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Technical solutions for automation of warehouse operations and their implementation challenges

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Abstract

Purpose
The purpose of this study is to focus on the challenges with the implementation of technical solutions for automation of warehouse operations for the movement and tracking of goods. Additionally, the focus is on the similarities and differences between the identified challenges in theory and practice.

Methodology
This study employs a qualitative research strategy with a cross-sectional research design. A qualitative analysis of the challenges for the automation of warehouse operations is done, with the help of semi-structured interviews of 9 different companies.

Theory
The theory chapter starts with an introduction of warehouse management systems (WMS) and the differentiation between the main and supportive warehouse processes, whereby the focus is drawn on the supportive processes. The supportive processes are differentiated into the movement and tracking of goods. For the movement of goods automated guided vehicles (AGVs), Automated forklifts and Automated conveyor systems are analyzed. For the tracking of goods Barcodes, QR-Codes and RFID technology is examined. These two areas are also analyzed regarding their identified challenges.

Analysis
The analysis is based on the identification of the challenges from theory and empirical data for the tracking and movement of goods within a warehouse. Therefore, the empirical perceived challenges are processed and merged together. Afterwards, the theoretical and empirical identified challenges are compared for each of the technical solutions for automation for the movement and tracking of goods. Additionally, a comparison between the degrees of importance of the perceived challenges is drawn.

Conclusion
Technical solutions for automation for the movement and tracking of goods perceived in theory and practice are analyzed in this thesis. The conclusion of this study is that there are differences and similarities between the challenges for the movement and tracking of goods. Regarding the movement of goods, theory is more directed to see challenges after the implementation in contrast to the focus of practice on the pre-implementation challenges. For the tracking of goods, the perceived challenges in practice are more about the usage and not as technical oriented as the theory.

Key words

Warehouse, challenges, movement and tracking of goods, AGVs, Automated forklifts, Automated conveyor systems, Barcodes, RFID technology, QR-Codes

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Table of contents

Table of Figures

1 Introduction

This chapter introduces the area of interest of this study and tries to give a short overview of the most important subjects. It starts with the explanation of the background of this study, which includes the cost pressure and the need of efficiency in supply chains and therefore the need of automation, especially in warehouses. This is followed by the problem discussion and the purpose of this study. After raising the research questions, this chapter introduces shortly the used methodology and concludes with the explanation of the structure of the paper.

1.1 Background

> "Technologies that were previously considered futuristic, overly complex, and unable to be financially justified are becoming mainstream. This is no longer emerging technologies. It is here, it works, and it is now being implemented. Changing the supply chain in both warehouses and distribution centers." Supplychainbrain (2018).

For many companies the change to a more global environment has completely changed the business. They have the possibility to reach new customers, but so have competitors. This have made businesses obligated to look at their own efficiency to make sure they are doing whatever they can to improve their way of conducting business. Customers nowadays are more demanding than before. They are looking for cheap products with an excellent quality, covering all their needs at the same time. To be able to fulfill those requirements, companies or rather whole supply chains, need to improve their efficiency continuously. One possible and necessary way of applying this change of market in the daily business is by implementing innovative technology and solutions. As Hamberg and Verriet (2012) mentioned, the easiest and most obvious way of implementing new technical solutions for automation in a company is via their warehouses, caused by the standardized and repetitive working tasks within this business area.

1.1.1 **Increasing need of efficiency in supply chains**

Not only the mentioned global environment has companies led to increase their level of automation, also the increased need of efficiency in their supply chains motivated companies to implement more and more technical solutions for automation, especially in their warehouses. (Faben, de Koster and van de Velde, 2002)

As Bahr and Lim (2009) stated, "warehouse is an essential component in the supply chain, linking the chain partners and providing them with functions of product storage, inbound and outbound operations along with value-added processes" (Bahr and Lim, 2009, p. 1). Many researchers like Gunasekaran (Patel and Tirtiroglu, 2001), Barratt (2004), and Schoenherr and Speier-Pero (2015) see a lot of potential to reduce costs and increase flexibility in supply chain processes by implementing automation in warehouses. These processes are often a big part of the company's total costs and are therefore scrutinized more and more. De Koster (Le-Duc and

Roodbergen, 2007) explain that automation in the supply chain is used, because the company wants to reduce costs by gaining effectiveness.

Costs and the higher degree of efficiency can be stated as the main motivator for the usage of technical solutions for automation in supply chains. Before focusing on automation, it has to be stated, that a warehouse management system (WMS) is needed to implement information technologies and provide the technical backbone in a warehouse to make sure the all information can be collected and analyzed. (Poon, et al., 2009)

1.1.2 **Technical solutions for Automation in Warehouses**

David Allais stated, that "Automation is a powerful tool and comes in many shapes and forms" (Industry Week, 2017, p. 1). He highlighted the importance of the power of that tool, which can be very helpful and necessary for companies to increase revenue and be competitive sustainable. Automation in warehouses can have many possible forms and is therefore very comprehensive and diversified.

A commonly used form of automation in warehouses was analyzed by Connolly (2008). She examined e.g. the advantages and challenges by using optical and radio-frequency product-labelling technologies in warehouses, which are currently used in most companies. Another mentionable technology used in warehouses was examined by Wurman (D'Andrea and Mountz, 2008). They analyzed the influence on the efficiency in a warehouse with the use of autonomous vehicles. Their purpose was to examine the effect in warehouses by using "moveable storage shelves that can be lifted by small, autonomous robots" (Wurman, D'Andrea and Mountz, 2008). To highlight the current importance and development of this area, new technical solutions like the machine-to-machine technology are already used by more than 25% of the manufacturers and retailers (Logistics Bureau, 2017).

These exemplary technologies show the possible diversity within the area of automation in warehouses. According to Säfsten (Winroth and Stahre, 2007), the main reason to initiate automation is to reduce costs through higher efficiency. But it is not certain that this target can be reached by a company. After the decision of the implementation of automation, companies face a lot of challenges. Gwynne pointed out, that a challenge can be e.g. the high costs of the automation (Kogan Page, 2017). One of the most important aspects regarding the perception of the challenges is the awareness of the company according to those.

1.2 Problem discussion

Based on the mentioned cost pressure in supply chains caused by more demanding consumers and the progressed competitive situation among supply chains (Yu, Yan and Cheng, 2001), there is a high need of standardization, which enables the usage of automation. A high degree of standardization can be especially found in warehouses, which have a high level of standardized operations and procedures (LeanCor, n.d.). This enables the implementation of technology and therefore opens up the potential for cost savings in the warehouse operations.

As it is explained by Aguilar-Saven (2004), there are different kinds of processes within a warehouse which can be automated. Aguilar-Saven differentiated between 'core' or rather primary processes, like the Inbound, Storage and Outbound process of a warehouse. Additionally, there are 'support' or rather secondary processes, like the movement and tracking of goods in a warehouse. The purpose of the primary processes, which will be called 'main processes' in this paper, is to provide the main functionalities of a warehouse, according to (Bastian Solutions, 2017; Ecommercewiki, n.d.). In contrast to that, the secondary processes, which are called 'supportive processes' in this paper exist to provide the functionality of the main processes. Without supportive processes and their functionality, the main processes and also the whole warehouse would not be able to work (Rouwenhorst, et al., 2000). Caused by this importance of the supportive processes, this study focuses mainly on the movement and tracking of goods within a warehouse. Nevertheless, in both types of processes, technical solutions for automation are needed and are implemented in warehouses to increase the efficiency of a warehouse.

When companies start with the implementation of automation in their warehouses, they usually face a lot of challenges, which have to be overcome to achieve their targets. With the implementation of automation for warehouses, the need of mapping these challenges rises and also the foundation of these challenges is of high interest. A lot of challenges, like the costs for implementation of these technical solutions for automation, are already examined by theory (Hultman, 1979). With the advance of technology, new challenges appear all the time. This study examines the challenges of technical solutions for automation of warehouse operations, with a focus on the movement and tracking of goods, and compares them to the empirical perceived challenges gathered by interviews with 9 different companies. It is interesting to see, if companies in practice have to overcome all of the theoretical examined challenges or if they face other challenges, which are not analyzed by theory yet.

1.3 Purpose and Limitations

The purpose of this study is to focus on the challenges with the implementation of technical solutions for automation for warehouse operations, especially for the movement and tracking of goods, and the reason of their existence.

Hence, an analysis of the challenges for the technical solutions for automation of the movement and tracking of goods is needed. After analyzing the theory about these challenges, companies are interviewed to get impressions about the challenges facing in practice regarding this matter.

The aim is to compare the theoretical and empirical perceived challenges and to draw conclusions from this regarding the perception of challenges. This study is interested in the differences and similarities of those challenges regarding their theoretical and empirical perception and importance. Additionally, this study is also interested in the foundations and reason of existence of those challenges.

As a limitation for this study, no financial or ownership aspects will be thoroughly discussed. This study concentrates on a standardized framework of a warehouse, handling the standardized type of products. Hence, no conclusions will be drawn regarding exceptional aspects of warehouses like the handling of bulky items or duty-free warehouses, which are mainly used for foreign trade zone warehousing to simplify the toll process (Bilogistik, 2016).

At the same point, this study has to clarify, what definition of technology is used in the following. Technology can be briefly defined, as “products and processes used to simplify our daily lives” (Ramey, 2013, p.1). The main purpose of technology is to solve problems via application developed from science. Grübler (2003) stated, that “technology is defined as consisting of both hardware and software (the knowledge required to produce and use technological hardware)” (Grübler, 2003, p.19). This study makes no distinction between different kind of technological developments, like the “invention (discovery), the innovation (first commercial application) and diffusion (widespread replication and growth)” (Grübler, 2003, p.19).

Beside of the definition of technology, it is worth to define the term automation as well, caused by the importance of this term in this thesis. The term automation in warehouses is defined in many different ways. According to Pettinger (2018) automation is defined as “the process of automatically”, handling goods, “through the use of robots, control systems and other appliances with minimal direct human operation” (Pettinger, 2018, p.1). In the following, the definition of automation is used based on the explanation of Pettinger (2018). This does not exclude the involvement of humans in the automation process, but reduces it to a needed minimum level to ensure the full functionality of the device unit.

1.4 Research questions

To elaborate this study, the following research questions (RQ) are raised to guide the structure of this paper.

RQ 1: What technical solutions for automation of the movement and tracking of goods are currently applied in warehouse operations?

RQ 2: What are the differences and similarities between the challenges with the implementation of these technologies identified in theory and experienced in practice and why do these challenges exist?

1.5 Methodology Outline

The study has chosen a deductive research approach with elements of induction. Alvesson and Sköldberg (2008) describe that deduction derive from theory and induction from empirical evidence. According to Bryman and Bell (2015) an inductive study is, when conclusions are derived from empirical experiences. Backman (2016) explained that looking at a context objective from ‘helicopter view’ is deduction, while induction puts more interest in the subjective experience someone have. Therefore, the deductive research approach with elements of induction was chosen to use the advantages of both research approaches.

This study employs a qualitative research strategy with a cross-sectional research design, which enables a qualitative analysis of the challenges for the automation of warehouse operations. Additionally, for validation and completeness reasons, a cross-sectional research design was chosen to get the impressions and ideas from different companies. (Bryman and Bell, 2015)

Regarding the procedure and research method of this work, first research questions were formed and afterwards a literature review is done to find relevant theories. This theoretical approach is enriched by primary data, like the knowledge and data gathered from the interviewed companies. The research method chosen are semi-structured interviews with companies, which face some of the challenges currently or in the past or think they will face them in the future. The semi-structured interviews will be conducted by phone. The study wants the companies to answer the same questions since the purpose is to compare experiences of challenges in the automation process. The method of the interviews will be semi-structured since this, gives the respondent possibilities to influence the interview (Alvehus, 2013). The interviews will be recorded, transcribed, compared and analyzed in later chapters.

1.6 Structure

The study is structured as the following: the next chapter deals with the methodological outline of this paper. This chapter includes the explanation of the qualitative research approach and the cross-sectional research design, according to Bryman and Bell (2015). Additionally, qualitative semi-structured interviews are presented as the research method to gather primary data from different companies.

In the next part, this study focuses on the theoretical background of this paper. It briefly starts with the explanation of warehouse management system (WMS), which is an essential part of a warehouse to be able to integrate technical solutions for automation. Afterwards, a theoretical perceived delimitation between the main and supportive processes of a warehouse is drawn, including the used technical solutions for automation of these processes. This chapter concludes with the theoretical perceived challenges of the supportive processes of a warehouse and the reason of their existence in theory.

Afterwards, the empirical gathered data is presented from the taken interviews. Each sub-chapter presents the interviewed company and the perceived challenges for the movement and tracking of goods at this company. For further information about the data of the interviews, the most important facts of the interviews are attached in the Appendix 2 of this work.

The next chapter includes the analysis part of this study. Therefore, a comparison between the theoretical and empirical perceived challenges is done. The challenges will be structured regarding their importance and their specification related to a specific technology.

This study is concluded by an outlook for further research within the fast-changing area of technology for warehouses and their challenges for the implementation of a higher degree of automation.

At this point, it has to be mentioned that the format of this work is according to the guidelines of the Linnaeus University (Linneuniversitetet, 2018). Additionally, the Harvard Referencing style is used, to create this study.

2 Methodology

In the following chapter the used methodology is examined, including the used research characteristics and the quality criterions of this study. Additionally, this chapter focuses on the description of the research process, the scientific credibility and the ethical considerations.

As a brief summary, this study employs a qualitative research strategy with a cross-sectional research design. Qualitative semi-structured interviews as the research method with qualitative methods for the data collection and the data analysis were used throughout the study. The methodology terminology is aligned to Bryman and Bell (2015).

The chosen methodologies for this thesis are summarized into this table:

Methodology	**Methodology selection**	**Chapter**
Research strategy	Qualitative research	2.1
Scientific approach	Deductive with elements of induction	2.1.1
Scientific perspective	Conformity of thinking and elements of hermeneutics	2.1.2
Research design	Cross-sectional research design	2.2
Research method	Qualitative semi-structured interviews	2.3
Sampling Method	Convenience sampling	2.3
Data collection	Primary data from interviews and secondary data from online references	2.4.1
Data Collection Process	Iterative data collection process	2.4.1
Empirical data analysis – Analysis Method	Thematic analysis and pattern matching	2.4.2
Scientific credibility	Recorded and transcribed interviews. Best practice	2.5
Ethical considerations	Anonymous and informed respondents	2.6

Figure 1. Methodology Selection

2.1 Research strategy

This chapter examines in the following the research strategy of this paper, which includes the scientific approach and the scientific perspective. Related to the qualitative research strategy, this paper employs a deductive research approach with elements of induction. A qualitative and iterative approach is chosen as a research strategy.

2.1.1 Scientific Approach

Deduction with elements of Induction

There is no easy way of describing the link between theory and research. According to Bryman and Bell (2015) the deductive approach means that what is known within an area leads the researcher to draw conclusions given to these specific premises. From theory, a perception of the reality can be get, which gives the authors the research questions to solve issues. Often the base is theory or models which help the researcher formulate and test hypothesis against reality through observations. At the same time Bryman and Bell (2015) describe that an inductive approach starts with a research effort and has theory as an outcome. This is the other way around, where the researcher through observations about the reality does generalizations in a theoretical framework. The researcher draws theoretical conclusions based on empirical observations.

Bryman and Bell (2015) also write that deduction often holds elements of induction and induction always includes small parts of deduction since reality in relation to the authors pre-knowledge can be observed. The scientific approach of this study will be deductive with elements of induction, since the source of the base knowledge comes from theory. However, the primary purpose is not to contribute with theory in that sense. Instead, the research questions answers in what ways theory and practitioners perceive challenges of new technical solutions in automation of warehouse operations. Do they differ and why? In a way this paper deduces theory, but is more an elucidation to how and why challenges are interpreted.

Qualitative approach

This study is conducted with a qualitative approach. According to Bryman and Bell (2015) a qualitative research is more directed into words than numbers. As they stated, a qualitative research is also more detailed and in-depth in comparison to the quantitative.

Since the aim of this study is to get a deeper understanding for the subject, the decision for a qualitative research approach was consistent and coherent. Saunders (Lewis and Thornhill, 2016) describe that when the researcher wants a more in-depth understanding of the subject, he should apply a qualitative method. Another crucial factor for the qualitative research approach is described in Backman (2016). He highlighted the advantage of a qualitative research approach of being less standardized and therefore providing the researchers a less strict framework.

2.1.2 Scientific perspective

Conformity of thinking and elements of hermeneutics

The scientific perspective of the conformity of thinking is applied in this study, to interpret and analyze the statements of the semi-structured interviews in a unified way. Therefore, information in the interviews is used and understood in an appropriate and reliable way from the authors. Additionally, different formulations of the statements during the different interviews are interpreted and summarized in the same way.

The study is also conducted with a hermeneutic approach as described by Eklund (2009), where the authors have interpreted, understood and mediated the results of the interviews in comparison to the conclusions from theory. Eklund (2009) means that it is necessary to get hold of the respondent's own experiences of the phenomenon investigated through a widespread freedom of speech. This study uses a hermeneutic approach by interpreting the interviews with the respondents as the authors think, they want to get interpreted.

