.

As of today, the Put-away & Storage process is done in the following order of activities, as it is also illustrated in Figure 56.

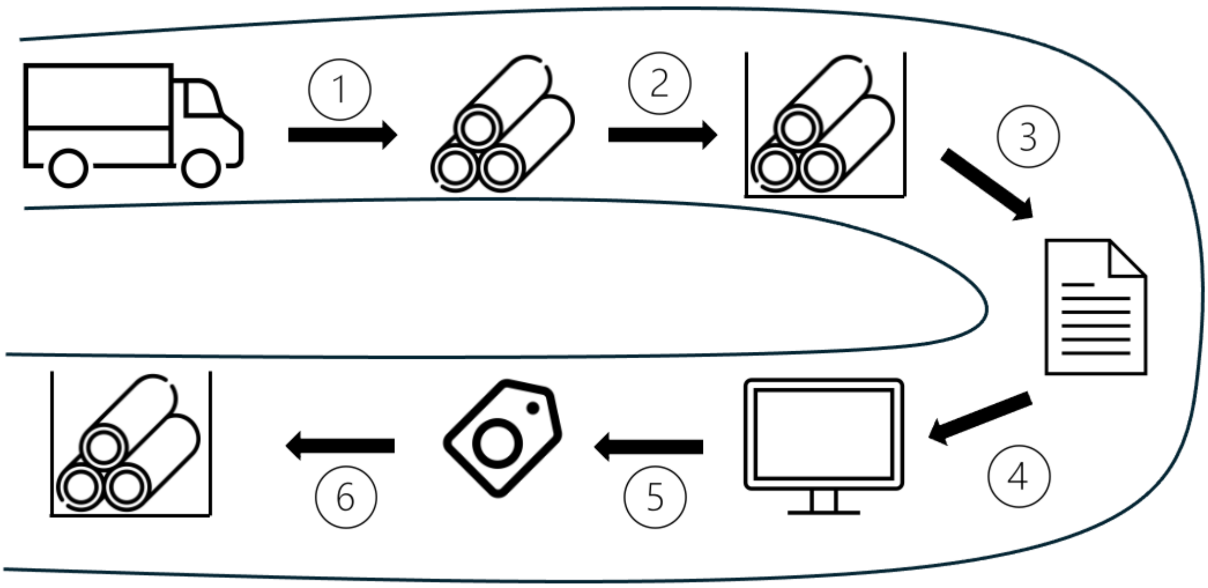


Figure 56: Activities of the Put-away & Storage process not using handheld scanners and mobile printers.

After the material has arrived in the warehouse of the case company, the warehouse employee checks the material and places the material within a storage place. Since the handling of the material is done either by forklifts but more often by overhead cranes, which therefore is a purely mechanical process, digitalization cannot replace the handling.

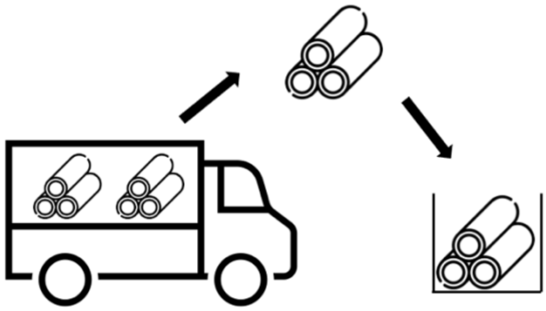


Figure 57: Activity 1 and 2.

Next, the warehouse employee walks to the warehouse management, to pass on the information in form of shipping papers that material has been received. As the walking distances were documented in Table 8, an average time for the warehouse employee to pass on the information was calculated to be 2:00 minutes. Since the warehouse employee needs to travel both ways, this adds up to 4:00 minutes of travel time.

Figure 58: Activity 3.

After the warehouse management has received the information about the delivered material, the warehouse management documents the received material within their WMS, prints the label that is going to be marked at the received material as well as scans the shipping papers to document the receiving. This process takes 4:07 minutes in average, as it can be seen in Table 7.

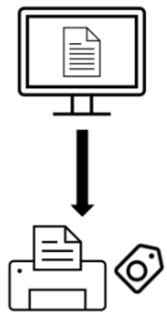


Figure 59: Activity 4 and 5.

After the warehouse management has documented the received material, the warehouse employee picks up the label and marks the label on the received material. Hereby, possible search time could occur as soon as the employee has forgot where the material was placed, or another employee picks up the label that has not placed the material after receiving it. That could extend the travel time of 4:00 minutes that the warehouse employee must take in average in order to pick up the label and mark the material, as it is documented in Table 8.

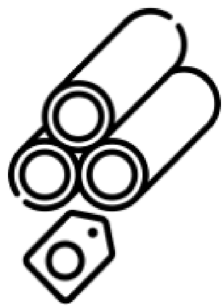


Figure 60: Activity 6.

Looking at the **Put-away & Storage process** in total, it **takes 12:07 minutes** in average adding up all times of the described activities that are taken into account to compare them further to the time the process would take when digitalizing the process.

When digitalizing the Put-away & Storage process using handheld scanners and mobile printers, the following order of activities needs to be walked through, as it is also illustrated in Figure 61.

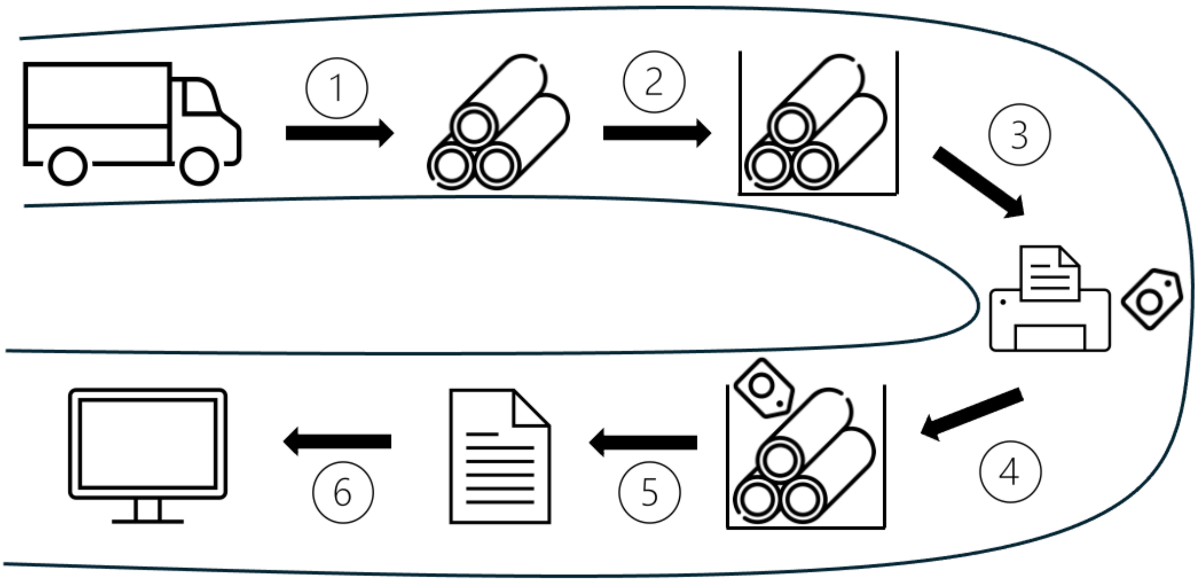


Figure 61: Activities of Put-away & Storage process using handheld scanners and mobile printers.

Like for the non-digitalized process, after receiving the material the warehouse employee checks the material and places the material within a storage place. Since the arrival of the material cannot be digitalized as well as the material handling, those activities are equally to the non-digitalized process. However, as the warehouse employee works with a handheld scanner and a mobile printer, the documentation of the storage location of the material can be digitalized. This takes 0:56 minutes in total, as the average time for scanning takes 0:46 minutes (Table 5) and the time for printing the label with the mobile printer takes 0:10 minutes (Figure 54).

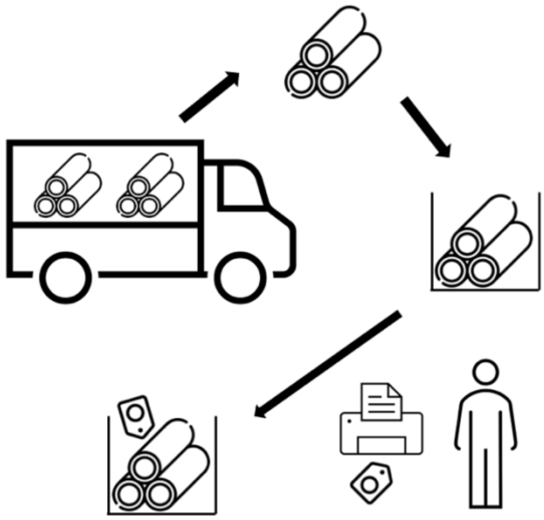


Figure 62: Activity 1 to 4.