2.2 Research Design

This paragraph examines the used research design of this study and differentiates between the research design and the research method. It includes the definition of the used research design and its characteristics.

Cross-Sectional Research Design

Bryman and Bell (2015) stated, "a research design provides a framework for the collection and analysis of data" (Bryman and Bell, 2015, p. 49). Therefore, it is necessary to set the framework conditions for a valid guideline of this study by deciding the research design. Additionally, the decision of the research design should be orientated regarding the chosen research strategy. The function of the research design "is to ensure that the evidence obtained enables us to answer the initial" (NYU, n.d., p. 1) research questions.

At this point, it is important to differentiate between the research method and the research design. As mentioned above, the purpose or function of the research design is to specify the used research approach to examine the type of design, which is needed to answer the research questions. In comparison to that, the research method is based on the decision of the research design. The purpose of the research method is to explain, how the data is collected. (Bryman and Bell, 2015)

As mentioned in the beginning, the purpose of this study is to map and compare the perceived challenges of the implementation of a higher degree of automation in warehouses from theoretical and empirical sources. Therefore, to have a valid and informative study, it is important to gather data and information from different companies to get various opinions and subjective assessments regarding the perception of challenges with the implementation of a higher degree of automation. To be able to gather data and information from different companies, a cross-sectional research design is selected for this study.

Bryman and Bell (2015) defined, that a "cross-sectional design entails the collection of data on more than one case and at a single point of time" (Bryman and Bell, 2015, p. 62). This study will focus and gather data about more than one case or rather more than one company. The data and information will be gathered at a single point of time. This characteristic differentiates as well the research design used in this study, from a longitudinal research design, which is related to the cross-sectional research design. The data from the companies will be gathered via semi-structured qualitative interviews with each company (see Chapter 2.3 Research Method). A cross-sectional research design covers and contains all necessary characteristics and is therefore chosen for this study.

2.3 Research Method

Bryman and Bell (2015) defined a research method as being "simply a technique for collecting data" (Bryman and Bell, 2015, p. 49). Therefore, the research method of this study is to gather data via qualitative semi-structured interviews. After the clarification of the research method, the selection process of the interview partners has to be explained, which is a convenience sampling in this study. (Bryman and Bell, 2015)

Qualitative semi-structured interviews

This study gathers its empirical data via semi-structured interviews, done with different companies related to the mentioned cross-sectional research design. The decision for a semi-structured interview in comparison to a structured interview has been made due to flexibility reasons during the interviews.

The aim of a structured interview is to give all respondents the same interview stimulus and questions in a standardized framework with the purpose to ensure that the interviews can be aggregated and compared afterwards. In comparison to that, a semi-structured interview enables a more informal structure of the interview and offers the interviewees more scope for individual, extensive and informative answers. The interviewers have the possibility to react in a more flexible way with their questions on the course and outcome of the interview (Bryman and Bell, 2015). Based on the Research Questions of this qualitative study, the decision was made to use semi-structured interviews to be able to react more flexible during the interview.

Convenience Sampling

The way of selecting participating companies in this study, is done through a convenience sampling. As Unu (n.d.) stated, the selection of participants via a convenience sampling is based on the authors' opinion, who they think will provide the study with the best information. The subjects or rather chosen companies are "selected because of their convenient accessibility and proximity" (Explorable, n.d., p. 1) to the authors.

2.4 Research Process and Empirical Data Analysis

In the following chapter, the research process is examined, including the data collection approach and the empirical data analysis.

2.4.1 Data collection

According to Bryman and Bell (2015), the qualitative data that comes from interviews and observations tends to be unstructured and extensive, which makes it hard to analyze. The qualitative data analysis differs from quantitative since there are no clear rules for how the analysis should be carried out.

Primary Data

The primary data in this paper comes from semi-structured interviews with the chosen companies and their respondents. One interview is conducted with each company. In case, the company recommended an additional contact person, a second interview with the same company was conducted. The interviews are conducted with an Interview Guide that was created to make sure that the interviewers get the answers to questions that were needed. The questions are not necessarily asked in the same order, since the interviewers want the respondents to talk more freely and it is therefore of great importance to make sure that the respondent understand the background to the subject.

The most important facts about the interviewed companies are presented in the following table, including the company's area of business, the position of the interviewed respondent in the company, the date and the duration of the interview. A more detailed description of the interviewed companies and respondents is given in the empirical chapter (see Chapter 4). The most important statements of the interviews are attached in the Appendix 2.

Interviewed companies				
Number of company	Industry area of interviewed company	Position of respondent	Date of the interview	Duration of the interview (in minutes)
1	Supplier in automotive industry	Director of warehouse logistics	30.04.2018	27:33
2	Distributor of office material	Warehouse logistics manager for northern Europe warehouses	02.05.2018	20:50
3	Online retailer for clothing and sport articles	Logistics manager of warehousing	03.05.2018	24:20
4	Logistics service provider	Engineering consultant for corporate contract logistics of the company group	04.05.2018	39:20

5	Logistics service provider	Logistics manager for one warehouse in a specific region	07.05.2018	18:15
6	Manufacturer for electronic parts	Head of logistics management and data systems	07.05.2018	51:03
7	Retailer within food and beverages	Supply chain and Logistics manager	07.05.2018	24:50
8 (Part 1)	Manufacturer of professional office chairs	Director of Operations	07.05.2018	33:57
8 (Part 2)		Technical Director	07.05.2018	08:43
9	Product wholesaler	Director of logistics and warehousing	15.05.2018	24:40

Figure 2. Overview of interviewed companies

Secondary Data

Secondary data is mainly represented through web-based research. As Bryman and Bell (2015) stated, secondary data is collected from other researchers and is often made for another purpose. Because of limited time and money, secondary data is indispensable for most of the research studies. For this study, secondary data is mostly used for the data collection about the participating companies and the perception of the theoretical challenges of the technical solutions for automation of warehouse operations.

Iterative data collection process

This study is also aligned to the iterative data collection process, as an additional characteristic, to increase the level of flexibility during the research and the analysis. Bryman and Bell (2015) describe that an iterative data collection process is when a researcher does a reflection about the theory and collected data. It is when the researchers are "weaving back and forth between data and theory" (Bryman and Bell, 2015, p. 25) to make sure that the correct data is collected for the assumptions. When the researcher finds that he wants or needs further information to draw conclusions whether a theory is strong enough to hold, he can go back and get more data.

2.4.2 Empirical data analysis

Regarding the empirical data analysis, this study uses the thematic analysis approach and examines the gathered data via a qualitative pattern matching.

Thematic analysis

This study is aligned to a thematic analysis of the empirical evidence. Bryman and Bell (2015) mention this method as one of the most common. Alvehus (2013) also describes thematic analysis as a good way of sort, reduce and argument for the empiricism. He means that when researchers have gathered material from interviews, there is a need to get a good overview of it and to be able to read the transcriptions again and again to fully understand what the respondent says. After understanding the subjects, this study starts categorizing, aggregating and comparing the respondent's answers in the same order, as it is done in the theory chapter.

Qualitative pattern matching

This study has a qualitative analysis method, including a pattern matching to be able to compare the theoretical and empirical perceived challenges of the technical solutions for automation of warehouse operations. The most important aspect is the possibility to compare those two areas of challenges and "to determine whether they match or do not match" (Sage Research Methods, 2010, p. 1) for this qualitative analysis.

2.5 Scientific Credibility

According to Bryman and Bell (2015) concepts like reliability and validity have been questioned in qualitative research. Many other researchers have discussed how relevant these concepts are in qualitative research due to its connection to measures. However, they describe that if the "concepts are assimilated to the qualitative research" (Bryman and Bell 2015, p. 379) and does not consider the measurements parts of the concept, they are still valid.

Validity

Bryman and Bell (2015) stated, "Validity is concerned with the integrity of the conclusions that are generated from a piece of research" (Bryman and Bell, 2015, p. 50). It has to be mentioned, that the concept of validity is mainly used for quantitative research, although it is also used in qualitative studies and therefore it is worthy of discussion at this point. Nevertheless, it is a scientific credibility aspect, which has to be examined. (Trautmann, Bals and Hartmann, 2009)

Hence, it has to be differentiated between internal and external validity. LeCompte and Goetz (1982) highlighted in their work, that the internal validity is the strength of qualitative research. The characteristics of internal validity in this study are covered by the semi-structured interviews, which provide a guideline during the interviews. Additionally, these interviews will be recorded, transcribed and on request shared with the respondents to avoid misunderstandings and provide them with the opportunity for adaptations.

As defined in Sagepub (2008), "external validity is generally concerned with the generalizability of research results and findings to the population that the sample has been taken from" (Sagepub, 2008, p. 1). Therefore, for this qualitative study it is difficult to conclude, if the results can be generalized. Based on the valid research process, the authors tried to reach the highest level of external validity as possible.

Reliability

Bryman and Bell (2015) describe different types of reliability. First, it is the external reliability, which includes the possibility to replicate the research. In qualitative research this is problematic since the social environment and conditions affects the conclusions of the study. It is impossible to do an exact replica of a qualitative research when interviews with respondents are used as the method. As Bryman and Bell (2015) stated, the “social setting and the circumstances of an initial study to make it replicable” (Bryman and Bell, 2015, p. 400, according to LeCompte and Goetz, 1982), makes it difficult to fulfill the characteristic of an external reliability study. The authors tried to facilitate the framework and the replicability by indicating all specifications of the taken interviews, including the most important statements of the interviews in the Appendix 2. On request, the transcriptions of all the 10 interviews with the 9 companies can be submitted.

Secondly, there is internal reliability, which is when the authors agree on how to interpret empiricism. This study is done by two researchers. Therefore, the inter-observer consistency is taken into account to have a valid interpretation of the interview results with regards to the internal reliability (Bryman and Bell, 2015). The authors of this study have similar background knowledge of the topic and have therefore agreed upon how to interpret answers given during the interviews.

Trustworthiness

Lincoln and Guba (1985) highlighted the importance to specify the quality of a qualitative study by the trustworthiness of it. The quality criterion trustworthiness consists of four equivalent sub-criterions, like the credibility, the transferability, the dependability and the conformability. (Bryman and Bell, 2015)

Credibility

The credibility of this study is employed by using the concept of best practice, so that the research is done to the best knowledge of the authors. According to the credibility, the technique of triangulation, which was recommended by Guba and Lincoln (1985) as an importance quality technique for qualitative studies, has to be mentioned. Bryman and Bell (2015) explained triangulation as “using more than one method or source of data in the study of social phenomena” (Bryman and Bell, 2015, p. 402). In this study more than one source of data is used to analyze the exact position and identification of the challenges of technical solution for automation of warehouse operations by interviewing 9 different companies.

Transferability

The transferability of this study, which is explained by the applicability of the research results, is fulfilled by the application of a cross-sectional research design in comparison to a case study. This study places the research area in the forefront and not the case of a company, as it is done in most case studies. Therefore, results concluded through the input of different companies can be adapted to other companies as well.

Dependability

The quality criteria of dependability is taken aware of in this study by the gapless documentation of the research process, including the mentioned data gathering steps of the interviews

Conformability

Regarding conformability as the quality criterion for the objectivity of a study, Bryman and Bell (2015) stated, that it is impossible to ensure complete conformability in a qualitative research study. Even though, conformability is tried to ensure via the discussion, the reciprocal control and the good faith of the two researchers.

2.6 Ethnical Considerations

The gains of this paper are only knowledge based. Since this study can be transferred and used for other businesses, the authors claim that there is no need of presenting the company names. Instead, they are referred to as Company 1, Company 2 and Company 3 and so on. There will be a short presentation of the companies in Chapter 4, so that the reader gets an understanding about what type of company it is regarding the industry, size, employees and turnover.

Information and data is also gathered from the companies' homepages. To maintain the anonymity of the companies, the sources are not listed in the text and also in the reference list.

According to Bryman and Bell (2015), it is important to present and clarify the purpose with the research. Additionally, all the respondents were sent an interview outline before the interview, so that they could be better prepared and think over their answers. They were also informed that the interviews were recorded. No names, only time, date and respondents position in the company, will appear in the paper to protect the respondent and the companies, if there is any sensitive information. Bryman and Bell (2015) explain that it is important that there is no possibility to identify the respondent and company, if this could be harmful in any way for them.

3 Theoretical Background

In the following chapter the theoretical background of this study is explained, based on the stated Research Questions at the beginning of this thesis. The theoretical background starts with the technical backbone of a warehouse, the warehouse management system (WMS). The WMS provides the needed technical conditions for the integration of automated systems or rather applications, to ensure the functionality and the usage of the full potential of these technologies. The WMS represents the backbone of warehouse operations, which include main and supportive processes. Therefore, this chapter also presents the theoretical foundation of these processes, including their technical solutions for automation. Additionally, the theoretical perceived challenges with the implementation and usage of these technical solutions for automation in the supportive processes within a warehouse, like the movement and tracking of goods, will be examined.

The following two figures show the theoretical composition of the raised Research Questions and their theoretical concepts, covered by this theory chapter.

Literature Review

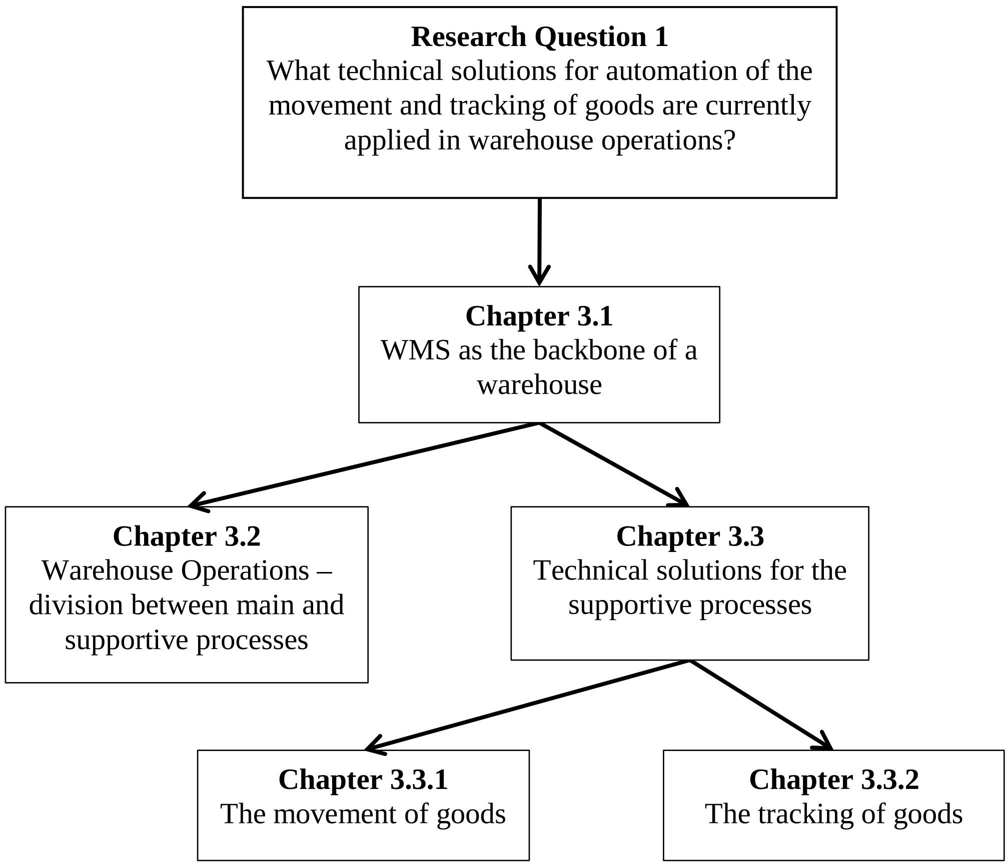

Figure 3. Theoretical composition RQ 1

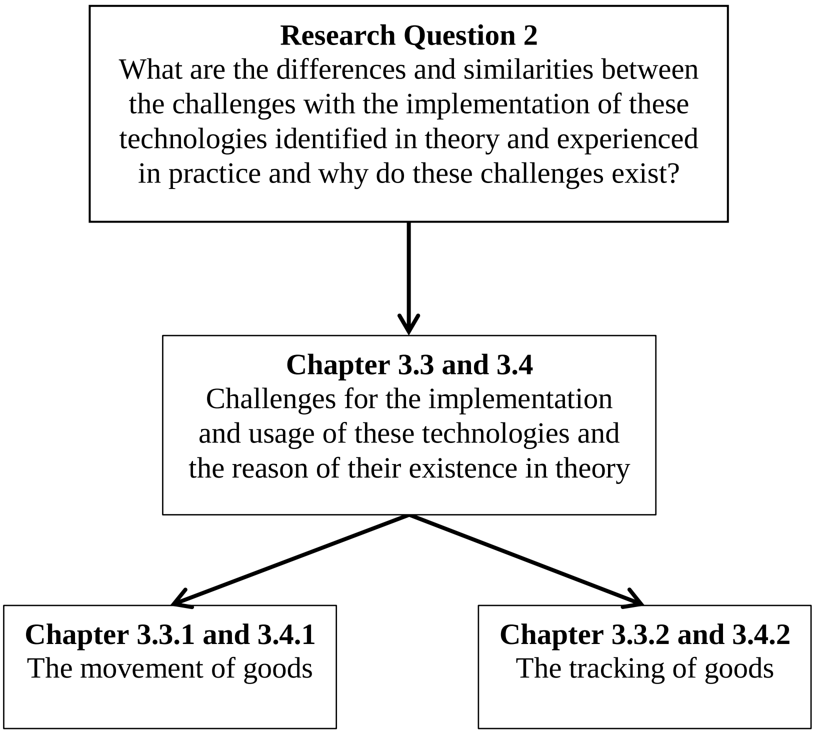

Figure 4. Theoretical composition RQ 2

3.1 Warehouse Management System - the backbone of technical integration

The supply chain activity has changed during the last decades because companies understood the importance of competitive advantage. Chow, et al. (2006) describe that many authors before them, have noted that warehouses should be redesigned and automated to achieve a better flow rate of goods. The challenge of lowering costs and at the same time become more effective, have led to dramatic changes. They mentioned, that “warehousing is needed to perform routine logistic operation such as inventory storage, order product mixing, cross docking and customer service” (Chow, et al., 2006, p. 2).