Afterwards, the warehouse employee walks to the warehouse management to pass them the information in form of the shipping papers that material has been received. This takes the warehouse employee 4:00 minutes of travel time.

Figure 63: Activity 5.

Lastly, the information is documented into the WMS by the warehouse management. However, in the digitalized process of Put-away & Storage, this only takes 3:35 minutes as the time for labeling 0:32 minutes (Table 7) can be subtracted from the previous total time of 4:07 minutes.

Figure 64: Activity 6.

Looking at the **digitalized process of Put-away & Storage**, the total time it takes for all activities to fulfill the process **is 8:31 minutes**.

When **comparing the total times** of the non-digitalized process of put-away and storing (12:07 minutes) with the digitalized process (8:31 minutes), it can be identified that the digitalized process is roughly **30% more time efficient** than the non-digitalized process as travel time is reduced.

Picking process

In this section the Picking process is going to be analyzed. To identify possible waste and therefore room for improvement by using mobile devices, first the current process of picking target material is being described and afterwards compared with how much of an impact there would be when using handheld scanners and mobile printers during the picking process of today.

As of today, the Picking process is done in the following order of activities, as it is also illustrated in Figure 65.

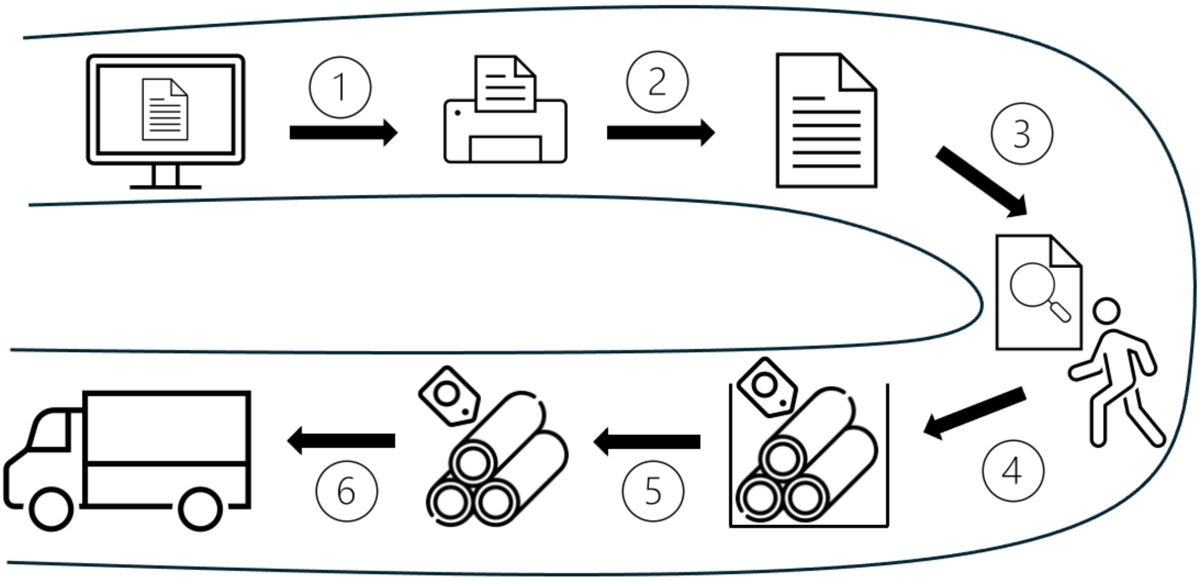


Figure 65: Activities of Picking process not using handheld scanners.

After the warehouse management has received an order, the order is going to be printed in form of an invoice. That invoice needs to be passed to the warehouse employee, who will further pick the material that was ordered. Therefore, the warehouse management needs to walk to the working station of the warehouse employee to inform the warehouse employee about the order and to hand over the invoice. This takes 4 minutes, as documented in Table 8, since the warehouse management needs to walk to the working station as well as back to the warehouse management office.

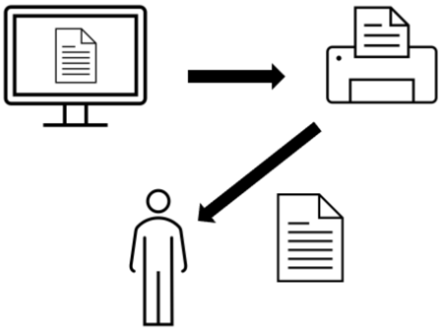


Figure 66: Activities 1 to 3.

After the warehouse employee has received the invoice with all the information one needs in order to process the order correctly, the warehouse employee starts searching for the material. This takes 3:33 minutes in average as documented in Table 5.

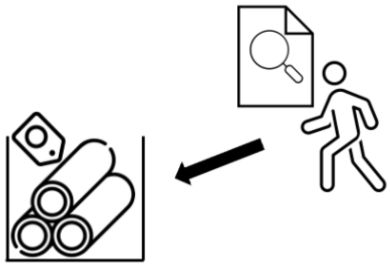


Figure 67: Activity 4.

Once, the warehouse employee has found the target material, the material can be picked either by a forklift or by an overhead crane. This process can possibly be interrupted if the target material is underneath unneeded material. In this case, the material needs to be sorted, and another process must start which is described further in the analysis.

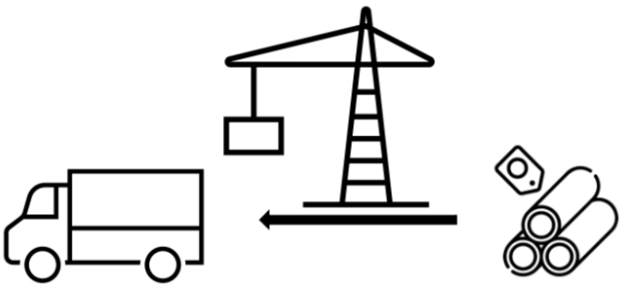


Figure 68: Activities 5 and 6.

Looking at the **Picking process** in total, it **takes 7:33 minutes** in average adding up all times of the described activities that are taken into account to compare them further to the time the process would take when digitalizing.

When digitalizing the Picking process using handheld scanners, the following order of activities needs to be walked through, as it is also illustrated in Figure 69.

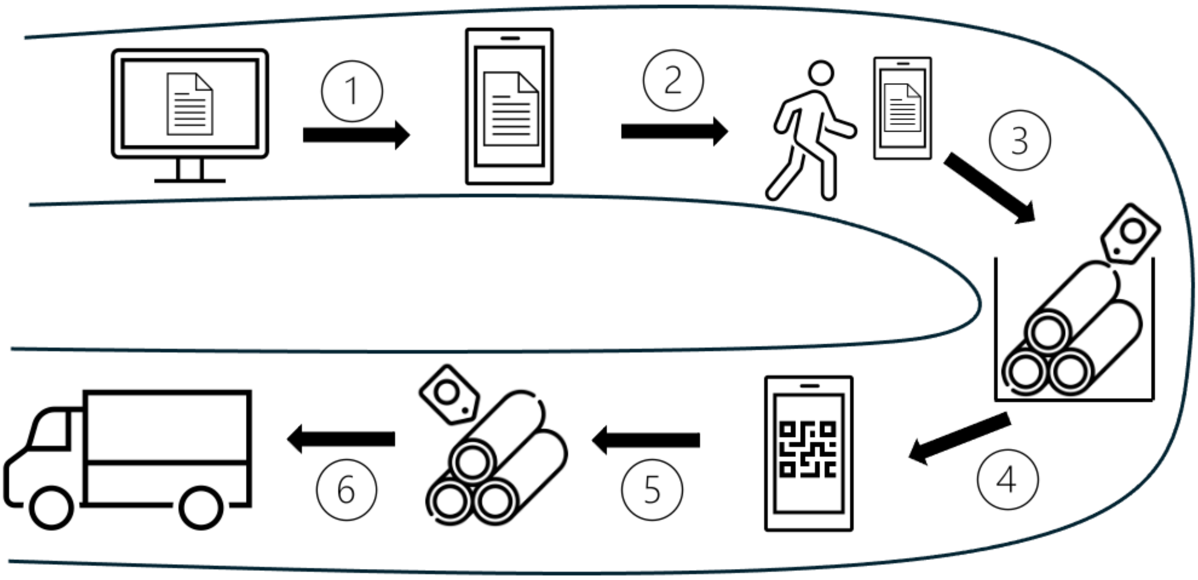


Figure 69: Activities of Picking process using handheld scanners.

In the digitalized Picking process, the warehouse management receives the order and can transfer the order onto the handheld scanner of the warehouse employee, thus eliminating the travel time of 4 minutes to manually hand over the invoices by paper. This process is equivalent to the process of pressing the print button as it is equal to the process documented in Figure 54 and is therefore calculated with a time of 0:10 minutes.

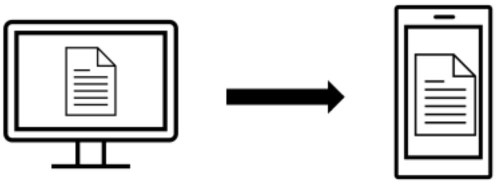


Figure 70: Activity 1.

Next, the warehouse employee can walk to the target material. In the digitalized process the search time of 3:33 minutes can be eliminated because the scanner system does know where the material is located. Therefore, only the travel time of the warehouse employee needs to be considered, which is 0:42 minutes, as it was documented in Table 6.

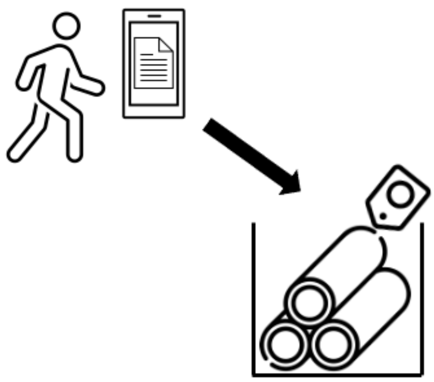


Figure 71: Activities 2 and 3.

Lastly, the warehouse employee documents the picking process by scanning the label of the material as well as the barcode of the storage location. This takes 0:46 minutes as it was documented in Table 5.

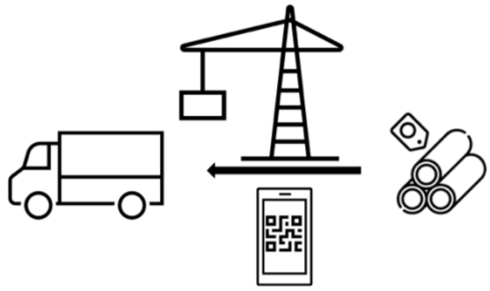


Figure 72: Activities 4 to 6.

Looking at the **digitalized Picking process** in total, it **takes 1:38 minutes** in average adding up all times of the described activities that are considered to compare them further to the time the process takes when not digitalized.

When **comparing the total times** of the non-digitalized process of picking (7:33 minutes) with the digitalized process (1:38 minutes), it can be identified that the digitalized process of picking is roughly up to **78% more time efficient** than the non-digitalized process. This is due to the significant reduction of waste during the search activity as well as the travel time, which is in line with the research that has been gathered about efficiency increases in picking processes (Sgarbossa et al., 2022; SAP, 2024b; Woods, 2024). However, to analyze this process correctly, it needs to be mentioned that in a non-digitalized picking process orders are not passed to the warehouse employee individually. As they are mostly handed over to the warehouse employee in a bundle of four different orders, the travel time to hand over the information by paper needs to be divided by four in order to get the real efficiency increase per order. Therefore, the non-digitalized process of picking takes 4:33 minutes while the digitalized process still takes 1:38 minutes. However, this is still an **efficiency increase of 64%** during the picking process when digitalizing by using mobile scanners.

<u>Sorting process</u>

In this section the Sorting process is going to be analyzed. To identify possible waste and therefore room for improvement by using mobile devices, first the current process of sorting material is described and afterwards the digitalized process is described to be able to compare how much of an impact there would be when using handheld scanners during the sorting process of today.

As of today, the Sorting process is done in the following order of activities, as it is also illustrated in Figure 73.

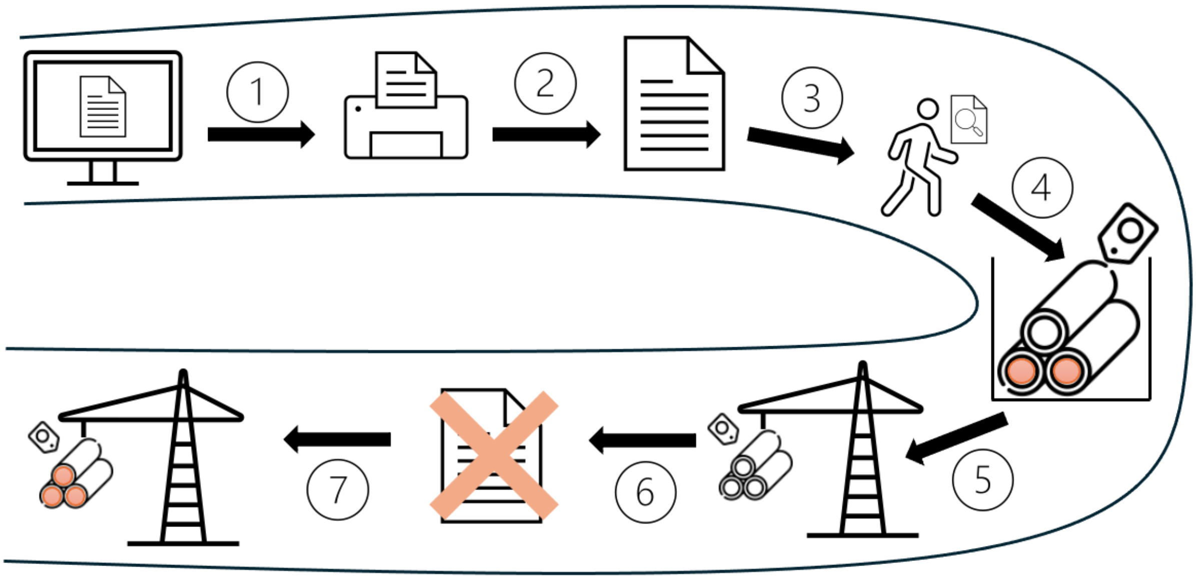


Figure 73: Activities of the Sorting process using no handheld scanners.

As the activities 1 to 4 of the non-digitalized Sorting process are equal to the Picking process and they have been described previously, the analysis of the activities starts at the point where the warehouse employee notices that the target material is blocked by other material. This material needs to be moved away to be able to pick the target material. Until the target material can be picked, the **non-digitalized Sorting process takes 9:59 minutes in average** (disregarding the time for transferring the order to the scanner of the warehouse employee, as this is not part of the actual Sorting process), as it was documented in Table 5. As the unneeded material is only placed somewhere else and this process is not documented, the new location of the unneeded material is not known in the future.

When digitalizing the Sorting process using handheld scanners, the following order of activities needs to be walked through, as it is also illustrated in Figure 74.

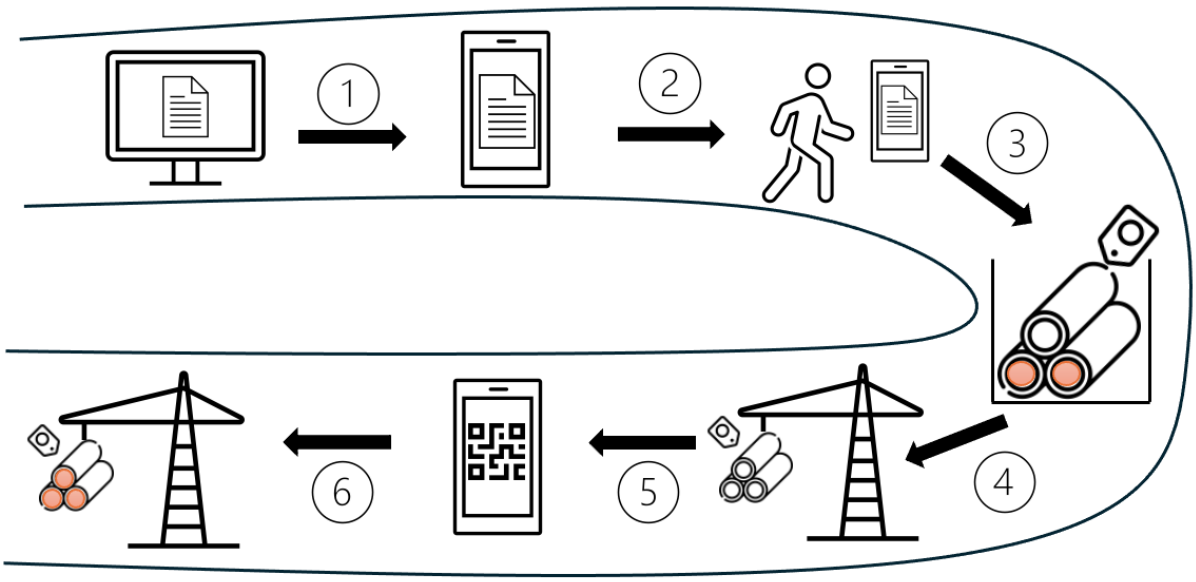


Figure 74: Activities of the Sorting process using handheld scanners.