Faber (de Koster and van de Velde, 2002) wrote that the need of automated warehouses was due to the need of a higher speed, higher productivity and lower process costs within warehousing. With this came the requirement of accurate information about products, resources and processes to get control and be able to plan better. To do this the warehouse management information system (WMS) was implemented. This system “provides, stores and reports information necessary to efficiently manage the flow of products within that warehouse from time of receipt to time of shipping” (Faber, de Koster and van de Velde, 2002, p. 382).

Poon, et al. (2009) describe, that warehouses are an essential component of linking the supply chain partners together. WMSs were developed to handle the warehouses resources and monitor the warehouse operations. The WMSs were adopted to collect data of warehouse operations in order to solve different problems within the warehouse like material handling problems, available resources and the merge of all information to the same system. A WMS is required for the implementation of technical solutions for automation in warehouse operations to provide the technical framework for the connectivity of these technologies. The application of a WMS supports the day-to-day business in a warehouse and the integrity and functionality of the used technologies.

The reason for automation in supply chains is, according to Baker and Halim (2007), the need of being more agile and flexible to serve the rapidly changing markets. They describe that this need in the terms of warehouses, has increased the importance of maximizing space and equipment utilization.

Hwang, et al. (2004) state, that businesses constantly need higher flexibility, adaptability and support to make decisions. They mean, that there are different solutions to this and one of them is to adopt warehouse technology. Warehouse technology is used to collect data from several sources so that the users can store and analyze the needed data. A WMS can be one way of doing this, but there are also other solutions, like the Enterprise Resources Planning (ERP) system, which has nearly the same functionalities as a WMS for the management of warehouse resources (Nettsträter, et al., 2015). Therefore, to implement technologies into a warehouse, a support system is needed, which collects information regardless of the usage of a ERP or a simple WMS system.

Yan (Chen and Meng, 2008) use Radio Frequency Identification (RFID) to describe how a WMS works. In their paper, they describe the different parts of an WMS, when RFID is used within the warehouse. They explain that the WMS is the operation support system that collects, filters and retransmits data. These are the basic functions of the WMS. The system is supposed to integrate all different functions seamlessly to make the whole platform run smoothly. The WMS can be used as a total independent information application within a warehouse, but it also can be integrated in other external systems, like the ERP, which have a broader focus than the WMS and is able to connect different information applications (Nettsträter, et al., 2015).

Yan (Chen and Meng, 2008) describe in their paper the area of responsibility of a WMS from a function-oriented perspective (Picot, 2002), when goods go through the warehouse. They explain that the WMS has different functions depending on what kind of warehouse operation it is handling. When the WMS is RFID based the goods are marked with electronic tags. When goods are entering the warehouse, the system should first receive a delivery order from the sender. In this way the system should know where each of the goods is, when they arrive in the warehouse. The WMS then automatically generate reception orders for the goods. In this phase, it is more about where the goods and the resources are located. (Yan, Chen and Meng, 2008)

The next operation in their paper is the funtion of picking. The WMS generates a picking order and then a warehouse employee uses, for instance, a forklift going around in the warehouse collecting and scanning items that are supposed to be picked. The scanner automatically checks the collected data, to see if it is correct. This makes the system control, if the picker picks correctly. When the goods are picked, the WMS system updates to know what has been done and not. Because of this the system can generate inventory results before, during and after picking. Since goods often are placed in a special zone before delivery, it is possible to see how much inventory there is in the delivery zone, but also at the original location in the warehouse. (Yan, Chen and Meng, 2008)

The next operation described by Yan (Chen and Meng, 2008) is the delivery process. The WMS gives the employee instructions of where to place the goods. After placing the goods, the driver confirms the delivery by scanning e.g. the pallet. When using RFID, the scanning process is done automatically as the goods pass by a certain point in the warehouse. Otherwise, some kind of confirmation is needed. After the driver confirms the delivery, the WMS updates again and declares the goods as delivered from the warehouse. Inventory is updated, and employees can proceed to new orders. These are all the functions of the WMSs, when it is based on RFID technology. There are similarities to all WMSs, since the information flow is the key factor within a warehouse. The knowledge of where and when operations are happening within the system and give the user information about it is the advantage. (Yan, Chen and Meng, 2008)

Power and Simon (2004) describe, that since adoption of technologies in the supply chain have become of higher interest, and there has also been a question of what is needed to facilitate the implementation of technologies. Their idea is that by using technology, trading partners and different parts within companies can be connected with information. Without the information connection many of the advantages of technologies are lost and unnecessary. A system to collect, store and analyze real-time data is therefore needed to adopt technologies. Without a WMS the adoption of technical solutions for automation of warehouses would not be useful.

3.2 Operations in a warehouse

Warehouses are of high importance in supply chains. They “provide important economic and service benefit to both the business and its customers”, (Lohrey, n.d.). By having warehouses in the supply chain, it is not necessary to ship items individually from multiple sources. Warehouses provide an enormously economic benefit through their functions of consolidation and accumulation. To be able to consolidate deliveries decreases costs in the supply chain and therefore also for the customers. Additionally, the function of accumulation provides supply chains with a much greater freedom of handling goods. To have a warehouse, which acts as a buffer for fluctuating demand or seasonal requirements has big economic benefit, when it comes to replenishment issues. (Lohrey, n.d.)

Warehouses also fulfill a service benefit for companies or rather supply chains, when it comes to delivery capabilities. Warehouses operate with safety stockings, which allow businesses to keep a specific amount of products at the warehouses for the prevention of unforeseen occurrences and to counteract negative effects like the Bullwhip Effect (Lee, Padmanabhan and Whang, 1997). To be able to deliver, despite of unforeseen occurrences like transportation delays, the requested products to the customers shows the great service benefits of a warehouse. (Lohrey, n.d.)

To provide and ensure the mentioned benefits, warehouses have different roles and contain interacting functions and processes. Before looking at the processes within a warehouse, it must be clarified, which roles can have a warehouse within a supply chain. Higginson and Bookbinder (2005) were one of the first, who identified a number of different roles of a warehouse in a supply chain: (Baker and Halim, 2017)

- Assembly facilities
- Product fulfilment centers
- Transshipment facilities
- Cross-docks
- Make-bulk/break-bulk consolidation centers
- Returned good depots
- Centers for miscellaneous activities, such as repairs and factory-outlet

Rouwenhorst, et al. (2000) examined in a detailed way, the different angles or rather perspectives from which a warehouse can be viewed. They mentioned that a warehouse contains processes, resources and organization. Arriving products go through different steps within the warehouse, before they will be shipped to their final destination. They defined in their paper, that these steps are called processes of a warehouse. The second angle is warehouse resources, which "refers to all means, equipment and personnel needed to operate a warehouse" (Rouwenhorst, et al., 2000, p. 516). The last angle described is the organizational part of a warehouse, which is responsible for all control and planning procedures to ensure a smooth operation of the system. (Rouwenhorst, et al., 2000)

In this study, warehouse resources, like storage units or picking equipment, are not explained separately and will only be used to explain technical solution within a warehouse process examination. Also, the warehouse organization, which includes the strategic decision-making process and the policy assignments within a warehouse will not be examined in the following, caused by the lack of technology within this area. (Rouwenhorst, et al., 2000)

When it comes to the business processes e.g. in a warehouse, the different types of business processes have to be explained. Aguilar-Saven (2004) has explained in her paper, that there are mainly two classifications of business processes, often called 'core' and 'support' processes. These 'core' processes (primary processes) are initiated from outside the business or their purpose is to create customer value. In comparison to that, 'support' processes (secondary processes) "creates the conditions for the primary process to be carried out" (Aguilar-Saven, 2004, p. 133), which means that these processes are not directly involved in the value creation for customers and only provide the functionality of the 'core' processes. By applying this concept to the warehouse management, a few adaptations have to be done. First, the primary processes, or in the following the 'main processes' within a warehouse, represent the main functionalities of a warehouse. This includes the Inbound, Storage and Outbound process of a warehouse (Bastian Solutions, 2017; Ecommercewiki, n.d.). The 'support' processes, or in the following 'supportive processes', provide the functionality of the main processes, which covers the warehouse areas of the movement and tracking of goods.

Before going more into detail of these processes, a clear delimitation of the responsibilities of these processes has to be made, which will be used in the following. In this study, the Inbound process starts with the reception of the goods and ends before the transportation to the storage area in the warehouse. The Storage process includes the storage and retrieval of goods. The Outbound process starts after the transportation from the storage area and ends after the leaving of the goods from the warehouse. The supportive process of the movement of goods includes all transportation actions on a horizontal and vertical direction. This includes activities like the transportation in the warehouse from point A to B. The second supportive process is the tracking of goods, which is done during the whole journey through the warehouse. (Rouwenhorst, et al., 2000)

3.2.1 **Main warehouse processes**

As it is mentioned above, the main warehouse processes include the Inbound, the Storage and the Outbound process. In the following, the functionalities and sub-processes of these main processes will be explained, before their technical solutions for automation will be presented.

3.2.1.1 Process functionalities

The operation of a warehouse starts with the reception of goods in the Inbound process, also called the receiving process (Rouwenhorst, et al., 2000). This process contains a few sub-processes, like the inspection of incoming goods, the repacking and the labelling. This warehouse process is mainly driven by recordings and receipts, which help to ensure a communication with accuracy (Williams, 2017).

The Storage process is mainly oriented at the later use of the product in the Outbound Process. There are mainly two kinds of storage within a warehouse, namely the bulk storage and the pick storage (Clements, et al., 2016). The bulk storage, also called reserve area where "products are stored in the most economical way" (Rouwenhorst, et al., 2000, p. 516), is for large amount of goods mostly stored on pallets and without the need of easy access through the warehouse staff. In comparison, the pick storage, also called forward area (Rouwenhorst, et al., 2000), is easily accessible for the warehouse staff and contains mainly small numbers of products. The pick storage is normally replenished by the bulk storage, whereby the bulk storage is filled up with the incoming products of the warehouse (Calzavara, et al., 2017).

The most common storage methods within a warehouse are pallet racking, shelves and flow racks. Pallet racking is mostly used in high-bay warehouses for a big amount of products, whereby shelves are only used for a limited amount of items (Topolski, 2016). Flow racks are used for higher throughput items, which are filled from one side and lighted from the other side.

The third process has the purpose to fulfil customer orders and is called Outbound process. There are three main sub-processes within the Outbound process of a warehouse, the order picking, the packing and the shipment. Starting with the order picking, there are a few different ways of picking an order, which depend on the industry in which the warehouse is used. For instance, the method of single-order picking can be used, which idea is to pick all items for a single order at the same time. Another method is the batch picking, where multiple orders are picked at the same time. A third method is the zone picking, where all items of a certain warehouse zone are collected at the same time. (Gu, Goetschalckx and McGinnis, 2010)

The purpose of the picking is the sorting and consolidation of orders (Rouwenhorst, et al., 2000). After the items are picked, they have to be packed, which includes the putting of items in a box together with packing material to prevent damages. Before the shipment can start, labels must be put on the boxes to ensure that the right customer gets the right box.

Nowadays, all of the mentioned warehouse processes are connected to the WMS. By using the technology systems of the WMSs, it is possible to have a smooth flow of goods within the warehouse. To keep track and to be able to control these processes a WMS, as it is explained in the previous chapter, is obligatory to have. Ross (2011) explained that businesses must have a business information systems, like the WMS or the Inventory Management System, to be able to perform economically sustainable. Information applications, like the WMS, are necessary to be able to track and control the movement of goods and also to manage the stock in the warehouse. Therefore, goods must be scanned in the Inbound process, but also during the other processes. WMSs provide all warehouse employees with accurate and valid data in all warehouse sections. By having business applications like the WMS, it is important that these systems are well integrated to each other to use the full potential of those technologies. (Qstock Inventory, n.d.; Richards, 2017)

3.2.1.2 Technical capabilities of the main processes

Even though, the explained main warehouse processes are all equally important, but the degree of automation, beside of the usage of the business information systems of the WMS, within those processes differs extremely. The Inbound process, including the inspection of goods, the quality control, the repacking and the labelling, has a high degree of human involvement and a low degree of automation. Beside of the usage of packing and labelling technologies, the human involvement in this warehouse process is a large part of it. (Zhou, 2008)

Nevertheless, there are technical solutions for automation in the Inbound process, which are mainly related to the tracking of goods and the notification of the company about incoming goods in advance. The most commonly used technology or rather technical solution in the inbound process is the advanced shipping notification (ASN). The ASN enables suppliers to notify its customers about specific orders and expected arrival times in a structured way. The purpose of it is to reduce costs by structuring the incoming process of goods to avoid randomly shipments, which accompany with delays for both participating companies (Magaya, 2016).

After the Inbound process has finished, the products will be transported to the storage area. The storage contains automation like the wrapping of the goods with specific wrapping robots. With the help of these technologies costs for the wrapping regarding spent time or wasted wrapping material decreases, but for most wrapping technologies a minimal human involvement is still needed (Campbell, 2016).

The most important development at companies in the last years was the implementation of automated storage and retrieval system (AS/RS) in their storage process. The purpose of an AS/RS system is to automatically store the goods at the determined position. It is a computer-controlled system that store and retrieve product from the storage. Additionally, an AS/RS system also retrieves items or products from the storage area regarding the request of a customer order. Therefore, this system is not only responsible for the storage area, it also fulfills tasks of the Outbound process, like the picking of products. By having such systems, companies can save enormously storage space by up to 40% and increase their picking efficiency significantly, reduce labor effort and increase accuracy. (Marchet, et al., 2012; Unarcorack, n.d.).

Completely different regarding the degree of automation is the Outbound process. Starting with the picking, there are a lot of technologies currently used for the picking of items in warehouses to lower the risk of errors and to speed up order picking (Ecommercewiki, n.d.). These technologies must be divided into two different systems. On the one hand, there are technologies, where the warehouse staff has actively go to the storage position of the item and pick it (Person-to-Goods systems). On the other hand, there are technologies, where the goods are brought to the warehouse staff for the picking process (Goods-to-Person systems) (Brockmann, 2014). The Person-to-Goods systems have a wide variety, when it comes to the usage of different technologies. One system in the area of the Person-to-Goods systems is the pick-to-light system, which "consists of a network of lights and displays integrated with pick location media" (Forte, n.d.). In the standardized version of this system, the picker scans an item and a light shows up at the shelf location, where this item is supposed to be. Another technology in this area, is the Voice-directed and Radio Frequency (RF)-directed picking. These technologies work in the same way as the pick-to-light systems. By using RF-directed picking, the need for the manual scanning of items is made redundant. After the identification of the item via the RF-technology, the voice-directed application guides the picker to final position of the item. For completeness reasons, there are also pick-to-conveyor systems, which are another way of moving picked goods to their destination. (Forte, n.d.)

As it is stated in Welsman (2010), the Goods-to-Person systems act the other way around. The requested goods will be transported directly to the picker, which increases the efficiency of the picking process by reducing the search time of the picker. The used technologies in this area differ from fully automated robots to horizontal/vertical carousels. Regarding the functionality of these technologies, it has to be emphasized, that these technologies are in the area the movement of goods, which will be analyzed in the next chapter. (Forte, n.d.)

Another mentioned sub-process in the Outbound process is the packing of goods, before they will be shipped to their destination. As described before, there are a few technologies like wrapping robots, which are used for the packing of goods, but a minimal human involvement is still need. (Campbell, 2016)

3.2.2 **Supportive warehouse processes**

Based on the theoretical insights of the degree of automation in the above presented warehouse processes, the technical development in these processes is of high importance. Nevertheless, the presented warehouse processes are dependent on supportive processes within the warehouse, like the movement or the tracking of goods. The tracking and the movement of goods is necessary for all mentioned warehouse operations and is irretrievable for the operability of a warehouse. Especially in these processes, technical solutions for automation are mostly used and needed. (SupplyChain247, 2011)

The movement of goods is exemplary necessary for the connection of the inbound and Storage process, to ensure that the products of the Inbound area are stored in the right storage zone of the warehouse. Goods need to be moved constantly within the warehouse and therefore a high importance for automation exists in this area. As it is defined above, the movement of goods includes the horizontal and vertical movement. The horizontal movement is mainly used for the transportation of goods from one zone of a warehouse to another zone. The vertical movement is mostly used to lift and pick goods in or from the storage area.

For the Inbound process, goods will be tracked directly with the entering of the warehouse. The need of tracking goods is throughout the whole warehouse, to ensure the availability of the product and to be able to locate this product constantly. Without tracking goods through the whole warehouse, it is not possible to control and therefore to manage the inventory during its journey in the warehouse. (Buchberger and Hiebl, 2015)

Based on the importance of the movement and tracking of goods within a warehouse, the next chapter employs the recent development and commonly used technical solutions for automation of warehouse operations within the movement and tracking of goods and the challenges of the implementation of these technologies.

Additionally, to be able to track and control the movement of goods, a warehouse must have a well-integrated business information system. A business information system, like an ERP system or a WMS (Qstock Inventory, n.d.), is responsible to provide the technical integrity of business application within the warehouse. These systems are the technical backbone of a business and therefore for a warehouse as well. As it is described in the previous chapter, without having this technical backbone, it would not be possible to provide the needed preconditions for the implementation of technical solutions for automation in the main warehouse processes nor in the supportive processes. (Garvin, 2015)

3.3 Technical solutions for the movement and tracking of goods

The following chapter presents the technical solutions for automation for the supportive processes of a warehouse, which means the movement and tracking of goods. This includes the presentation of currently applied technologies in the area of moving goods through the warehouse, like automated guided vehicles or Automated conveyor systems. The theoretical perceived technical solutions for automation in the area of tracking goods within a warehouse will be examined. The selection of the technologies for automation is based on the appearance in literature.

3.3.1 The movement of goods

In this chapter covers automation systems that are used within the movement of goods in warehouses. An explanation of the functionality is given and what challenges derive from implementing and using it, according to the theory. Thereby, this chapter examines Automated Guided Vehicles (AGVs), Automated forklifts and Automated conveyor systems as technical solutions for automation for the movement of goods.

3.3.1.1 Automated Guided Vehicles

AGVs can, according to Oleari, et al. (2014), be used for “automatizing movement of goods among different locations within an industrial environment” (Oleari, et al., 2014, p. 233). Each movement is often referred to a mission, which are controlled by a WMS. The system assigns each specific AGV with missions that it completes on its own. The main functionality of an AGV is the horizontal movement of goods.

The AGVs normally do not plan their route on their own and are instead following the WMS orders of their assigned mission. To make sure, they avoid each other, their movement is often constrained to a predefined route map. Wurman (D’Andrea and Mountz, 2008) write that AGVs are used to move goods to the worker that picks instead of making the picker move around in the warehouse (Goods-to-Person).

There can be AGVs, which drive around the warehouse and are small enough to fit under the inventory pod. They use a lifting mechanism to minimally lift the whole inventory pod and bring it to the picker. The picker then removes or refills the desired item from or of the bin, and then the AGV brings the whole inventory pod back to the warehouse.

The implementation is often mentioned as one of the biggest concerns with AGVs. An AGV system can be implemented into both new and already operating warehouses. If the warehouse is new and designed from scratch, this often makes the implementation less difficult, according to Oleari, et al. (2014). Since the possibilities of adapting an existing warehouse to the AGVs can be more difficult. The problems often lay within space utilization and safety issues. An AGV movement can be controlled, but often the warehouse should be fully automatized to simplify the programming of these vehicles (Dematic, 2015).

One other challenge with implementing AGVs is to get high efficiency. Oleari, et al. (2014) state, that AGVs in general are more efficient than manual or other half-automated solutions. If it works all the time, as it is supposed to, the warehouse will gain in efficiency. However, there are flaws to the system. Bottlenecks and stuck conditions can decrease the performance. An exemplary situation for that can be, when many AGVs operate in small areas with limted space, they need to be programmed to perfection to not stop occasionally due to safety reasons caused by overlapping sensor scanning areas.

Another challenge, that Oleari, et al. (2014) mention for AGVs is the safety aspect. This is often the biggest concerns for AGVs. Because human workers and AGVs share the same environment, the safety issue needs to be fully addressed in so called mixed operations (Oleari, et al., 2014). The sensors on AGVs are often not able to distinguish between different kinds of obstacles and know nothing about the surrounding areas, except the predefined routes. In an AGV based warehouse there will be critical zones, where they meet or rather cross with other manual handled vehicles. Therefore, AGVs have to reduce their speed significantly, which decrease the efficiency of the whole system. The complexity of many of these challenges often rises as the number of AGVs that are supposed to cooperate, coordinate and share the same environment, exceeds a specific point.

Cardarelli, et al. (2017) stated, that safety could not be guaranteed when the collision avoidance for the AGVs only rely on data from one specific vehicle and its surrounding area. They mean that, to ensure safety and best possible solution for the pickup system, they need to be connected to each other. The AGVs can share data among each other in several ways. One of them is to broadcast data from each AGV, integrate it with data coming from infrastructural sensors and from the other AGVs. If this is done each vehicle will be constantly updated about the status for the whole warehouse. For this type of solution a large quantity of data needs to be transmitted at the same time over the network. This requires that companies reserve a large amount of bandwidth so that the system can provide reliable communication. At the same time the AGVs needs to be equipped with high performance processing units or computers. To equip all AGVs with this is costly and therefore the communication system between the AGVs comes along with higher costs. (Cardarelli, et al., 2017)

According to Vivaldini, et al. (2013) an AGV system needs an administrative input to be able to solve problems. Since the AGVs need to be connected to the material handling system to do their work, like moving goods in the warehouse, they need to be connected to each other. If they are only connected to e.g. the material handling system, they cannot communicate with each other. To make sure AGVs fulfill their purpose, they must be connected to each other to be able to communicate (Kongezos and Allen, 2002). When they are cooperating, they are able to solve problems occuring not only for themselves, but for the whole system. A system that the AGVs can be connected to is the WMS. This system gathers information from many different sources within the warehouse and is therefore able to give even more information to the AGVs. Vivaldini, et al. (2013) mean that it is not only about where to transport the goods for the AGVs. The system exchanges information with the AGVs and gives orders, but at the same time the WMS analyzes and keeps into mind the bigger picture including problems occuring by the minute.

3.3.1.2 Automated forklifts

Another solution for automating the movement of goods in warehouses is Automated forklifts. The purpose of this innovation is both for the horizontal (e.g. the movement to different loading zones) and vertical movement (e.g. for collection and storage) of goods. It is a part of the AGVs, but works as a normal forklift with the lifting device. (Jacobus, Beach and Rowe, 2015)

Jacobus (Beach and Rowe, 2015) describe Automated forklifts in a more detailed way and state, that the invention mainly can be used in automated material handling and transporting systems. It removes the requirement to operate fully manually and even fully automatically. They explain that for many technical solutions there is no possibility to still do the work manually at the same time and therefore the investments of those often are bigger. The invention itself is a replica of a fork truck without the space for driver in the back. It works in the same way but there is no driver needed. Instead the fork truck controls itself with cameras attached at several places. It measures distances, see objects blocking its path and is smart enough to change the determined path, if the closest way is blocked. When it lifts pallets, it always lifts with the same speed and controls the weight of the pallet. The Automated forklifts are able to plan their path themselves, pick up pallets and move them to the right place, whether it is to a picking area, cross-docking area or storage area. The Automated forklifts can be driven at different speeds limited depending on the warehouse environment. (Jacobus, Beach and Rowe, 2015)

It reads both static and dynamic obstacles and stops or avoids them until potential collision risk is avoided. The forklifts can also identify pallet location through radio frequency identification (RFID) technology, Barcodes or Quick Response (QR)-Codes. There are also other special requests that the Automated forklifts can do, according to Jacobus (Beach and Rowe, 2015). They can move automatically to parking stations or proceed to work cells for preventative maintenance.

The challenges with Automated forklifts, that Jacobus (Beach and Rowe, 2015) describe, are almost the same as for AGVs. The implementation can be very expensive and take a long time caused by the addition complexity of the vertical movement direction.

3.3.1.3 Automated conveyor systems

Automated conveyor systems have been around for a long time. According to Gu, (Goetschalckx and McGinnis, 2007), the last decade of innovations has changed how carousels work in many ways with e.g. RFID and better computerized solutions. Bartholdi and Platzman (1986) describe an Automated conveyor system as the “length of a shelf fashioned into a closed loop that is rotatable (under computer control) in either direction … the benefits of a carousel is that rather than have a picker, human or robot, travel to retrieve an item, the item can travel to the picker” (Bartholdi and Platzman, 1986, p. 1).

Gu (Goetschalckx and McGinnis, 2007) explained that nowadays, an Automated conveyor system usually consists of a lane, accumulation conveyor, recirculation conveyor, and exit lanes. Once an order is set the goods get released from its storage position onto the lane at the right times. The goods then travel inside the warehouse in the lane towards a sorting zone as other goods join it on the lane. The sortation then sorts out the goods according to the orders. When orders are sorted, they are removed from the sorting lanes to get checked, packed and delivered. They mention, that before it was more usual that the sortation and picking was done manually at a station where goods passed by.

According to Westfaliausa (n.d.), Automated conveyor systems enable faster transports of goods in warehouses, especially for covering long distances within a warehouse and where vertical movement is involved. The purpose of an Automated conveyor system is to transport goods from position to another horizontally, but the vertical movement is used to make it work. The system is also used to move goods smoothly without human involvement and to reduce product or pallet damage. Automated conveyor systems can be customized for many different purposes to overcome challenges at the warehouse.

Since various lengths, widths and belt types can be implemented into the warehouses, the most important challenge for a company is to decide the best strategy for their Automated conveyor system. The implementation is often rigorous, and it is easier to implement when a completely new warehouse is used, than a rebuilt. The decisions, regarding what kind of technology design for the reading devices like RFID or Barcodes is implemented, is an important choice and depends on what the company used earlier. (Westfaliausa. n.d.)

According to Jiamruangjarus and Naenna (2016), there are several factors to consider when choosing an Automated conveyor system. The types of Automated conveyor systems can be differentiated in several ways. It can be used for bulk or unit loads and be placed close to the ground or overhead. There are also different kinds of belts and depending on what the Automated conveyor systems will be used for it can be built in a lot of ways.

As they described, the investment for Automated conveyor systems is often big from the beginning and the strategic function of the Automated conveyor system is very important. It needs to be built in a way that fits the company and therefore it is a challenge with knowledge. Jiamruangjarus and Naenna (2016) suggest that there should be several experts about Automated conveyor systems included, but also personnel from the company, that cooperates and discuss how the best solution would look like. Other challenges mentioned, are that an Automated conveyor system is not flexible related to the configuration and direction of product flow without bigger adaptations. In the building process this needs to be considered, if the company's usage of it will change in the future and how hard it will be to adapt to new changes. If there is an error in the Automated conveyor system, this often means a complete stop of the warehouse operations. The Automated conveyor systems therefore need to address quality issues and have people on site that can fix errors that occur.

3.3.2 **The tracking of goods**

The need for tracking goods in the supply chain is stronger than ever before. Especially, increased visibility and transparency is needed for businesses caused by the fast moving economy during the last decade (Tzoulis and Andreopoulou, 2013). Monsreal, et al. (2011) stated, that “tracking systems can provide visibility, traceability, and associated information across different stages of a supply chain, which enables competitive advantages” (Monsreal, et al., 2011, p. 1). To emphazise on the idea of Monsreal, et al. (2011), Bahr and Lim (2009) stated, that ” warehouse information should be as accurate as possible" (Bahr and Lim, 2009, p. 3), to be able to gain advantage.

The purpose of businesses by implementing tracking systems is to have the control about their goods during the journey through the warehouse and also about their inventory as a consequence of that. Tracking systems have to cover the requirements of companies, like the cheap implementation, the easy maintenance or the flexibility of the system. (Monsreal, et al., 2011)

After searching for technical solutions for tracking systems in research and literature, it can be noted, that there are mainly five different kinds of tracking systems currently applied in businesses. Even though, most of those technologies have been launched a while ago, businesses still use them, caused by efficiency and cost reasons. These technologies are Barcodes, Quick Response (QR)-Codes, Near Field Communication (NFC), Radio Frequency Identification (RFID) and Global Positioning Systems (GPS). (AHG, 2017)

Although, the basic principle of these technologies is not developed in the last years, there are still ongoing technical developments for these technologies to adapt those to the technical evolution e.g. like the Internet of Things (IoT) or the invention of robotics in warehouses. (Beacon, 2010)

3.3.2.1 (1D)-Barcodes

The most common used tracking technology in warehouses during the last decades are still Barcodes. Even though, they have been invented decades ago, companies do not want to refuse them caused by cost aspects and applicability. Currently, there are two types of Barcodes, namely 1-dimensional (1D)-Barcodes and 2-dimensional (2D)-Barcodes, which are called QR-Codes (Wasp, 2015).

Barcodes store information through a string of number between 0 and 9 represented via specific line patterns on the code. They can contain up to 85 characters (Wasp, 2015). To be able to get information out of these codes, they have to be scanned by a Barcode scanner, which contains photoelectric cells that send out light and receive reflection from the code. Afterwards, this reflection will be transformed into the implemented string and analyzed via e.g. an electronic Point-of-Sale (POS) terminal or any other terminal (Lotlikar, et al., 2013). To be able to use Barcodes in the warehouse, a Barcode label printer, Barcode label design software and a label roll is needed. Additionally, a Barcode scanner with a physical or wireless connection to a terminal is needed to transform the received string into useful information. (Explainthatstuff!, 2017, *Barcodes and Barcode scanners*)

A scanner for a Barcode is composed of three parts, the illuminator, the decoder and the sensor. The code can be read through Barcode basic wand scanners, pen scanners, laser scanners and also through mobile devices. To be able to use Barcode scanning in a warehouse, there are relatively high acquisition costs in relation to other tracking systems. On a day-to-day basis, there are only the costs for the Barcode rolls, which are up to 0,05$ USD per label. (BarcodesInc n.d.; Lotlikar, et al., 2013)

Barcodes are easy to generate and to use in a warehouse. Also the maintenance of this tracking technology is easy, when it comes to the creation, the printing and labelling of these codes. Another big advantage of Barcodes, especially in the era of IoT, is the possibility to read Barcodes through any kind of mobile device with a camera. The reason why companies still use this tracking technology is, beside of the easy handling, the cheap running costs with regards to the creation of Barcodes. (Wasp, 2015; Lotlikar, et al., 2013; Pihir, Phir and Vidacic, 2011)

On the other hand, the usage of Barcodes is also challenging for companies. Barcodes only have a limited amount of storage capacity, which is caused by the limited amount of space on the Barcode. To be able to use Barcodes in a warehouse, the equipment, like the Barcode generator, the printer, the label rolls and the scanners, have to be acquired. (Explainthatstuff!, 2017, *Barcodes and Barcode scanners*; Lotlikar, et al., 2013)

A big challenge for the usage of Barcodes is the assurance of the visibility of the Barcode, during the scanning process. The Barcode has to be visible for the scanner during the reading process. Beside of the manual scanning, scanning in automated systems, like on Automated conveyor systems, still need a minimum human involvement to assure the visibility of the Barcode for the scanner. (Pihir, Phir and Vidacic, 2011)

Based on the limited amount of space for information on a Barcode, every scratch or damage in general has to be avoided to save the stored information. Therefore, Barcodes are very vulnerable and a little damage can cause the loss of information, which mostly leads to the damage of the whole Barcode. (AHG, 2017; Explainthatstuff!, 2017, *Barcodes and Barcode scanners*)

The most challenging aspect of the usage of Barcodes is the easy illegibility. The readability of a Barcode can be affected by several reasons. Beside of the mentioned damages, there can be as well a violation of the quiet zone of a Barcode. The quiet zone, which is a blank area around the Barcode responsible for the delimination between the Barcode and the product printing, can be damaged or can be applied to the product surface too close to an edge. Also a poor printing quality or the usage of wrong colors for the printing can be a reason for the illegibility of the Barcode. Additionally, every unexpected and unintended reflection of the Barcode or its surrounding can affect the readability negatively. Companies have to overcome these challenges, when they want to use the full potential of Barcodes for the tracking of goods in their warehouses. (Lotlikar, et al., 2013)

3.3.2.2 QR-Codes

Barcodes and QR-Codes mainly differ in the storage capacity. QR-Codes store information in modules, which contain two different types, black and white modules, in a two-dimensional Barcode. A QR-Code, which is also called a Data-Matrix code, can store up to 7000 characters, which includes a string of information. QR-Codes can easily be created online and printed with a standard printer. QR-Code scanners are composed in the same way as Barcodes. There are different possibilities to read a QR-Code, e.g. through fixed scanner, optical QR-Code scanners and mobile devices with a built-in camera. To run a QR-Code tracking system in a warehouse, there are nearly no costs, beside of the eventually acquisition costs of the scanners. (Lotlikar, et al. 2013; AHG 2017)

QR-Codes are easy to create by an online program free of charge (QR-Code generator, n.d.). These codes are also more resistant to damages than the normal Barcodes. Caused by the big storage capacity, there is enough space for redundant information, which allows a lot more damages than Barcodes, before the whole information is lost. QR-Codes also provide much more open space for creativity to design the QR-Code individually. (AHG, 2017; Rcodemonkey, n.d.)