In the digitalized Sorting process, the activities 1 to 3 are equal to the activities of the digitalized Picking process and are therefore not described. As previously described, the analysis starts when the warehouse employee has noticed that the target material is blocked. After that, the warehouse employee moves the unwanted material to another storage location to be able to pick the target material. However, this process is going to be documented using the handheld scanner by scanning the label of the unwanted material as well as the new storage location. By that the new storage location of the unwanted material is known in the future. The process of the **digitalized Sorting process takes 10:45 minutes**, as rearrangement takes 9:59 minutes and scanning 0:46 minutes in average disregarding the time for transferring the order to the scanner of the warehouse employee, as this is not part of the actual Sorting process, as documented in Table 5.

Comparing both Sorting processes one can identify that the **digitalized Sorting process takes roughly 8% more time** than the non-digitalized Sorting process. However, comparing the two different sequences of activities of the Sorting process, more than only the process time needs to be discussed. Digitalization cannot fasten up the rearrangement of the forklift or the overhead cranes, however, digitalizing the Sorting process does fasten up future processes, as it documents the new location of the unneeded material (Woods, 2024; Integer Solutions, 2024). Therefore, the **digitalized Sorting process reduces the search time** of the moved material **by roughly 80%**, as documented in Table 5 and Table 6 where 3:33 minutes of search time are reduced to only the travel time of 0:42 minutes. As rearrangement of the material happened in 30% of the times when observing the Picking process (Table 5), it can be concluded that the digitalized Sorting process increases efficiency rather than decreasing it, since the process time increase of 8% is valued less than the search time decrease of 80%, as the Sorting process only happens in 30% of the cases but the search time happens in 100% of the times material is going to be picked.

5.2 Limitations of the analysis

Looking back at the analysis and the results drawn from it, some limitations of the analysis are recognizable, particularly attributable to the data that has been collected. There have been efforts collecting comprehensive and accurate data, however, there are still limitations, which can influence the conclusions. This section will take a closer look at the limitations of the data and how this affects the analysis.

Firstly, the more data that is being observed the better. This means that with more data about the material flow as well as the information flow, the more realistic the as-is situation of the processes can be displayed and analyzed. With forty observations in total for the material and the information flow, sufficient data has been observed in order to get different cases of the daily processes. However, by gaining more data about specific cases the quality and the completeness of the data could be increased.

Moreover, despite carefully checking the data, there may be errors that can lead to bias. Certain data sources may not provide all relevant information or bias the data because when observing work, the warehouse employees may work differently than they do when no one is observing their work. Additionally, it is possible that shifts or people work differently and therefore provide other data. Other than that, seasonality could possibly bias the data. The time of the observations was during a time of a lower order book situation than it usually is. This may result in the analysis not reflecting the full picture, thus limiting its informative value.

Another important aspect is the methodological limitation. When selecting the experimental method, sometimes assumptions must be made, for example that the warehouse employees' affinity to technological change could be limited since most of them have done their work processes for multiple years and their increased age makes technological change more difficult. Moreover, during the experimentation phase of the scanners and the mobile printers, assumptions in the usability needed to be made in order to simulate the usage of someone who is not as affine for the usability as the person who was doing the experiment.

It is also important to note that the results of this analysis cannot be generalized to other situations. Therefore, the conclusions of the analysis could only be relevant for the specific case of Heine + Beisswenger and should be interpreted cautiously when applying to other contexts. However, to interpret the results of this analysis and their applicability, it was important to transparently report the limitations of this analysis and interpretation therefore is possible for further research or other companies facing efficiency problems.

6. DESIGN PROPOSITIONS

To fulfill the purpose of the thesis, which is to investigate opportunities to increase warehouse efficiency by digitalizing warehouse processes using mobile devices, this chapter provides design propositions that will include opportunities to increase efficiency for the material flow as well as the information flow using mobile devices. After answering the first three research objectives, the current warehouse processes have been described and their performance was measured as well as analyzed. The findings of these research objectives helped creating design propositions that show how mobile devices such as scanners and mobile printers can be used to increase the efficiency of warehouse processes.

As it can be seen in Figure 75, the design propositions are followed by an analysis of the propositions. Furthermore, the applicability of the design propositions is investigated.

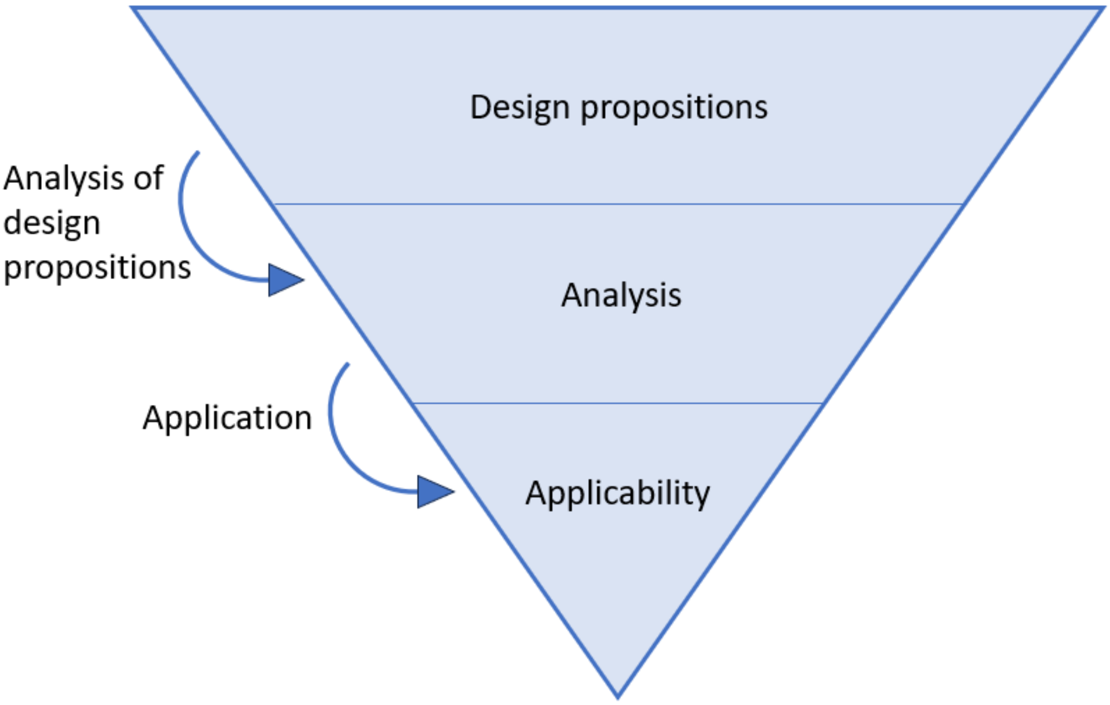


Figure 75: Overview of the design proposition process.

6.1 Design propositions

Having the purpose, the scope of the thesis as well as the results drawn from the analysis and previous literature review in mind, this section provides design propositions of how the processes could be designed more efficiently using mobile devices. As described in the methodology section of the thesis, the design propositions are created with the help of the CIMO approach of Olhager (2023a) and Denyer et al. (2008), illustrated in Figure 76.