Nevertheless, there are also a few challenges for the implementation and usage of QR-Codes in warehouse operations for tracking goods. QR-Codes, which are also printed and put on items, contain most of the same challenges as Barcodes. These codes have to be visible for the reader and they also have illegibility problems, like too low printing quality, violation of the quiet zone or illegible label caused by damages.

There is also a challenge, which rises from the increased flexibility of designing a QR-Code. Too much customization can influence the readability of a QR-Code negatively. When a QR-Code is designed, it has to be assured, that the QR-Code colors are not inverted, that there is enough contrast in the code, that the codes are not too blurry neither too small and that not too much content is stored on the codes. (Rcodemonkey, n.d.)

The speed of the scanning process can be a challenge for a company, especially in high frequency warehouses, caused by the increased amount of information, which has to be scanned in comparison to Barcodes (Visaisouk, 2013). The last challenge, which might appear by the usage of this technology for the tracking of goods, is the need for special and fixed installed readers in the warehouses. QR-Codes are normally scanned by smartphones with specific QR-Code applications. To read these codes on, e.g. Automated conveyor systems, specific fix installed readers are necessary (AHG, 2017).

3.3.2.3 RFID technology

The third tracking technology presented in this study is the RFID technology. RFID was first used for military purposes before it was launched in the business sector (Xiao, Boulet and Gibbons, 2007). The RFID technology consists of a RFID reader, a RFID antenna and a RFID tag. Information, which is stored on the RFID tag, is transmitted via radio waves over the antenna to the receiver. A typically tag can contain up to 2 Kilobyte (Kb) of data, which covers basic information about the item and a unique serial number (Explainthatstuff!, 2017, *Radio frequency (RF and RFID) tags*).

There are two different types of RFID tags, namely active and passive tags. The principle of those tags is the same, but the way of transmitting data differs between these tags. The receiver of the data sends out a signal and the passive RFID tag receives that signal via the antenna, which catches the incoming radio waves, and responds to that and sends the signal with the information back to the receiver. In comparison to that, active RFID-tags contain an internal energy source, like a battery. Therefore, active RFID tags continuously broadcast their own signal to send their information and also their unique serial number all the time. Caused by the internal energy source, the distance for transmitting information is much wider for active RFID tags in comparison to passive RFID tags. Active RFID tags are mostly used in high speed environments to accurately track the real-time location of the item. These tags can cover up to 100 meter for the transmission of data. Passive RFID tags can cover, caused by the lack of an internal energy source, an average distance of about 5 to 6 meters, if they use a specific frequency for the transmission. Regarding the costs of these tags, passive RFID tags cost between 0,20$ USD and 1,5$ USD, depending on their features. Active RFID tags cost between 15$ USD and 20$ USD (AMI, 2013). RFID tags "uniquely identify the article to which they have been attached" (Explainthatstuff!, 2017, *Radio frequency (RF and RFID) tags*), nevertheless what kind of RFID tag it is. Passive RFID tags cover the requirements of a standard warehouse in the logistic sector and are regarding the costs of the tags and the needed amount of the tags the only economic reasonable solution for high throughput warehouses. (Smiley, 2016)

Bahr and Lim (2009) stated that RFID is a tool "to maximize the productivity and efficiency of the warehouse operations" (Bahr and Lim, 2009, p. 2). In comparison to other tracking technologies, the RFID technology does not need any kind of human involvement (Bahr and Lim, 2009). RFID technology, especially the active RFID tags, in combination with the IoT enables the real-time tracking within a warehouse (Jia, et al., 2012). Also the reading speed is much faster, than it is for Barcodes and QR-Codes, because RFID technology provides the possibility to read multiple items at the same time, on condition that the RFID tags do not overlap (AHG, 2017).

There are also a few challenges for the implementation and usage of RFID technology in warehouses. Lim (Bahr and Leung, 2013), Kumar (Kadow and Lamkin, 2011) and Bahr and Lim (2009) emphasize in their papers on the high investment and running costs for the usage of RFID. The need of the investment in tags, readers, network hardware, software, system maintenance, employee training and the attaching of the tags on the products are high costs, which influence the Return on Investment (ROI) of this technology extremely negatively.

RFID technology also does not have 100% accuracy, according to Bahr and Lim (2009). Tags can disturb each other, or the environment of the reading area disturbs the reading process. Also if the "antenna is perpendicular to a reader antenna" (Bahr and Lim, 2009, p. 5) the reading process fails. Lim (Bahr and Leung, 2013) stated, that the integration of the RFID technology in the WMS can be challenging for companies caused by the multiple and complex connection points. It also has to be mentioned, that RFID tags can store less than QR-Codes, but much more than Barcodes (AHG, 2017).

Lim (Bahr and Leung, 2013) and Bahr and Lim (2009) highlighted privacy and security problems of the RFID technology. This is caused by the transmission of information via radio waves, which means, that it is also possible that an unintended reader receives the tag information. In comparison to Barcodes or QR-Codes, RFID tags are normally not readable by mobile devices caused by the lack of capable mobile devices sending radio waves (AHG, 2017).

The last challenge mentioned, is the lack of standardization of the RFID technology. It is common, that different countries use different radio frequency spectra for the transmission of data and for the programming of RFID tags. This is problematic, especially in supply chains, where products are shipped international and tags are read in different countries. This challenge is started to address by the development of the global standards, like the Electronic Product Code (EPC) compliance, but still remains to a certain degree. (Lim, Bahr and Leung, 2013; Bahr and Lim, 2009)

3.3.2.4 NFC systems and GPS systems

The last two tracking technologies are the NFC systems and the GPS systems. NFC tags are based on the RFID technology, but only work on really short distances in comparison to RFID tags. The reason for the invention of NFC tags was mainly for confidentially reasons, so that the information stored on these tags can only be read by the supposed readers. Caused by the restriction of the short distance, NFC tags are normally not used in warehouses, which do not take special care about the confidential aspect. (Faulkner, 2017)

GPS systems use GPS tags, which communicate with the receiver in the same way as navigation devices work. Therefore, GPS tags, which transmit the location information via the Global Navigation Satellite System (GNSS) network, communicate through the sending of microwave signals. For the usage at a specific area, there is also the possibility to create a local network, which can be used as a satellite compensation, to enable the communication of the devices via microwaves signals. Caused by the high investment costs in the system and in the tags, this technology is only used for high value products and so it is normally not used for a standard warehouse (Bertagna, 2010). Based on the area of application, this study focuses in the following on the challenges of the implementation and the usage of Barcodes, QR-Codes and RFID technology. Since NFC systems and GPS systems are not normally used in warehouses, they will not be considered more in detail.

Technologies applied in theory and used for this thesis	
The movement of goods	The tracking of goods
AGVs	Barcodes
Automated forklifts	QR-Codes
Automated conveyor systems	RFID technology

Figure 5. Technologies identified in theory

3.4 Visualization of the perceived challenges in theory

This chapter includes the visualization of the theoretical perceived challenges with the implementation and usage of technical solutions for automation for the movement and tracking of goods. The perceived challenges will be mentioned and listed, but also explained and justified.

3.4.1 **The movement of goods**

In the following table, the theoretical perceived challenges for the presented technical solutions for automation for the movement of goods, including the sources of these challenges. Additionally, this table refers to the chapter, which also explains the reason of their existence.

	Automated Guided Vehicles (AGVs) (Chapter 3.3.1.1)	Automated forklifts (Chapter 3.3.1.2)	Automated conveyor systems (Chapter 3.3.1.3)
Purpose / Challenges	Horizontal movement of goods	Horizontal and vertical movement of goods	Horizontal and vertical movement of goods
Implementation /investment costs	Oleari, et al. (2014)	Jacobus (Beach and Rowe, 2015)	Jiamruangjarus and Naenna (2016)
Integration in an existing warehouse	Oleari, et al. (2014)		Oleari, et al. (2014); Gu (Goetschalckx and McGinnis, 2007)
Knowledge and maintenance of the system	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015); Jiamruangjarus and Naenna (2016)	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015); Jiamruangjarus and Naenna (2016)	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015); Jiamruangjarus and Naenna (2016)
Efficiency issues	Oleari, et al. (2014)		Jiamruangjarus and Naenna (2016)
Safety issues when interacting with humans	Oleari, et al. (2014): Jacobus (Beach and Rowe, 2015)	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015)	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015)
Number of automated units used within a specific area	Oleari, et al. (2014)	Oleari, et al. (2014)	

IT integration in the system landscape	Wurman (D'Andrea and Mountz, 2008)	Wurman (D'Andrea and Mountz, 2008)	Wurman (D'Andrea and Mountz, 2008)
Time for implementation	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015)	Jacobus (Beach and Rowe, 2015); Oleari et al. (2014)	Oleari, et al. (2014); Jacobus (Beach and Rowe, 2015)
Flexibility in the future	Westfaliausa (n.d.), Jiamruangjarus and Naenna (2016)		Westfaliausa (n.d.), Jiamruangjarus and Naenna (2016)
Communication among vehicles	Cardarelli, et al. (2017)		

Figure 6. Challenges of technical solutions for the movement of goods

Explanation of the challenges:
Some of these challenges are described in the context of the specific automation system. However, the challenges are transferable to the other systems, because they are similar in many ways. When the box is empty there is nothing found in theory that approves that this is a challenge for that automation solution.

Implementation/investment costs: There are high implementation costs to almost all technical solutions for automation in warehouses. This is a cost challenge, and this is something that all companies consider when implementing automation. (Jacobus, Beach and Rowe, 2015)

Integration in an existing warehouse: If a completely new warehouse is built, there is less need of thinking about the current situation. However, if the company rebuild their current warehouse the automation needs to be fitted for that specific warehouse, mostly considering space and if there are technological changes. Since the same space is needed for Automated forklifts as for regular forklifts this will not be a challenge. (Oleari, et al. 2014)

Knowledge and maintenance of the system: If there is no knowledge about automation within the company, they need to get that information both for implementing and maintenance of the automation. (Jiamruangjarus and Naenna, 2016)

Efficiency issues: The new automation solution would not be implemented without considering if it would improve the efficiency. Efficieny issues mainly appear in the beginning from the implementation of a new technology on. However, automation needs to be configured to work as it is supposed to. Since Automated forklifts are normally used at the same time as regular forklifts the efficiency will not decrease, according to Oleari, et al. (2014).

Safety issues when interacting with humans: This is an important challenge, especially when it comes to unexpected errors in the automation systems. If the automation system does not work as it is supposed to with efficiency, this implies that there also can be safety issues. In these innovations they have considered safety, but new solutions often mean new problems. For instance, warehouse areas have limited access when the systems are running to avoid safety problems. (Oleari, et al., 2014)

Number of automated units used within a specific area: For AGVs and Automated forklifts there is a challenge rising, when using too many in a specific place. When the ratio between the number of automated units and space increases, then there is need for higher level of communication among the automated units. In contrast to that, an Automated conveyor system is one system and cannot be divided into several units. (Oleari, et al., 2014)

IT integration in the system landscape: The integration in the existing system landscape can be challenging for companies, because it has to be ensured that a new implemented technology is well connected to the already used systems to use the full potential of the technical solution for automation. All these automation solutions need to work with RFID, QR-Codes and Barcodes or similar tracking systems and also have to be able to be integrated in a WMS. What will work best for each company, is something they need to figure out and is a challenge for them to overcome. (Jacobus, Beach and Rowe, 2015)

Time for implementation: Depending on how big the implementation, is the company needs to consider the time spent for implementation. Many things need to be considered, like how will the warehouse work during the rebuilding? (Jiamruangjarus and Naenna, 2016)

Flexibility in the future: Changes in the company with e.g. bigger or smaller goods can be a challenge for the automation system, and therefore the adaptability is of high importance. In contrast to that, Automated forklifts are used at the same time as regular forklifts, which will not decrease the flexibility, according to Oleari, et al. (2014). This also includes the degree of customization, which means that there are challenges with the automation system. If it is customized too much or too less there can be a problem with flexibility or a need for adaptations in the future. Since Automated forklifts are used at the same way as regular forklifts there is no customization challenge to them. (Westfaliausa, n.d.)

Communication among devices: As Cardarelli, et al. (2017) stated, the communication among the devices can be challenging caused by the connection of these devices and this comes also along with higher costs. Nevertheless, a good communication among the devices is needed to ensure a smooth flow of the system.

Accentuation of most important challenges identified in theory
The following table shows the most important challenges based on their importance in theory. The decision and selection of their importance is based on the appearance of the challenges in literature and on the scientific insights of previous researchers.

Most important challenges identified in theory for the tracking of goods		
Technology	Challenge	References
AGVs	Implementation/investment costs	Oleari, et al. (2014)
	Safety issues when interacting with humans	Oleari, et al. (2014) , Jacobus (Beach and Rowe, 2015)
Automated forklifts	Implementation/investment costs	Jacobus (Beach and Rowe, 2015)
	Number of units	Oleari, et al. (2014)
Automated conveyor Systems	Implementation/investment costs	Jiamruangjarus and Naenna (2016)
	Time for implementation	Oleari, et al. (2014), Jacobus (Beach and Rowe, 2015)
	Flexibility in the future	Westfaliausa (n.d.)

Figure 7. Accentuation of challenges for the movement of goods

3.4.2 The tracking of goods

The following table shows the challenges of the tracking technologies and refers also to the chapter, which explains the reason of their existence.

Challenge	(1D)-Barcodes (Chapter 3.3.2.1)	QR-Codes (Chapter 3.3.2.1)	RFID technology (Chapter 3.3.2.1)
Low amount of storage capacity	Lotlikar, et al. (2013); Explainthatstuff! (2017)		
Illegibility	Lotlikar, et al. (2013)	Lotlikar, et al. (2013)	Lim (Bahr and Leung, 2013); Bahr and Lim (2009)
Condition of visibility for the scanning process	Pihir (Phir and Vidacic, 2011)	Pihir (Phir and Vidacic, 2011); Visaisouk (2013)	
High aquisition and running	Lotlikar, et al. (2013); AHG		Kumar (Kadow and Lamkin, 2011); Lim

costs	(2017)		(Bahr and Leung, 2013); Bahr and Lim (2009)
Highly vulnerable for damages	AHG (2017)		
Slow scanning speed		Visaisouk (2013)	
Possibility for live-tracking	Wasp (2017); Jia, et al. (2012)	Wasp (2017), Jia, et al. (2012)	
Human involvement needed	Pihir (Phir and Vidacic, 2011)	Pihir (Phir and Vidacic, 2011)	
Integration in the WMS			Bahr and Lim (2009)
Privacy and Security			Lim (Bahr and Leung, 2013), Bahr and Lim (2009)
Standardization in technology			Lim (Bahr and Leung, 2013), Bahr and Lim (2009)

Figure 8. Challenges of technical solutions for the tracking of goods

Explanation of the challenges:
Some of these challenges are described in the context of the specific automation system. However, the challenges are transferable to the other systems because they are similar in many ways. When the box is empty there is nothing found in theory that approves that this is a challenge for that automation solution.

Low amount of storage capacity: As it is explained e.g. in Lotlikar, et al. (2013), the low amount of storage capacity on tracking tags can be challenging for companies. This challenge appears in particular by the usage of Barcodes. QR-Code and RFID tags can store in comparison to Barcodes much more information.

Illegibility: Illegibility of codes or tags means that their readability is negatively affected, which leads in the end to the loss of the information of the code or tag. The readability of Barcodes and QR-Codes can be affected by e.g. the violation of the quiet zone or a poor printing quality and much more. Also the excessive customization of QR-Codes based on the increased freedom of design, might lead in the end to the illegibility of that code (Visaisouk, 2013).The illegibility of RFID tags can be caused by the overlapping and disturbance of tags among each other. (Lotlikar, et al., 2013; Lim, Bahr and Leung, 2013; Bahr and Lim, 2009)

Condition of visibility for the scanning process: According to Pihir (Phir and Vidacic, 2011), it might be challenging for companies to ensure that the visibility of codes is always given. To be able to scan Barcodes and QR-Codes, the label has to be visible for the reader in comparison to the RFID tags.

High acquisition and running costs: To be able to use Barcodes or RFID tags in a warehouse relatively high acquisitions costs have to be paid, e.g. for the scanners, the readers, the tags and the software. Lotlikar, et al. (2013) mentioned that there are mainly high acquisitions costs for the usage of Barcodes in a warehouse, but the running costs of this technology are beside of the purchase of Barcode label rolls a minor aspect. In comparison to that, Kumar (Kadow and Lamkin, 2011) and many other researchers examined the high costs for the usage of RFID technology in a warehouse. Beside of the costs for the tags and the readers, costs for programming of the tags, attaching those to the packages and the training of the staff has to be taken into account. (Lim, Bahr and Leung, 2013; Bahr and Lim, 2009)

Highly vulnerable for damages: Barcodes are highly vulnerable for damages, caused by the limited space for the information storage. Every damage or negative acting of the code causes the loss of important information, which leads in the end to the loss of the whole information of the code. (AHG, 2017)

Slow scanning speed: Barcodes and RFID tags can be scanned at high frequency. RFID tags can also be scanned simultaneously by the same reader, if they do not disturb each other. In contrast to that, the scanning speed of QR-Codes is in comparison to the scanning speed of the other technologies less. This is e.g. caused by more information on QR-Codes, which has to be read. (Visaisouk, 2013)

Need for live-tracking: With the usage of RFID tags, especially active RFID tags, it is possible to track products in live through their way in the warehouse. Barcodes and QR-Codes are not able to provide this capability on their way through the warehouse without increasing the amount of scanners significantly. The position of a product, which has a Barcode or QR-Code attached can only be located when the scanner reads the information on the code. (Jia, et al., 2012; Wasp, 2017)

Human involvement needed: Another challenge by the use of Barcodes and QR-Code might be the human involvement, which is needed for the scanning process of the codes. This might be e.g. for an automated scanning line, where it has to be ensured that the labels of the codes are visible for the scanner. In comparison to that, RFID tags can be scanned without human involvement caused by the scanning with radio waves. (Pihir, Phir and Vidacic, 2011)

Integration in the WMS: Another challenge, which appears by the implementation of RFID technology in a warehouse, is the integration of that system in the used WMS. As Bahr and Lim (2009) explained, the integration of RFID in a WMS is a challenging task for a company, which has to be done in an accurate way to ensure the functionality of RFID tracking. (Bahr and Lim, 2009)

Privacy and Security: One of the most important challenges, when it comes to the usage of RFID technology in a company, is the privacy and security aspect. Since RFID transmits information via radio waves over a specific distance, there might arise the problem, that this information can be received by other readers, which are not supposed to receive that information. Barcodes and QR-Code do not have this challenge, because the scanning process is based on the direct visible reading of the Codes. (Lim, Bahr and Leung, 2013; Bahr and Lim, 2009)

Standardization in technology: The challenge of the standardization in the technology especially appears by the use of RFID tags in an international business context. In supply chains, which interact throughout different countries, there might be the problem that the different countries use different kind of RFID scanning frequencies, which is caused by the lack of a unified and standardized RFID frequency agreement. So there might be the situation that RFID tags cannot be read in different countries. (Lim, Bahr and Leung, 2013; Bahr and Lim, 2009)

Accentuation of most important challenges identified in theory
The following table shows the most important challenges based on their importance in theory. The decision and selection of their importance is based on the appearance of the challenges in literature and on the scientific insights of previous researchers.

Most important challenges identified in theory for the tracking of goods		
Technology	Challenge	References
Barcodes	Illegibility	Lotlikar, et al. (2013)
	High aquisition costs	Lotlikar, et al. (2013); AHG (2017)
	Condition of visibility for the scanning process	Pihir (Phir and Vidacic, 2011)
QR-Codes	Illegibility	Lotlikar, et al. (2013)
	Condition of visibility for the scanning process	Pihir (Phir and Vidacic, 2011); Visaisouk (2013)
RFID technology	Illegibility	Lim (Bahr and Leung, 2013)
	High aquisition and running costs	Kumar (Kadow and Lamkin, 2011); Lim (Bahr and Leung, 2013); Bahr and Lim (2009)
	Privacy and Security	Bahr and Lim (2009); Lim (Bahr and Leung, 2013)

Figure 9. Accentuation of the challenges for the tracking of goods

4 Empirical findings

In the following chapter the most important results of the empirical data is presented. These results are based on the most important aspects of the semi-structured interviews, which are attached in the Appendix 2 of this thesis. The data of the empirical findings includes a short presentation of the company, an overview of the stated challenges regarding the movement and tracking of goods and an explanation of the existence of the stated challenges.

If a challenge could be identified for one of the technologies, the appropriate cell is marked with “x”. In case, the interviewed company mentioned that a specific challenge is identified and not applicable for one of the technologies, the cell is marked with “-“. Otherwise, the cell is left without a marking, which can be caused by the lack of information or by the silent consent interpreted by the authors.

The purpose of the differentiation between the different levels of perception (see “x”, “-“or empty cell) at the companies is to increase the quality of the data. Nevertheless, the fact that the interviewed companies mentioned a challenge as not applicable (see “-“), will not be analyzed further into detail in the rest of the paper. Therefore, there will not be a differentiation between a not perceived challenge (see “-“) and an empty cell caused by e.g. the lack of information, since the focus of this paper is on the analysis of the identified challenges.

The most important challenges for each company are highlighted in bold. The decision regarding the importance of a challenge is based on the perceived information during the interviews, which can be caused by the permanent repeating of the challenge or the mentioning of the importance of that challenge.

4.1 Company 1 – Supplier in automotive industry

This chapter includes the presentation of company 1 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 1 is working in the automotive sector as a supplier for Electrics, Electronics, Interiors and battery systems, which includes the production of e.g. wiring harnesses, connector systems, door panels and many more. Company 1 is located in more than 60 sites in over 20 countries throughout the world. It has currently approximately 75.000 employees around the world and has a turnover in 2017 of about 41 billion SEK. (Company 1, 2018)

The strategy of this company is to find individual solutions for the premium automotive industry, by focusing on the development of innovative ideas and relying on future-oriented technologies, like the development of electronic components to support the electrical mobility.

As a supplier for the automotive sector, this company has a lot of competencies. These competencies include the research and development of new product ideas, the design and production of these ideas and the testing of these products regarding specific characteristics. Additionally, Company 1 is specified in Just-in-Time (JIT) and Just-in-Sequence (JIS), as it is mostly required by the automotive manufacturers.

The warehouses of Company 1 have in average between 1.000 and 6.000 pallet places and in these warehouses work between five and 100 employees. The contact person for this interview was the director of the warehouse logistics department for the whole company group. This department is specified and responsible for the warehouse processes and technologies in all sites globally. (Company 1, 2018)

Based on the interview, Company 1 uses an Automated conveyor system, Barcodes, QR-Codes and RFID technology. They also considered AGVs and Automated forklifts, but will not implement them.

The following findings are based on the interview with Company 1, which is attached in the form of the most important results in the Appendix 2. (Company 1, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Physical integration in the warehouse	x	x	
Added-value in comparison to the investment	x	x	-
Investment justification in relation to the size of the warehouse	x	x	
Integration complexity - planning and organization			x
IT integration in the system landscape			x
Efficiency issues	x	x	-

Figure 10. Company 1 - The movement of goods

Implementation costs: Company 1 considered the implementation of AGVs and Automated forklifts, but caused by the immense costs, they decided not to implement it. For the already implemented Automated conveyor system the implementation costs were one of the biggest challenges. In general, Company 1 highlighted the importance of the Implementation costs for movement technologies within the warehouse.

Physical integration in the warehouse: After considering about AGVs and Automated forklifts, Company 1 realized that the physical integration of the system is challenging, because the required space on the floor of the warehouse for the usage of AGVs and Automated forklifts is not available. In contrast to that, Company 1 implemented the Automated conveyor system at the ceiling of the warehouse.

Added-value in comparison to the investment: The added-value in comparison to the investment, is one of the most important challenges as Company 1 stated, of the AGVs and the Automated forklifts would be challenging for Company 1 caused by the immense investment costs. Since, Company 1 implemented Automated conveyor systems, the Added-value in comparison to the investment was not perceived as a challenge.

Investment justification in relation to the size of the warehouse: Since Company 1´s warehouse is not very big, the usage of AGVs and Automated forklifts would be limited. Therefore, the investment in these technologies would not be justifiable.

Integration complexity – planning and organization: The integration complexity was challenging for that company for the implementation of the Automated conveyor system, caused by huge planning effort for the integration in an existing warehouse. The consideration about AGVs and Automated forklifts stopped before a detailed planning was started.

IT integration in the system landscape: The technical integration of the Automated conveyor system was an important challenge caused by the huge amount of existing systems of Company 1. The consideration about AGVs and Automated forklifts stopped before a detailed planning was started.

Efficiency issues: Caused by the complexity of the existing warehouse, the increase of efficiency in operation for AGVs and Automated forklifts would be challenging for Company 1. In contrast to that, this challenge was not perceived for the implementation of Automated conveyor systems.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs	-	-	x
Added-value in comparison to the Implementation costs			x
Limited storage capacity	x	-	

Visibility problems	x	x	-
Vulnerable for damages	x	-	
Wi-Fi connection for mobile devices	x	x	x
Illegibility	-	-	x

Figure 11. Company 1 - The tracking of goods

Implementation costs: Since Company 1 uses RFID in a minor part of the warehouse, they are aware of the huge implementation costs as an important challenge for e.g. the tags, the readers and the antennas. Nevertheless, Company 1 stated as well that the Implementation costs for Barcodes and QR-Codes were not perceived as challenging.

Added-value in comparison to the Implementation costs: After testing and partly using, Company 1 is aware of the challenge that the added-value in comparison to the investment costs is mainly regarding the capability of live-tracking.

Limited storage capacity: One of the challenges for Barcodes, in contrast to QR-Codes as they stated, is the limited storage capacity caused by the limited amount of storage positions on the code.

Visibility problems: Challenging for Barcodes and QR-Codes, as Company 1 perceived, is the assurance of the visibility of the label, especially for the use in automated reading processes. Company 1 mentioned as well, that this challenge is not perceived for the usage of RFID technology.

Vulnerable for damages: Especially Barcodes are highly vulnerable for damages caused by the limited amount of storage positions, which increases the importance of the integrity of each position. Caused by the extended storage capacity of QR-Codes, this challenge was not perceived by Company 1.

Wi-Fi connection for mobile devices: To have a reliable Wi-Fi connection throughout the whole warehouse is currently challenging for Company 1, which is then also challenging for the usage of mobile devices for all kind of tracking technology. Therefore, this challenge is stated as one of the most important ones.

Illegibility: The illegibility of tracking technology mainly appears at Company 1 for the usage of RFID and there especially with interferences of antennas of RFID readers. For Barcodes and QR-Codes, they did not perceive or consider any illegibility challenges.

4.2 Company 2 – Distributor of office material

This chapter includes the presentation of Company 2 and the empirical findings based on the taken interview with the Company respondent.

Company presentation

Company 2 is part of a global group that is the world's biggest distributor of office material both for work and home. Their core products are promotional products, copying paper, envelopes, pencils, packaging, binders and hygiene products. Company 2 is located in around 30 countries and serves companies in all different sizes but also private customers. Their turnover for 2017 was approximately 200 billion SEK.

They offer different ways for customers to shop, either by contract, in-store or online. Many of their products are from their own brand, but they are also using other well-known suppliers for some products. Their strategy is to meet all different kind of customer expectations and be able to deliver low prices across the world, by working with industry leading products, services and expertise.

The contact person for this interview was the warehouse logistics manager for the northern Europe warehouses. As he mentioned, his company built in 2011 one of Europe's most sophisticated warehouses within his area of responsibility. The contact person talked mostly about this warehouse, but also about the company in general. In this warehouse, there are currently 80 people working, while Company 2 has approximately 80.000 employees in total. (Company 2, 2018)

Based on the interview, Company 2 uses an Automated conveyor system and Barcodes. They also considered AGVs, Automated forklifts, QR-Codes and RFID technology, but will not implement them.

The following findings are based on the interview with Company 2, which is attached in the form of the most important results in the Appendix 2. (Company 2, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Physical integration in the warehouse	x	x	x
Added-value in comparison to the investment	x	x	x
Investment justification in relation to the size of the warehouse	x	x	x
Integration complexity - planning			x

and organization			
IT integration in the system landscape			x
Flexibility in operations			x
Efficiency issues	x	x	x
Safety issues in mixed operations			x

Figure 12. Company 2 - The movement of goods

Implementation costs: Company 2 considered AGVs and Automated forklifts. These solutions were ruled out caused of the high costs. Instead Automated conveyor systems were implemented. But still one of the biggest and most important challenges with the Automated conveyor system was the high costs for implementation.

Physical integration: Company 2 considered many different solutions in their old warehouse, but did not do any changes, until they built a new warehouse. They considered that many of the solutions did not fit in the old smaller warehouse from a physical integration point of view. Caused by this requirement, Company 2 perceived this challenge as one of the most important ones.

Added-value in comparison to the investment: As Company 2 mentioned, the added-value in comparison to the high investment costs for all of the mentioned technologies, is one of the most important challenges, which has to be considered.

Investment justification in the relation to the size of the warehouse: Company 2 considered that the old warehouse itself was too small and did not handle enough goods to justify a huge investment in the technology. When they merged several warehouses together into the new built warehouse, this change and the investment justification had been overcome.

Integration complexity – planning and organization: To make the Automated conveyor system work properly was challenging for Company 2. Also, a lot of planning and organization was needed to enable a smooth integration.

IT integration in the system landscape: Caused by the existence of two different WMSs at the time of implementation, the technical integration in these two systems was challenging.

Flexibility in operations: Company 2 recognized that it is harder for employees to adapt to changes during the operations of the new system. If a customer wanted to add something to an order, the order still needed to go through the system as it did from the beginning. Therefore, changes or adaptations during the operation are challenging.

Efficiency issues: Costs had not been the only reason for Company 2 to choose Automated conveyor system, instead of AGVs and Automated forklifts. According to their calculations, the efficiency increase was not good enough with those two technologies in comparison to Automated conveyor systems. Company 2 also had problems in the beginning, before the Automated conveyor system did run smoothly to reach high enough efficiency.

Safety issues in mixed operations: Company 2 had challenges regarding safety, when it came to the handling of automated and manual workforce together in the warehouse.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs			x
Added-value in comparison to other technologies		x	-
Generation of added-value in comparison to the investment		-	x
Switching cost for technology	x	x	

Figure 13. Company 2 - The tracking of goods

Implementation costs: Company 2 has also considered RFID technology, but the high investment costs caused by the aquistion of e.g. tags and readers have been too high.

Added-value in comparison to other technologies: Company 2 has considered QR-Codes, which have benefits like the extended storage capacity. However, it is not enough added-value in comparison to Barcodes to plan an elaboration transition between these two technologies. For the implementation of RFID technology, this important challenge is not perceived, as Company 2 mentioned, caused by irrefutable benefits of RFID technology in comparison to the other tracking technologies.

Generation of added-value in comparison to the investment: As Company 2 stated, the challenge of generating added-value in comparison to the investment is one of the most important challenges for them, when it comes to the tracking of goods. RFID technology would add value e.g. via the capability of live-tracking, but not enough compared to the high investment costs. In contrast to that, QR-Codes need nearly no implementation costs and therefore the generation of added-value in comparison to the investment is not applicable as a challenge for Company 2.

Switching costs for technology: The costs for switching from Barcodes to QR-Codes is a challenge. Company 2 does not see enough justification of the added-value of QR-Codes for changing from on technology to another.

4.3 Company 3 – Online retailer for clothing and sport articles

This chapter includes the presentation of Company 3 and the empirical findings based on the taken interview with the company respondent.

Company presentation

Company 3 is an online retailer mostly within clothing and sport market. Their products are for men, women and children mostly for sporting activities, but also other sports gear like balls and rackets. They do not have an own brand and are therefore working with well-known brands in the different sections.

Company 3 does not have a store and are exclusively available online. The company was founded a few years ago, but since that it has grown a lot. In less than a few years, they have a revenue of approximately 0.7 billion SEK.

This company has around 150 employees, with 50 employees working in their warehouse. The company contact was the Logistics manager at their only warehouse. They have recently moved to a new automated warehouse that is still under development to fit all their products and requirements. Before, they had a warehouse without any kind of automation. (Company 3, 2018)

According to the interview, their strategy is to supply customers with good quality clothes and sports gear. They are focused on having a good customer satisfaction with fast deliveries, returns and lowest price guarantee.

Based on the interview, Company 3 uses AGVs and Barcodes. They also considered Automated forklifts, Automated conveyor systems, QR-Codes and RFID technology, but will not implement them.

The following findings are based on the interview with Company 3, which is attached in the form of the most important results in the Appendix 2. (Company 3, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Physical integration in the warehouse	x	x	x
Added-value in comparison to the	x	x	x

investment			
Integration complexity - planning and organization	x		
Flexibility in the future	x		x
Implementation time	x		-
Flexibility in operations	x		
IT integration in the system landscape	x		
Efficiency issues	x	x	x

Figure 14. Company 3 - The movement of goods

Implementation costs: Company 3 did consider different solutions before implementing their AGV system. The costs for the Automated conveyor system and Automated forklifts were considered too high, when implementing in their warehouse with their specific requirements. Nevertheless, the costs for AGVs were a big challenge. As Company 3 stated, the Implementation costs are for any kind of movement technology in the warehouse an important challenge.