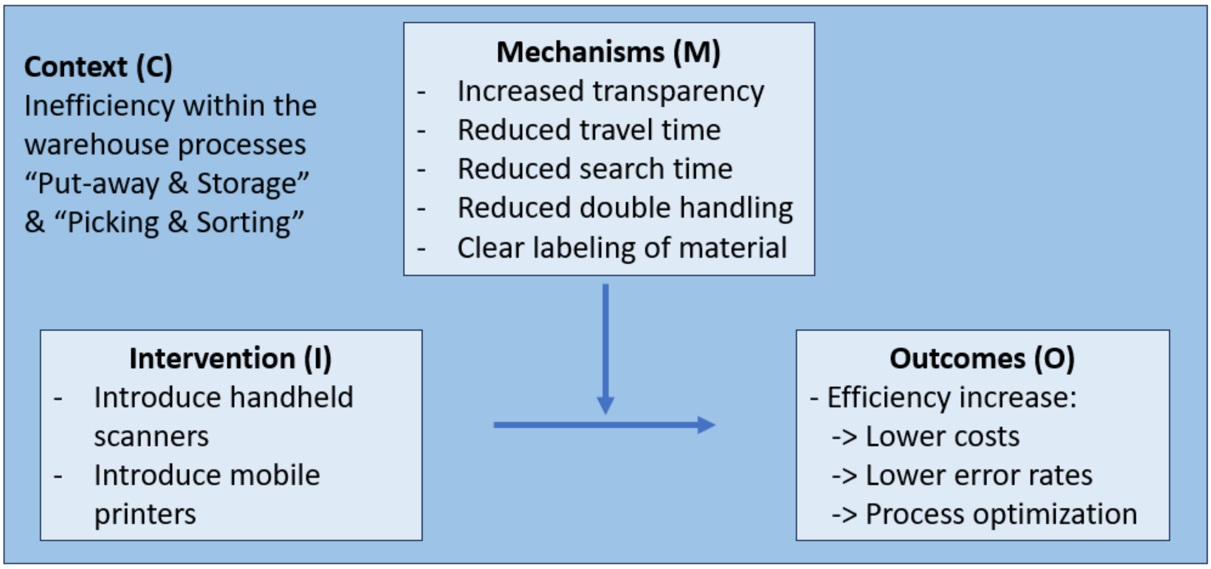


Figure 76: CIMO approach (Source: Olhager, 2023a and Denyer et al., 2008).

Further, the different design propositions for the warehouse processes "Put-away & Storage", "Picking", and "Sorting" will be formulated and explained with the help of illustrations of the process.

Design proposition 1: If Put-away & Storage processes are inefficient due to high travel times (context), use handheld scanners and mobile printers (intervention) to increase efficiency (outcome) by reducing travel time and mistakes as well as increasing transparency (mechanism).

Based on the design proposition handheld scanners and mobile printers are suggested to use during the process of Put-away and Storage, as the information which is stored in the WMS needs to be connected to the goods (Faber et al., 2002) providing transparency about the identity of each good in the warehouse (van Geest et al., 2021) and therefore leading to reduced error rates (Woods, 2024). Moreover, this is proposed, to reduce the travel time of the warehouse employee. As the analysis has provided, the warehouse employee travels eight minutes in total to label the material, since the warehouse employee needs to walk from the place where the received material is stored to the office of the warehouse management back and forth twice. When introducing handheld scanners as well as mobile printers, as illustrated in Figure 77, the warehouse employee is able to scan the shipping document (1) and print out a label (2) which can be attached to the just received material right away. This eliminates mistakes as well as half of the travel time, as the warehouse employee only needs to pass the shipping documents to the warehouse management but does not need to come back to pick up the label, as it is done currently. Furthermore, the warehouse employee can directly scan the printed label of the material as well as the label of the storage location, to document the storage location of the received material and therefore create transparency for upcoming picking processes (3).

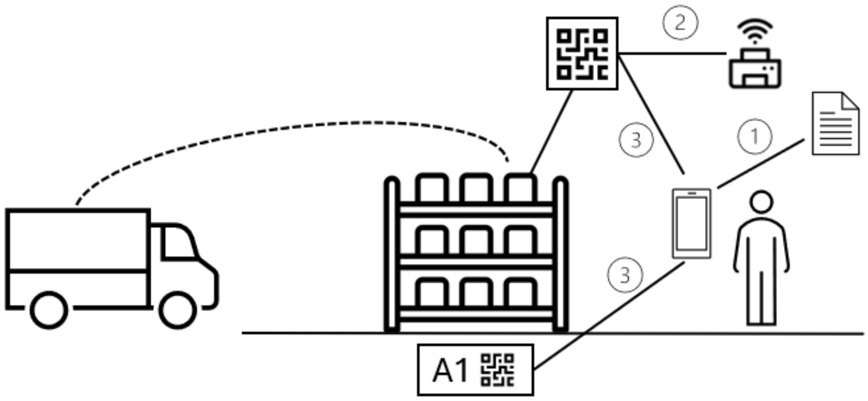


Figure 77: Design proposition 1.

Design proposition 2: If Picking processes are inefficient due to high search effort, use handheld scanners to increase efficiency by creating transparency and reducing search time.

Based on the design proposition handheld scanners are suggested to use during the process of Picking, as they can read the information stored behind a barcode (Integer Solutions, 2024) creating transparency by sharing information between internal functions (Kembro et al., 2017). This is proposed, to reduce the search time of the warehouse employee. As the analysis has provided, warehouse employees need 3:33 minutes in average to find the material they need to pick. However, when handheld scanners are introduced the search time can entirely be eliminated and reduced to the travel time the warehouse employee needs to walk to the storage location, as the exact storage location is displayed on the screen of the scanner (Figure 78) as soon as the warehouse employee receives the order by the warehouse management on the scanner. Besides that, the travel time of the warehouse management to hand over the orders by paper is also eliminated, as the order can be handed over to the respective warehouse employee by sending it on the scanner.

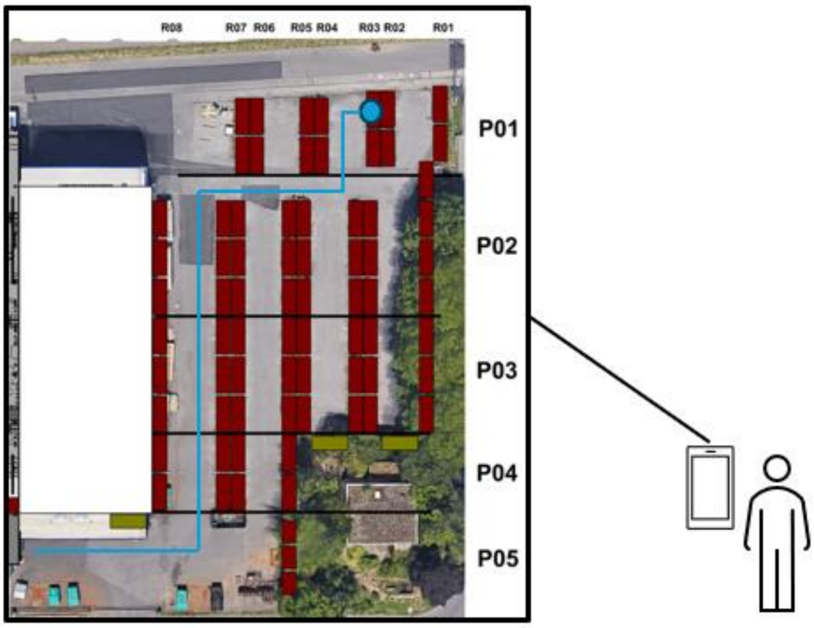


Figure 78: Design proposition 2.

Design proposition 3: If Picking processes are inefficient due to unclear, wrong, or no labeling, use handheld scanners and mobile printers to decrease error rates and therefore increase efficiency by clear labeling of the material.

Based on the design proposition handheld scanners as well as mobile printers are suggested to increase the efficiency during Picking processes, as they can be used for labeling goods directly in the goods receipt (4Logistic, 2024) and therefore increase efficiency further in the picking process as handheld scanners can read the labeling (Integer Solutions, 2024) reducing errors by not using spreadsheets and manual data (Woods, 2024). This is proposed, as of today material gets lost due to wrong or no labeling as well as unclear labels, as they get unrecognizable over time. When labeling the material and documenting the location as soon as the material is stored, as it was described in the first design proposition, wrong labeling can nearly be eliminated. Moreover, if a label detaches from the material or gets unrecognizable due to dirt or other reasons (Figure 79), the system still knows which material was documented on the respective storage location and a new label can be printed. This reduces errors of picking the wrong material.

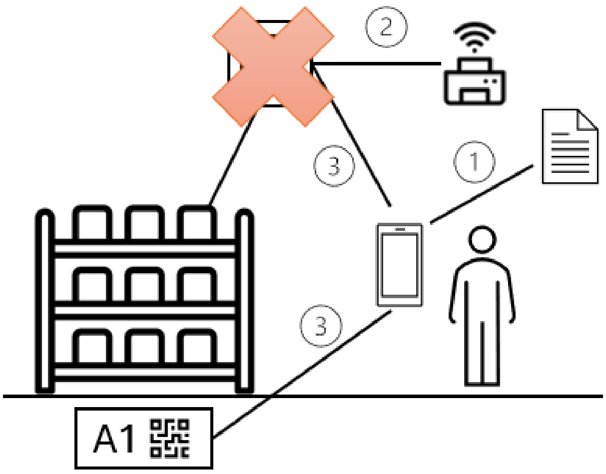


Figure 79: Design proposition 3.

Design proposition 4: In case of double handling during the Sorting process, use handheld scanners and mobile printers to increase efficiency by creating transparency and therefore reducing upcoming search times.

Based on the design proposition it is suggested to use handheld scanners during the sorting process. As the documentation of material movement and therefore information sharing is of great importance for companies (Kembro & Selviaridis, 2015) handheld scanners can be used to efficiently create transparency about material movement by scanning the labels on the material that previously have been created by mobile printers within the goods receipt. This is proposed, as after rearranging material, for example from storage place A1 to A2 (illustrated in Figure 80), the storage location is no longer A1. As long as that process is not documented, the upcoming picking process for the respective material will take a warehouse employee in average 3:33 minutes to find the material. In order to reduce and eliminate the upcoming search time and reduce it to the travel time, it is suggested to use handheld scanners during the sorting process to document the material movement.

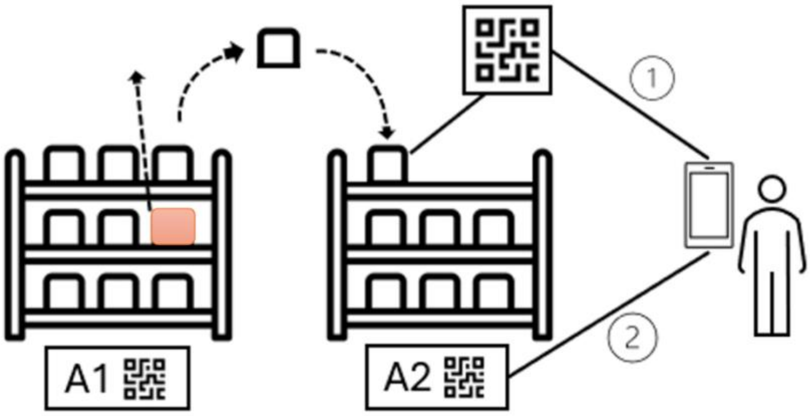


Figure 80: Design proposition 4.

Design proposition 5: If Sorting processes are inefficient due to high numbers of double handling, use an intelligent system with handheld scanners and mobile printers during the put-away & storage process to increase efficiency by reducing double handling effort.

Based on the design proposition it is suggested to use an intelligent system with handheld scanners and mobile printers already during the put-away and storage process that can organize itself (Integrated Production Hannover, 2024c) and therefore providing help and transparency for the warehouse employee to increase efficiency. It is proposed, to create a classification of material in A, B, and C material, which could stand for materials that are often moved (A), material that are moved from time to time (B), and material that is hardly ever moved (C). This could be furthermore shared with an intelligent system that will then tell the warehouse employee as material is received, where the respective material based on the classification, should be stored in order to reduce double handling in future picking processes. That would have the consequence, that materials with the same classification are stored in the same racks which decreases the likelihood of double handling compared to when materials of all three classifications are stored on top of each other in the same rack.

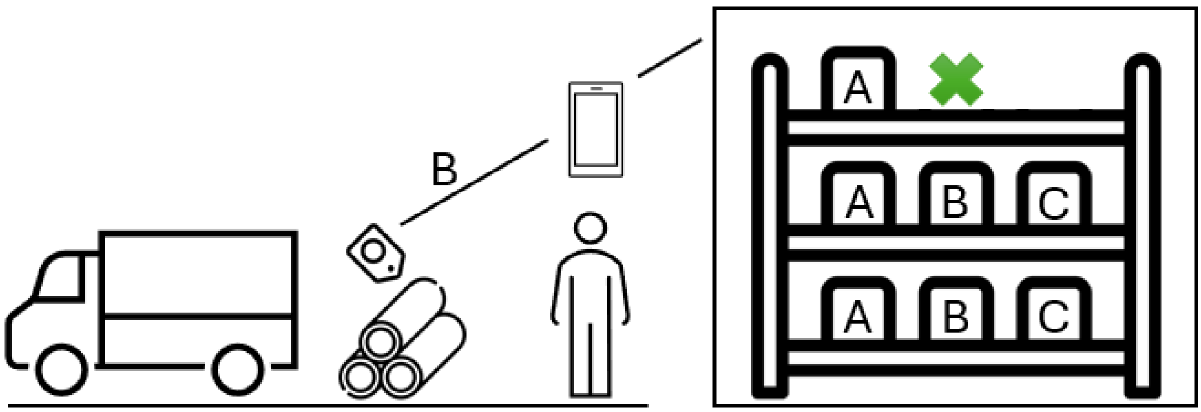


Figure 81: Design proposition 5.

Design proposition 6: If Sorting processes are inefficient due to long rearrangement times, use handheld scanners and an intelligent system to increase efficiency by increasing transparency and reducing future double handling.

Based on the design proposition it is suggested to use an intelligent system with handheld scanners during the Sorting process, as it makes material handling activities like transportation and sorting easier (Sgarbossa et al., 2022) and therefore the process more efficiently. This is proposed, because in case of the need to rearrange material in order to pick the target material, the warehouse employee can scan the unwanted material and an intelligent system can display the best location on the scanner. It is suggested to base the best location on the decision parameters distance, space as well as the classification the material was categorized to, as described in the fifth design proposition. This would increase transparency for the warehouse employee when rearranging as well as reducing the need for double handling in future picking processes. Figure 82 illustrates how such a system could be displayed. In this case the warehouse employee needs to relocate "B" material. Since the scanner marks all free storage locations of each category, the warehouse employee saves time for the relocation as well as for sorting the material together with the material of the same category which reduces upcoming double handling.

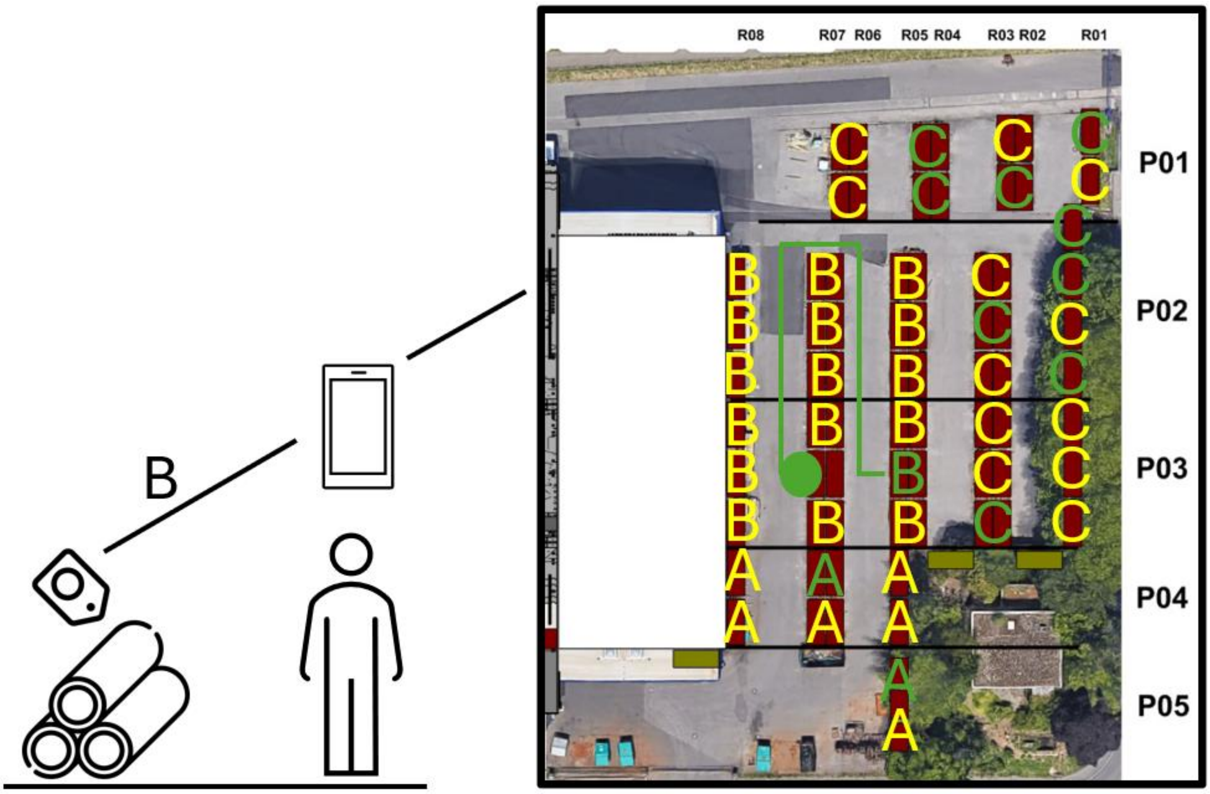


Figure 82: Design proposition 6.