Physical integration in the warehouse: This was one reason, why Company 3 did decide to implement AGVs in front of Automated forklifts and Automated conveyor systems. There was simply not enough room in the warehouse. When they built the new warehouse, they considered AGVs as the best solution for that warehouse. Therefore, for the implementation of these technologies, the Physical integration in the warehouse is considered as one of the most important for Company 3.

Added-value in comparison to the investment: Since Company 3 considered all three different solutions, they also compared which one added the most value. Before building the new warehouse the costs of implementing AGVs in the existing one were too high.

Integration complexity – planning and organization: Company 3 did not have any previous knowledge about AGVs and therefore needed help implementing it. The planning and integration was elaborating and took a long time.

Flexibility in the future: The challenge of Flexibility in the future is considered as an important challenge for this company. Company 3 realizes that the boxes that the AGVs pick up and deliver can be a challenge in the future, since these boxes are limited regarding their space. Would the product line be changed to bigger items, this would definitely become a challenge. For the Automated conveyor system, it was stated that the set route of the system would limit the flexibility for the future regarding transportation paths.

Implementation time: Company 3 exceeded their planned implementation time, which led to higher costs and the need for using their old warehouse. After considering Automated conveyor systems, Company 3 did not perceive the Implementation time as a challenge for the implementation of Automated conveyor systems.

Flexibility in operations: Since the AGV system is more complex than their previous technologies in their manual warehouse, the assurance of the flexibility in operations is challenging for Company 3, which is caused by the complex adaptation of this system.

IT integration in the system landscape: Caused by the complexity of the existing system landscape, the technical integration in the old and new WMS was challenging for Company 3.

Efficiency issues: The reason for choosing AGVs was, according to their calculations that the efficiency compared to the Automated forklifts and Automated conveyor systems would be higher. Especially in the beginning, they had problems reaching high efficiency with the AGVs as well.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs			x
Added-value in comparison to other technologies		x	x
Generation of added-value in comparison to the investment		-	x
Switching cost to technology	x	x	

Figure 15. Company 3 - The tracking of goods

Implementation costs: Company 3 has considered RFID technology, but caused of the high investment costs in this technology for the needed devices, they decided not to implement it.

Added-value in comparison to other technologies: The challenge of the Added-value in comparison to other technologies is one of the most important challenges for the tracking of goods, as Company 3 stated. The added-value for QR-Codes, which can be reached by the increased storage capacity or the simplification of the code generation, was in total not enough in comparison to the usage of Barcodes, to justify the transition between these two tracking technologies.

Generation of added-value in comparison to the investment: For Company 3, the added-value of the RFID technology, which can be e.g. generated via the capability of live-tracking, is too low in comparison to the huge investment in this technology. In contrast to that, caused by the low implementation costs of QR-Codes, the Generation of added-value in comparison to the investment was not perceived by Company 3.

Switching costs for technology: Company 3 already considered to switch from Barcodes to QR-Codes, but the switching costs of this process are too high to justify the benfits of the usage of QR-Codes. Therfore, Company 3 does not see any reason for changing currently.

4.4 Company 4 – Logistics service provider

This chapter includes the presentation of Company 4 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 4 is a family-owned company in the logistics sector, providing different logistics services for its customers. The company was founded in 1930 and is right now one of the global leaders for system logistics. The business model of that company includes transport logistics, warehousing and customer-specific services.

This includes transport solutions, like road-, air- and sea-freight, but also food logistics, retail logistics and project logistics. In the area of warehousing, Company 4 is specified in contract logistics, as a long-term daily business with its customer and also in value-added services, like the quality control, product refinement, assembly/disassembly work, repairs and packaging.

Company 4 also provides storage space in their warehouses as a transshipment center, as a service for its business customers. Based on its standardized processes and a uniform IT system, that company can provide “multi-user warehouses” with an enormous level of efficiency in Europe, North Africa and China. Therefore, Company 4 has around 2.1 million spaces on hand for Euro pallets in its warehouses.

The turnover of that company group was in 2017 at approximately 61 billion SEK, with a number of employees of around 30.000. The interview partner at this company was the engineering consultant for corporate contract logistics at the head office of the company group. (Company 4, 2018)

Based on the interview, Company 4 uses an Automated conveyor system, Barcodes and QR-Codes. They also considered AGVs, which they will implement, and Automated forklifts and RFID technology, which they will not implement in the near future.

The following findings are based on the interview with Company 4, which is attached in the form of the most important results in the Appendix 2. (Company 4, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Integration complexity - planning and organization	x		x
Physical integration in the warehouse	x		x
Added-value in comparison to the investment	x		-
Flexibility in operations	x	x	x
IT integration in the system landscape	x	x	x
Safety issues in mixed operations	-		x
Efficiency issues	x	x	-
Running costs	x	x	

Figure 16. Company 4 - The movement of goods

Implementation costs: Since Company 4 has implemented and also considered the three kinds of movement technologies, the investment costs are one of the biggest and most important challenges for all three technologies, as they stated.

Integration complexity - planning and organization: Since the Automated conveyor systems are already implemented and the AGVs will be implemented, Company 4 is aware of the planning and organization effort caused by the complexity of the technologies.

Physical integration in the warehouse: Since Company 4 stopped considering about Automated forklifts, they see it as a challenge for AGVs and the Automated conveyor systems to integrate them in an existing warehouse caused by the building requirements.

Added-value in comparison to the investment: The added-value for AGVs is for Company 4 challenging caused by the limited areas of application of that technology in their warehouse.

Flexibility in operations: One of the most important challenges for Company 4 is the decrease of flexibility by the implementation of any kind of technology.

IT integration in the system landscape: Caused by the huge amount of existing systems, the perfect integration of an additional system to ensure a smooth run of the systems is one of most important challenges.

Safety issues in mixed operations: Since Company 4 only has implemented Automated conveyor systems, they see it as a challenge to ensure that there are no safety problems in mixed operations. Even though, they have considered AGVs, they do not perceive any challenges regarding the interacting in mixed operations caused by the high safety standards of these technologies, as they stated.

Efficiency issues: Especially in mixed operations, the decrease of efficiency with the usage of AGVs and Automated forklifts caused by permanent safety stops is one of the most important challenges, as Company 4 stated. For Automated conveyor systems, Company 4 did not perceive this challenge.

Running costs: Mainly the running costs for the adaptation of the systems for future changes or adaptation caused by the complexity in operation of AGVs and Automated forklifts.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs	x		x
Limited storage capacity	x		
Vulnerable for damages	x	-	
Human involvement needed for the scanning	x	x	-
IT integration in the existing systems	x		x
Illegibility			x
Generation of added-value in comparison to the investment		-	x

Figure 17. Company 4 - The tracking of goods

Implementation costs: For Company 4 the implementation costs for Barcodes, e.g. for the printers and scanners, and also for the RFID technology, e.g. for the tags, readers and antennas, is one of the most important challenges.

Limited storage capacity: With the usage of Barcodes, the challenge of the limited storage capacity arises caused by the limited amount of storage positions.

Vulnerable for damages: Also challenging with the usage of Barcodes is the vulnerability for damages caused by the importance of each storage position of the codes. In contrast to that, the Vulnerability of QR-Codes is not perceived as a challenge, caused by the higher level of resistance of these codes.

Human involvement needed for the scanning: For Company 4 it is challenging to ensure the human involvement in the scanning process of the Barcodes and QR-Codes to assure a correct scanning process. For RFID technology, this challenge is not applicable, which is caused by the transmission of information via radio waves, as Company 4 stated.

IT integration in the existing systems: The IT integration of the Barcode and RFID technology in the existing systems was and is an important challenge, as Company 4 stated.

Illegibility: Based on Company 4´s consideration, the illegibility of the RFID technology caused by the interferences of the antennas and the material surrounding the tags would be challenging.

Generation of added-value in comparison to the investment: Caused by the immense investment costs in the RFID technology for e.g. readers and tags, the generation of added-value would be a quite important challenge for Company 4. In comparison to that, the Generation of added-value in comparison to the investment is not perceived for QR-Codes caused by low investment costs and benefits of this tracking technology, as Company 4 stated.

4.5 Company 5 – Logistics service provider

This chapter includes the presentation of Company 5 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 5 is a logistics service provider for big and small actors. They help other companies solving their entire logistics chain and handle packages, parcels, mail and goods. They are present in the whole Nordic area and are specialized in transporting goods for companies. They do not handle the logistic for end-customers and are only working within B2B. (Company 5, 2018)

The company is part of a bigger group that is one of the top five actors in the Nordic region. Their strategy is to be the most future-oriented and innovative actor in the business through forcing the technological advances forward. According to the company webpage, they have several ongoing projects to offer their customers better solutions.

The contact person that was interviewed is the logistics manager for warehousing in the northern region of Europe. In total, the group has 19.000 employees. According to the contact person, the warehouse where he is based at, there are around 50 people working, depending on how much they have to do. The company's turnover was approximately 25 billion SEK in 2017. (Company 5, 2018)

Based on the interview, Company 5 uses only Barcodes. They considered also AGVs and will implement them in the near future. Additionally, they considered Automated forklifts, Automated conveyor systems, QR-Codes and RFID technology, but will not implement them.

The following findings are based on the interview with Company 5, which is attached in the form of the most important results in the Appendix 2. (Company 5, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Physical integration in the warehouse		x	x
Investment justification in relation to the size of the warehouse	x	x	x
Implementation time	x		
Flexibility in the future	x		x
Flexibility in operations	x		
IT integration in the system landscape	x		
Integration complexity - planning and organization	x		x

Figure 18. Company 5 - The movement of goods

Implementation costs: Company 5 has not yet implemented any automation into their warehouse. One of the biggest and most important reasons for that are the high implementation costs for each of these technologies.

Physical integration in the warehouse: Company 5 has decided to implement AGVs into their warehouse in the near future. They saw challenges regarding space limitations for Automated conveyor systems and Automated forklifts, which are considered as important challenges.

Investment justification in relation to the size of the warehouse: Company 5's warehouse is small and the number of goods that goes through it has made it really challenging to justify the investment.

Implementation time: Even though Company 5 has not implemented AGVs yet, they think that the implementation time will be challenging. They have talked to other companies with similar solutions that have had problems with that.

Flexibility in the future: Company 5's AGVs will use boxes that only fit certain sized products. One challenge for them will be changes in products, as the respondent stated. The flexibility aspect for future changes was also the reason, why they did not choose Automated conveyor systems.

Flexibility in operations: Company 5 thinks that they will lose flexibility in their operations when implementing AGVs, since tasks needs to be performed in a certain order.

IT integration in the system landscape: Company 5 knows that they might need to change their current WMS and that there might be a challenge to integrate the new system with the old one, which they still need to keep since the warehouse will be partly manual.

Integration complexity - planning and organization: Company 5 does not have any previous knowledge about AGVs and need help with the implementation from service providers. The planning and organization will be complex. They also discussed with other companies, which implemented Automated conveyor systems that the implementation for Automated conveyor systems is also complex due to that the company cannot use the warehouse during the implementation.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs			x
Generation of added-value in comparison to the investment			x
Added-value in comparison to other technologies		x	-
Visibility problems	x		

Switching cost for the technology	x	x	
Vulnerable for damages	x	-	
Illegibility	x		
Wi-Fi connection for mobile devices	x		

Figure 19. Company 5 - The tracking of goods

Implementation costs: Company 5 stated that the implementation costs for RFID technology is really challenging caused by the need of the acquisition of expensive devices.

Generation of added-value in comparison to the investment: The investment of implementing RFID does not add enough value in comparison to the investment, when it comes to e.g. live-tracking, according to Company 5 caused by the lack of need for live-tracking in their warehouse. Therefore, one of the most important challenges, when it comes to the tracking of goods, is the Generation of added-value in comparison to the investment for RFID technology.

Added-value in comparison to other technologies: QR-Codes would not improve Company 5's tracking of goods according to the respondent caused by lack of need for the storage of more information on the codes. This challenge is identified as not applicable for RFID technology based on the irrefutable benefits like the capability of live-tracking.

Visibility problems: Company 5 has experienced visibility problems in their warehouse for Barcodes caused by the need of visibility of the label for the scanner.

Switching cost for the technology: Company 5 already considered switching from Barcodes to QR-Code, to use the benefits of these codes. Caused by the immense elaboration of changing the warehouse characteristics, like the change of all scanners, the investment in this change would not justify the switching advantage.

Vulnerable for damages: The vulnerability for damages of Barcodes, which have to be replaced, is challenging for Company 5. In contrast to that, caused by the extended storage capacity, the Vulnerability for damages is identified as not applicable for QR-Codes, since these codes are more resistant.

Illegibility: Another challenge for Company 5 regarding the usage of Barcodes is the illegibility of those, which is affected e.g. by the quality of printing.

Wi-Fi connection for mobile devices: In Company 5 mobile scanners are used in the whole warehouse. Sometimes there have been challenges with good enough Wi-Fi connection and the scanners stopped working.

4.6 Company 6 – Manufacturer for electronic parts

This chapter includes the presentation of Company 6 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 6 operates in the area of electronic projects in the automotive industry, in the industry electronics, the building control systems, the automation control systems, the medical technology and many more.

This includes competencies in the area of research and development, layout, supply-chain management, component production, system installation and electronics production in different kind of electronic projects. The core competencies of Company 6 are in the electronic design and development, the production of these innovations and the after-sales service at the customer site.

Company 6 has around 1.000 employees and a production site of around 30.000 $[m^2]$. It was founded in 1994 and had 2017 a turnover of approximately 2.3 billion SEK. (Company 6, 2018)

The interviewed employee of Company 6 was the head of logistics management and data systems, who is responsible of the logistics processes and data systems for the production, but as well for the main warehousing sites.

Based on the interview, Company 6 uses AGVs, Barcodes and QR-Codes. They also considered Automated forklifts, which they will implement in the near future. They also considered Automated conveyor systems, and RFID technology, but will not implement them.

The following findings are based on the interview with Company 6, which is attached in the form of the most important results in the Appendix 2. (Company 6, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Running costs	x	x	
IT integration in the system landscape	x	x	
Number of automated units used within a specific area	x	x	

Orientation at the company site	x	x	
Flexibility for the future	x	x	x
Implementation time	x		
Safety issues in mixed operations	x	x	
Physical integration in the warehouse	-	-	x
Integration complexity - planning and organization	x	x	

Figure 20. Company 6 - The movement of goods

Implementation costs: After considering all kind of technologies and implementing AGVs and in the near future also Automated forklifts, Company 6 sees the implementation costs as a big and one of the most important challenges.

Running costs: The running costs for AGVs, especially for the permanent adaptations, and the Automated forklifts, especially for finding areas of application, is an important challenge, as Company 6 stated.

IT integration in the system landscape: The integration in the existing system landscape is really challenging for Company 6, especially to ensure the capability of the vehicles to be able to read different tracking codes.

Number of automated units used within a specific area: For the AGVs and the Automated forklifts, it is challenging if a specific amount of vehicles is used on a limited space. The overlapping scanning areas of the vehicles cause permanently security stops, which decreases the efficiency of the vehicles.

Orientation at the company site: The orientation at the site is challenging for AGVs and Automated forklifts caused by the chosen orientation method of finding trigger points in the warehouse, which is not the best option for the orientation.

Flexibility for the future: To adapt these technologies to future changes will be challenging, because for the AGVs and the Automated forklifts a lot of effort has to be put in the reprogramming and for the Automated conveyor system, there would have to be building changes made.

Implementation time: Since AGVs are already implemented, the time for this process is much longer than calculated, which is challenging for Company 6.

Safety issues in mixed operations: A big and important challenge is the safety aspect in the human/machine collaboration, e.g. how do the vehicles act in the case of a fire alarm.

Physical integration in the warehouse: The physical integration in the existing location is a big challenge for Automated conveyor systems caused by the distribution of the building parts. In contrast to that, Company 6 stated, that this challenge is identified, but not applicable for AGVs and Automated forklifts caused by the high flexibility of devices.

Integration complexity - planning and organization: Since AGVs are already implemented and Automated forklifts will be implemented in the next months, the planning and organization effort caused by the complexity was and is challenging.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Limited storage capacity	x		
Requirement of live-tracking	x	x	-
Illegibility	x	x	x
Switching cost for other technology	x	x	
Implementation costs	x	-	x
Generation of added-value in comparison to the investment			x
Visibility problems	x	x	
Human involvement needed for the scanning	x	x	-
Privacy and Security			x
Vulnerable for damages	x	-	

Figure 21. Company 6 - The tracking of goods

Limited storage capacity: With the usage of Barcodes, the challenge of the limited storage capacity caused by the limited storage positions arises.

Requirement of live-tracking: The requirement or need of live-tracking of products cannot be ensured with the usage of Barcodes and QR-Codes in comparison to RFID technology. Therefore, it is a challenge to have the requirement of live-tracking with the usage of Barcodes and QR-Codes.