6.2 Analysis of the design propositions

Considering the purpose of the thesis, the design propositions provide opportunities to increase warehouse efficiency by digitalizing the warehouse processes of material as well as information flow with the use of handheld scanners and mobile printers. With the help of the observations, unstructured interviews, as well as the experiments and literature review, the design propositions were created. By analyzing the newly designed processes, one can identify that there is not only a numerical increase of warehouse efficiency when implementing the design propositions.

Looking at the efficiency increase of the design propositions it is safe to say that one cannot calculate the efficiency increase to an extend where there is an exact percentage of how much efficiency can be increased. This is because the investigated flows, namely material and information flow, may happen not in the structured way as they were described. Reasons for that could be interactions with other stuff or problems could arise during the flows and the warehouse employee stops the working step for a moment to help someone else. However, after observing the current flows and comparing them with the proposed processes, the calculated efficiency increases of the Put-away & Storage process could be as high as 30% while the efficiency increase of the Picking process could be as high as 64%. This is attributable to the digitalization and the smarter use of mobile devices, eliminating multiple working steps that are currently part of the processes of the material and the information flow. Especially considering the possible efficiency increase of the Picking process is of interest, as Chen et al. (2015) and Bélanger et al. (2023) have stated that 60-70% of the warehouse costs equate to the process of picking.

Moreover, besides eliminating parts of the processes other sources of mistakes can also be reduced, which cannot be identified by only looking at the numbers. Particularly the search effort of finding the respective material includes some sources of mistakes that could not be calculated into the efficiency increase, but they will be eliminated through the design propositions thus they need to be analyzed.

Whenever, the warehouse employee receives new material, it is stored, and the warehouse employee will inform the warehouse management about a newly received material. However, sometimes the warehouse management needs a lot of time to document the received goods in the WMS and to create the labels that need to be attached to the material. In that case, a double search effort could occur since too much time has passed for the warehouse employee to remember exactly where the material was placed. Therefore, when picking up the labels that needs to be marked on the received material, the warehouse employee needs to search for that material. Even when finding the material quick, there still is an opportunity to label the wrong material, since mostly the warehouse employees pick up multiple labels for multiple different materials that they have received. Additionally, as the labels of today are not glued to the material, there is risk that labels detach from the material, making it difficult to allocate the material without any label. Those sources of mistakes cannot be measured directly in the efficiency increase calculations, but they will be reduced by implementing the design propositions, as they provide transparency, reduce travel time, search time, as well as double handling.

6.3 Applicability of the design propositions

To check the applicability of the design propositions, various factors must be considered. First of all, the applicability of the suggested design propositions needs to be looked at whether or how they can be integrated into the current warehouse processes.

When implementing the design propositions handheld scanners as well as mobile printers need to be introduced to the processes. Therefore, warehouse employees need to be trained on how those devices. Training needs to be organized where the new processes are described and how they are done with the help of handheld scanners and mobile printers. As the design propositions only create more efficiency when they are implemented correctly, there still needs to be someone who checks that the processes are carried out correctly in the beginning and who could help when there are problems.

Next to the training and the transition period that is necessary to implement the design propositions, it needs to be checked whether they require infrastructural changes in the warehouse. In addition to the expansion of the IT infrastructure which is required to run the software without errors so that the processes with the handheld scanners and mobile printers work, the layout of the warehouse does not need to be changed. Therefore, no new shelves or storage locations need to be set up.

However, in order to implement the design propositions, it is necessary to calculate the investment costs. For that, plans must be created on how many handheld scanners and mobile printers would be required to cover the daily processes with all employees. Setting up the IT infrastructure will be the largest financial investment, as an external company most likely will have to be commissioned for this. As those costs vary depending on the size of the company, the applicability considering the finances cannot be clarified. However, as the case company has shared their investment costs as well as their economic and logistic key figures, it was possible to calculate the return on investment after measuring the efficiency increases of the processes put-away & storage as well as picking. As illustrated in Figure 83, the case company has potential savings of 168.485,94€ per year after implementing the proposed design propositions for the processes of Put-away & Storage as well as Picking, leading to a return on investment of 1,59 as the investment is as high as 268.000€ for five years. In total, the case company would save 574.429,7€ for five years.

127894	Positions
00:03:08	per Position
6678:54:32	in h
25,23 €	Hourly rate
168.485,94 €	**Potential savings per year**
268.000,00 €	Invest for 5 years
1,59	**ROI**
574.429,70 €	**Savings for 5 years**

Figure 83: ROI calculations.

As the numbers show, implementing the design proposition leads to significant savings and therefore provides financial incentives to implement them. For future research or other companies considering adopting the design propositions, the following should be taken into account during the process of implementation. To ensure that the changes work well, tests must be run. These should take place in close cooperation with the company responsible for the IT installation, as any errors that occur can be addressed and changed directly with them. If the introduced IT system works, a test version of the day-to-day processes should be run through, as the system should only be introduced if the day-to-day processes can also be mastered without any problems. If this also works smoothly, the employees must be trained. One possibility would be to add them to the test processes, as they carry out the processes on a daily basis and may have concerns. At the same time, the employees are learning the new application to ensure a good transition when the new processes are finally introduced.

7. CONCLUSION

To round up the thesis this chapter will provide a conclusion about the research that has been done to investigate opportunities to increase warehouse efficiency by digitalizing warehouse processes using mobile devices. In order to conclude the thesis, the first part of the chapter discusses the purpose fulfillment. Secondly, the contribution of the thesis to the research field as well as the case company Heine + Beisswenger is being discussed. Lastly, limitations of the thesis as well as future research are going to be presented.

7.1 Purpose fulfillment

The purpose of the master thesis has been to investigate opportunities to increase warehouse efficiency by digitalizing warehouse processes using mobile devices. The intension of the purpose was to investigate opportunities on increasing warehouse efficiency by using handheld scanners and mobile printers and therefore contributing to existing literature as well as providing design propositions for the case company Heine + Beisswenger. Therefore, the thesis has followed a design science approach, based on which the research process was structured. In the following a foundation of knowledge was built through a thorough literature review that has been performed. Moreover, a conceptual framework was created to guide on how the purpose is going to be fulfilled. To understand the current processes observations, unstructured interviews as well as secondary data and experiments have been used to gather data which in the following was analyzed. Through analyzing the gathered data, design propositions were created to increase warehouse efficiency by using handheld scanners and mobile printers.

RO1: *Describe the current process of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.*

During the empirical part of the thesis, the first research objective was accomplished within two parts. First the current process of the material flow was described. This has been done with the help of 20 observations as well as unstructured interviews. Moreover, secondary data was used to create tools, such as the mapping of the layout, which has been used for the observations. To describe the current information flow, another 20 observations as well as unstructured interviews has been made. The results have been that previously whenever material is received it is stored within an area dedicated to the material type. Afterwards, the warehouse employee walks to the warehouse management office to inform about the material that has been received by passing on the shipping documents. The warehouse management furthermore documents the information about the received material within the WMS and prints a label that is going to be marked at the material by the warehouse employee to be able to find the material when it is going to be picked. Whenever the warehouse management receives an order, it informs the warehouse employee by handing over an invoice with the information about the respective material. Then, the warehouse employee starts looking for the material and is going to pick it when it is found. The first research objective therefore can be seen as a foundation for the design propositions suggested to fulfill the purpose of the thesis.

RO2: *Identify the performance of the current material and information flow between the incoming goods, the storage as well as the retrieval of the goods.*

The second research objective was done to identify the performance of the current processes. In order to be able to create design propositions the current performance needs to be recorded. This was done with the help of 40 observations in total for both, the material as well as the information flow. Each observation was carried out individually recording the total time of the process but also the time of the subdivided processes. For the material flow this has been done for the search time, which has been 3:33 minutes in average as well as for the rearrangement time, which in average took 9:59 minutes to relocate the material in order to pick the target material. The information flow was subdivided into the processes of SAP (2:40min), labeling (0:32min) and scanning (0:54min) providing an average total time of 4:07 minutes as well as the walking time it takes for the warehouse employee to pass the information to the warehouse management, which took on average 2:00 minutes. By observing all these processes, the performance of the current processes was identified between the incoming goods, the storage as well as the retrieval of the goods.

RO3: *Determine the parts of the material and information flow between the incoming goods, the storage as well as the retrieval of the goods that can be improved through digitalization by using mobile devices.*

In order to be able to propose digitalized solutions, the third research objective provided an analysis that identified parts of the current processes that can be improved through digitalization using handheld scanners as well as mobile printers. By using the previously gathered data as well as experiments, that have been carried out about the times it would additionally take when including handheld scanners (0:46min) and mobile printers (0:10min) into the current processes, the performance measurements of the processes of put-away and storage as well as picking and sorting have been analyzed. By documenting the data, the average performances of the different processes were calculated, allowing to determine the current performance. By comparing the performance of the current processes with the time it would take when including handheld scanners and mobile printers, parts of the processes were identified as waste. The results have been that the digitalized process of put-away and storage has been roughly 30% more time efficient than the non-digitalized process. Moreover, the picking process has been identified as being 64% more efficient as the current one while the sorting process takes roughly 8% longer but reducing future search time by roughly 80%, as the digitalized sorting process documents the material movement in contrast to the non-digitalized process of today.

The waste which has been identified during the third research objective plays a major role for the design propositions, as they propose opportunities to reduce the waste in order to increase efficiency.

RO4: *Propose digitalized solutions which improve the efficiency of the material and the information flow between the incoming goods, the storage as well as the retrieval of the goods.*

By using the data gathered from the first three research objectives, design propositions were proposed. Those design propositions focused on the waste identified during the analysis. With the help of experiments, the use of handheld scanners and mobile printers was tested as well as data was measured about their performance when using those devices within the material flow as well as the information flow. Since the analysis of the performance of the mobile devices has shown opportunities to increase efficiency when using those devices within the processes, the design propositions were designed around the usage of a handheld scanner and a mobile printer and have been formulated as followed:

Design proposition 1: If Put-away & Storage processes are inefficient due to high travel times, use handheld scanners and mobile printers to increase efficiency by reducing travel time and mistakes as well as increasing transparency.

Design proposition 2: If Picking processes are inefficient due to high search effort, use handheld scanners to increase efficiency by creating transparency and reducing search time.

Design proposition 3: If Picking processes are inefficient due to unclear, wrong, or no labeling, use handheld scanners and mobile printers to decrease error rates and therefore increase efficiency by clear labeling of the material.

Design proposition 4: In case of double handling during the Sorting process, use handheld scanners and mobile printers to increase efficiency by creating transparency and therefore reducing upcoming search times.

Design proposition 5: If Sorting processes are inefficient due to high numbers of double handling, use an intelligent system with handheld scanners and mobile printers during the put-away & storage process to increase efficiency by reducing double handling effort.

Design proposition 6: If Sorting processes are inefficient due to long rearrangement times, use handheld scanners and an intelligent system to increase efficiency by increasing transparency and reducing future double handling.

By answering those four research objectives throughout the thesis, with the help of the conceptual framework, the purpose of the thesis was fulfilled, as the design propositions illustrate opportunities to increase efficiency of the warehouse processes by using handheld scanners and mobile printers.

7.2 Contribution

As described in the methodology part of the thesis, the research process in Figure 13 followed the structure of gaining knowledge through the phases of framing, creating, and validating where knowledge was gained about the problem area, frameworks have been created to fulfill the purpose of the thesis and they have been validated by evaluating the performance of the design propositions. Furthermore, the gained knowledge was used to create more generalized theory which through the publication of the thesis is communicated to the research field and the case company.

Since the thesis was conducted using the Design Science methodology and thus has both theoretical and practical approaches, the thesis offers both theoretical and practical contributions. As BDI & PwC (2015) has stated that digitalization is already part in many industries, a lot of companies especially small and medium-sized enterprises lack behind and need to catch up. Therefore, the thesis contributed theoretical as well as practical contributions, that aim on providing valuable knowledge to further transform industries into digitalization as many small and medium-sized enterprises are facing major challenges implementing digitalization.

The theoretical contribution of the thesis is within the areas of: (1) providing knowledge about how to digitalize warehouse processes thus increasing their efficiency using handheld scanners and mobile printers, (2) how to analyze warehouse processes using observations combined with unstructured interviews and experiments, as well as (3) providing design propositions for increasing warehouse efficiency using handheld scanners and mobile printers. This has been done with the help of literature about warehouse digitalization (such as Tiwari, 2023 or Kembro & Norrman, 2021), performance efficiency (such as Jenkins, 2022 or Kusrini et al., 2018), mobile devices (such as van Geest et al., 2021 or Woods, 2024) as well as material and information flow (such as Meyers & Stewart, 2002 or Pereira, 2009). Moreover, frameworks have been created supported by existing literature, such as Romme & Dimov (2021) or Peffers et al. (2007). Those frameworks, provide guidelines for future research on how to gather data through observations combined with unstructured interviews, how to use different tools like spaghetti diagrams to further use these tools to analyze the data as well as designing propositions using the analyzed data. Moreover, the thesis not only provided design propositions about how to digitalize warehouse processes, but also has elaborated the positive financial impact implementing digitalization within warehouse processes using handheld scanners and mobile printers could have after analyzing the financial impact the case company will possibly have in the future.

This leads to the practical contribution the thesis has provided for the case company Heine + Beisswenger through the design propositions that has been suggested with the usage of the conceptual framework. First, the thesis provided Heine + Beisswenger with detailed description of the warehouse processes within the scope as well as data gathering about those respective processes. Secondly, experiments have been carried out using handheld scanners and mobile printer to identify possible efficiency increases. Moreover, the data of the current processes has been compared with the data of the experiments and furthermore analyzed to identify efficiency increases. Additionally, the gathered knowledge from the analysis has been used to create design propositions that provide Heine + Beisswenger how they can implement handheld scanners and mobile printers within their current processes.

7.3 Limitations and future research

As the thesis was completed with a case company, the design propositions are based on data that has been collected from Heine + Beisswenger. Therefore, the conceptual framework also was only applied to one company thus decreasing possible generalizability. This means that after going through the process of the conceptual framework the design propositions were adapted to the layout of the warehouse of Heine + Beisswenger as well as the processes that were recorded, analyzed and evaluated in their warehouse. Accordingly, the design propositions could be more generalized if the data could be compared with other but similar processes of other companies. This provides the possibility for future research as it would be interesting to experience the conceptual framework at different companies that are interested in increasing the efficiency of their warehouse processes with similar warehouse material. Moreover, this would provide new data which could be compared to the results of this thesis leading to findings that could provide interesting knowledge. As this would provide the possibility to develop advanced design propositions on how to increase efficiency within warehouse processes using mobile devices such as handheld scanners and mobile printers, the future research would be mainly interesting for the case company to look into.

Moreover, the gathered data of this thesis is limited to the methodology that was chosen. As described in the second chapter the chosen methodology is suitable for fulfilling the purpose of the thesis. However, changing the methodology by adding another data gathering method such as structured interviews, would provide more detailed data about the processes which would possibly lead to more advanced data that could be used by developing more advanced design propositions. This future research would be interesting for the case company as there is the possibility for more advanced design propositions that can be implemented. For the research area in general, this also would be interesting to gather data about more advanced design propositions as well as investigating the difference between the data gathering methods of observations with unstructured interviews and structured interviews. This could provide valuable data about which methods is better to use to get more accurate data, which can be used within the research field.

Another, limitation was that the scope was within the steel industry as well as long goods. Therefore, it would be interesting for the research field to gather more information about companies dealing with similar problems as the case company but are within different industries. This would provide the opportunity to compare the different data and identify new knowledge about the research field of increasing warehouse efficiency using handheld scanners and mobile printers.

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APPENDIX

Appendix A

	Number of Deposits	Number of Removals	
	1910	6052	
	2565	2850	
	1724	4576	
	454	948	
	2332	8853	
	366	559	
	2770	7967	
	4460	6407	
	2197	12926	
	2149	5517	
	2359	12783	
	4466	16627	
	271	1085	
	2871	9850	
Positions	**30894**	**97000**	**127894**
Time savings per position	**00:03:36**	**00:02:55**	**00:03:08**

127894	Positions
00:03:08	per Position
6678:54:32	in h
25,23 €	Hourly rate
168.485,94 €	**Potential savings per year**
268.000,00 €	Invest for 5 years
1,59	**ROI**
574.429,70 €	**Savings for 5 years**