Illegibility: The challenge of illegibility arises with the usage of Barcodes and QR-Codes at Company 6 caused by e.g. quality problems of printing. The challenge regarding this matter for the RFID technology is the overlapping of tags or interferences of antennas, as Company 6 stated.

Switching cost for other technology: A current and really important challenge for Company 6 is the switching process from Barcodes to QR-Codes, which includes the switching of all reading devices and also the attaching of QR-Codes to all 56.000 items.

Implementation costs: To avoid printing quality problem for Barcodes, Company 6 invested in high-quality printers. A challenge for the RFID technology is the installation of readers at all 16 gates at Company 6, as they internally examined. In contrast to that, this challenge cannot be perceived for QR-Codes caused by the lack of needed equipment for the usage of these codes.

Generation of added-value in comparison to the investment: In relation of the huge investment in the RFID technology, the current low pressure of perfect tracking accuracy is an important challenge for the added-value by using RFID in the warehouse.

Visibility problems: It is a challenge for Barcodes and QR-Codes to ensure the visibility of the codes, especially for the reading in automated processes, as it is done with AGVs.

Human involvement needed for the scanning: With the target of having fully automated processes, the still needed human involvement for the scanning process of the Barcodes and QR-Codes, like the scanning of the label or the attaching of the label at the exact position, is a challenge for Company 6. This challenge is not perceived for the usage of RFID technology, since the information is transferred via radio waves, as Company 6 stated.

Privacy and Security: For the usage of RFID technology it is challenging to ensure the privacy of the company information caused by the transmission of information via radio waves, which will be a challenge for Company 6 caused by the location of a competitor nearby.

Vulnerable for damages: The current usage of Barcodes and therefore the highly vulnerability of those codes caused by the importance of each storage position is a big and important challenge for Company 6 to ensure a smooth running of the business. In contrast to that, the extended storage capacity help the QR-Code to be more resistant against damages, as Company 6 mentioned.

4.7 Company 7 – Retailer within food and beverages

This chapter includes the presentation of Company 7 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 7 is a retailer within food and beverages. This company is also a part of a bigger group and their primary sales come from deep frozen dishes, fish and vegetables. According to the interview, they have a total turnover of 2.7 billion SEK and have approximately 700 employees.

They do not have any own stores and are instead selling to resellers in the whole Nordic region. The offered products are from being deep frozen to more of a mix between fresh and frozen. Their priorities are to work for a greener future and offer customers a healthier choice in the store. They also want to offer their resellers fast and reliable deliveries.

By being a modern and technology-based company with standardized products, automation has been on the map for a long time, mostly in production and also lately in the warehousing process. Their work of giving their resellers fast options for delivery starts in the production goes through the warehouse and ends in the stores.

The contact person for Company 7 is the Supply chain and logistics manager, responsible for the only warehouse in the northern region. The amount of staff in that warehouse differs depending on how much there is to do. Normally, due to the high degree of automation, this warehouse is run by less than 30 people per shift. The size of the warehouse is equivalent to 110.000 pallet places in a high-bay warehouse but the maximum capacity due to space requirements for transmission areas is around 80.000 pallet places. (Company 7, 2018)

Based on the interview, Company 7 uses AGVs, Automated forklifts, Automated conveyor systems and Barcodes. They also considered QR-Codes and RFID technology, but will not implement them.

The following findings are based on the interview with Company 7, which is attached in the form of the most important results in the Appendix 2. (Company 7, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Efficiency issues	x	x	x
Physical integration in the warehouse	x	x	x
Integration complexity - planning and organization	x	x	x

IT integration in the system landscape	x	x	x
Flexibility in operations	x	x	x

Figure 22. Company 7 - The movement of goods

Implementation costs: Company 7 has implemented a fully automated warehouse with AGVs, Automated forklifts and Automated conveyor system. The investment costs for all these were very high and therefore one of the most important challenges of these technologies.

Efficiency issues: Company 7 has efficiency issues with all different systems, especially in the implementation phase, which was and is caused by adaptation problems.

Physical integration in the warehouse: Company 7 had a completely manual warehouse before. At that warehouse there was not enough space for any of the solutions.

Integration complexity - planning and organization: They needed help from a company specialized in automated warehouse, since they did not have experience of any of the solutions. It took a long time for planning and organizing the implementation of all three kinds of technologies.

IT integration in the system landscape: These automation systems needed to be integrated into each other and into the new WMS, which was created for the new warehouse. This really important challenge was to make all the systems work together, as Company 7 stated.

Flexibility in operations: Since the warehouse is fully automated, there is a lack of human involvement. There are 80.000 pallets in the warehouse and if a customer calls and wants an extra pallet of something, it is an important challenge for Company 7 to adapt to the new situation.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs			x
Generation of added-value in comparison to the investment			x
Added-value in comparison to other technologies		x	-

Visibility problems	x		
Vulnerable for damages	x	-	
Illegibility	x		
Switching costs to other technologies	x	x	

Figure 23. Company 7 - The tracking of goods

Implementation costs: Company 7 considered implementing RFID in their warehouse, but caused by the high investment, the implementation was rejected.

Generation of added-value in comparison to the investment: The added-value of the implementation of RFID with the capability of e.g. life-tracking, did not justify the huge investment for e.g. RFID tags or readers and is an important challenge, when it comes to the implementation and usage of RFID technology, as Company 7 stated.

Added-value in comparison to other technologies: Company 7 considered QR-Codes, but the added-value of these codes has not been that much in comparison to Barcodes for the usage within Company 7. For the RFID technology, this challenge was identified, but not applicable caused by the huge benefits of that technology, like the capability of live-tracking.

Visibility problems: Company 7 has experienced visibility problems for the usage of Barcodes in their warehouse. In their automation there is a need for the Barcodes to be placed at exactly the right area of the pallet.

Vulnerable for damages: Especially in the past, Company 7 had challenges with damaged Barcodes due to moist on the codes. Caused by the extended storage capacity, the resistance of QR-Code against damages is much higher and therefore this challenge is not applicable for QR-Codes, as Company 7 stated.

Illegibility: The illegibility of Barcodes was and is still an important challenge for Company 7 caused by the printing quality of the codes, mainly attached by their suppliers.

Switching costs to other technology: Company 7 sees the cost and the needed time of switching from Barcodes to QR-Codes as a challenge, which included the change of e.g. all scanners and readers. They also feel that there is no need for it at the moment.

4.8 Company 8 – Manufacturer of professional office chairs

This chapter includes the presentation of Company 8 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 8 is producing and developing business and private office chairs. The company produces up to 10.000 chairs on 5 different production lines every day.

This includes swivel chairs, professional, multi-functional office chairs and also a kid's chair collection.

The company was founded in 1976 and is a family-run business. It has a production and storage area of 100.000 [m^2] and employs 450 people at one location. Company 8 as well develops and designs, in cooperation with other developers and designers, new innovative office chairs. The turnover of Company 8 was in 2017 about around 1 billion SEK. (Company 8, Part 1, 2018)

Based on the interview, Company 8 uses AGVs, an Automated conveyor system, Barcodes and RFID technology. They also considered Automated forklifts and QR-Codes, but will not implement them.

On request of the company, two interviews have been made. The first interview was done with the Director of Operations, who is in charge of the whole company operations. The second interview was done with the Technical Director of Company 8, as an expert for the technical aspects of the tracking of goods.

The following findings are based on the interview with Company 8, which is attached in the form of the most important results in the Appendix 2. (Company 8, Part 1, 2018; Company 8, Part 2, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x		x
Running costs	x		-
IT integration in the system landscape	x		x
Communication among the devices	x		
Number of automated units within a specific area	x		
Safety of mixed operations	x		
Efficiency issues	x		-

Figure 24. Company 8 - The movement of goods

Implementation costs: For Company 8 the implementation costs of the used AGVs and also the cable line, which works as an Automated conveyor system, was a huge and important challenge.

Running costs: The adaptations of the AGVs and therefore the costs of these adaptations have been a challenge for Company 8, caused by the complexity of the AGVs. For the Automated conveyor system, which is used at Company 8, this challenge is not applicable, caused by the smooth run of this system for a long time.

IT integration in the system landscape: The IT integration of the AGVs and the "conveyor system" was really challenging for Company 8 caused by the huge amount of existing systems and therefore the many interface connections

Communication among the devices: The communication among the AGVs is challenging for Company 8 caused by the usage of induction loop free devices, which are not restricted in their route and therefore have an increased level of complexity.

Number of automated units within a specific area: The AGVs work in an area at Company 8 with a bottleneck. Caused by the overlapping of the scanning areas of the vehicles, unplanned stops and so a decreased efficiency was an important challenge for Company 8.

Safety of mixed operations: For the usage of AGVs, the safety aspect for mixed operations is a challenge for Company 8, when it comes e.g. to the blocking of important corridors.

Efficiency issues: Especially in the implementation phase, there has been a lot of efficiency issues with the AGVs caused by unknown stops and problems, which was challenging for Company 8.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Human involvement needed for the scanning	x		-
Requirement of live-tracking	x		-
IT integration in the existing systems			x
Generation of added-value in comparison to the investment			x

Figure 25. Company 8 - The tracking of goods

Human involvement needed for the scanning: It is challenging for Company 8, that human involvement is still needed for the scanning process of Barcodes, especially in fully automated processes. In contrast to that, this challenge is not perceived for the RFID technology caused by the transmission of information via radio waves.

Requirement of live-tracking: The requirement of live-tracking, in contrast to the RFID technology, is challenging with the usage of Barcodes, in comparison to the usage of RFID technology.

IT integration in the existing systems: The technical integration in the existing system landscape was really challenging for Company 8, when it comes to the smooth flow of read information of the RFID readers.

Generation of added-value in comparison to the investment: The huge investment in RFID technology in comparison to the added-value of that technology was and still is challenging for that company.

4.9 Company 9 – Product wholesaler

This chapter includes the presentation of Company 9 and the empirical findings based on the taken interview with the company respondent.

Company Presentation

Company 9 is one of the leading distributors in the Nordic region of tools, supplies for installers within construction, electricians, power companies and also the public sector. They are present in the Nordic countries, but also Russia and Estonia. In total, the company employs around 5.000 people and has a turnover of approximately 27 billion SEK.

The company has their own stores, but also sell online to all their customers, but it is not possible as a private customer to order from them. Their product line contains of everything that is needed for electricians and companies working in the construction area e.g. gloves, screws, tools, cables and tubings.

Their strategy is to provide professionals with known brands with fast delivery to a competitive price. They are currently working with improving their delivery and giving their customers more options with deliveries to their home, where they currently work.

Based on the interview, Company 9 uses an Automated conveyor system, Barcodes, QR-Codes and RFID technology. They also considered AGVs, which they will implement in the near future. Additionally, they considered Automated forklifts, but will not implement them.

The respondent at the company was the Director of logistics and warehousing of the whole company. There are 3 warehouses in the company in total. The one with the highest degree of automation employs 750 people working. The warehouse is 235.000 $[m^2]$ and they use automated conveyor systems as automation solution. (Company 9, 2018)

Perceived challenges for the movement and tracking of goods

- The movement of goods

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	x	x	x
Integration complexity - planning and organization			x
Physical integration in the warehouse	x	x	x
Added-value in comparison to the investment	x	x	
Implementation time	x		x
IT integration in the system landscape	x	x	x
Efficiency issues	x	x	x

Figure 26. Company 9 - The movement of goods

Implementation costs: Company 9 has considered both AGVs and Automated forklifts, but decided not to implement it caused by high costs, which are important challenges for the implementation. They waited with the Automated conveyor system due to the high implementation costs.

Integration complexity – planning and organization: The integration complexity was challenging for Company 9 for the implementation of the Automated conveyor system, caused by the huge planning effort for the integration in an existing warehouse. The consideration about AGVs and Automated forklifts stopped before a detailed planning was started.

Physical integration in the warehouse: Company 9 needed to rebuild their existing warehouse to make it fit for the Automated conveyor system. The layout of the warehouse is one of the biggest reasons and challenges, that they have not implemented AGVs and Automated forklifts.

Added-value in comparison to the investment: The added-value of the AGVs would be an important challenge for Company 9 and calculations to make it profitable are already done. For Automated forklifts it is the same, but they are not that close in getting the calculation together.

Implementation time: The implementation time to make the Automated conveyor system work as it was supposed, took longer time than expected. Company 9 talks about problems with implementation times for AGVs at other companies.

IT integration in the system landscape: The technical integration of the Automated conveyor system was challenging caused by the new integration of the new and old systems.

Efficiency issues: The efficiency issues were one of the most important challenges for Company 9 for the movement of goods. It was hard for Company 9 to get the Automated conveyor system to reach the efficiency they had planned. AGVs and Automated forklifts were ruled out, because it was not considered effective enough from the beginning.

- The tracking of goods

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs			x
Added-value in comparison to other technologies		x	-
Generation of added-value in comparison to the investment			x
Switching cost for technology	x	x	
Vulnerable for damages	x	-	
Illegibility	x		

Figure 27. Company 9 - The tracking of goods

Implementation costs: Company 9 sees the implementation costs for RFID as high. They use it, but only for the transportation of pallets to repacking stations.

Added-value in comparison to other technologies: QR-Codes would not improve their customer offer more than they currently have by using Barcodes, which is an important challenge of the implementation of QR-Codes, as Company 9 stated. In contrast to that, this challenge is not applicable for the RFID technology, as they mentioned, caused by the huge benefits of that technology.

Generation of added-value in comparison to the investment: The investment of implementing RFID does not add enough value in their products and is an important challenge, according to Company 9.

Switching costs to other technology: Company 9 sees the cost of switching from Barcodes to QR-codes as a challenge. They feel that there is no need for it at the moment.

Vulnerable for damages: Sometimes there have been damaged Barcodes that are needed to be replaced at Company 9. For QR-Codes, this challenge cannot be applied caused by the extended storage capacity and so the higher level resistance against damages.

Illegibility: Another challenge for Company 9 regarding the usage of barcodes is the illegibility of those, which most often occur after printing problems.

5 Analysis

In the following chapter the analysis of this thesis is presented. It starts with an explanation of the procedure of the analysis to help and guide the reader. Afterwards, an overview of the implemented technologies for the interviewed companies is given. Additionally, a summary of the considerations of these companies is presented, whether they will or will not implement specific technologies. In the next part, the perceived challenges from the empirical data are merged together and unified depending on their affiliation to the movement or the tracking of goods. Afterwards, these empirical perceived challenges are analyzed regarding their importance stated in the taken interviews.

The next sub-chapter deals with the comparison of the theoretical and empirical perceived challenges, which includes the analysis of the similarities and differences of the challenges and their importance, divided into the movement and tracking of goods. This chapter is concluded with a discussion part, which deals with the most important findings of this comparison.

5.1 Analysis procedure and guideline of tables

The purpose of this chapter is to guide the reader through the following analysis and to structure the created figures in the context of the analysis. Therefore, it is also referred to the theory and its tables.

To be able to analyze the stated research questions, the analysis has to cover many aspects. Therefore, it is necessary to introduce a specific procedure and order of the analysis, which needs for clarity and transparency reasons quite a lot of figures.

Starting with RQ 1: What technical solutions for automation of the movement and tracking of goods are currently applied in warehouse operations?

To answer this question, the literature was analyzed and also the interviewed companies have been used as sources. Therefore, the following Figure 28 gives an overview of the structure of the created tables for answering RQ 1:

Overview of tables for answering RQ 1				
Purpose	Theory		Analysis	
	Chapter	Figure number	Chapter	Figure number
Identification of technologies	3.3	5	5.2	30 and 31

Figure 28. Overview of tables for answering RQ 1

Going on with RQ 2: What are the differences and similarities between the challenges with the implementation of these technologies identified in theory and experienced in practice and why do these challenges exist?

To be able to answer this, first the challenges in theory and in practice had to be identified including the perception of their importance. By interviewing 9 different companies, it is necessary that the perceived challenges are merged together in the next step. Afterwards, the comparison of the theoretical and empirical identified challenges for the movement and the tracking of goods are done.

The following Figure 29 gives an overview of the created tables and relates the analysis to the theory, including in which context they have been used and their purpose. Additionally, the chapter number of the tables is presented for an improved guidance within the work.

<table>
<tr><th colspan="5">Overview of tables for answering RQ 2</th></tr>
<tr><th rowspan="2">Purpose</th><th colspan="2">Theory</th><th colspan="2">Analysis/Empiri</th></tr>
<tr><th>Chapter</th><th>Figure number</th><th>Chapter</th><th>Figure number</th></tr>
<tr><td>Identification of challenges</td><td rowspan="2">3.4.1
3.4.2</td><td rowspan="2">6 and 7</td><td>4</td><td>10 – 27</td></tr>
<tr><td>Summary of identified challenges</td><td>5.3.1
5.3.2</td><td>32 and 33</td></tr>
<tr><td>Identification of importance</td><td>3.4.1
3.4.2</td><td>8 and 9</td><td>5.4.1
5.4.2</td><td>35 and 36</td></tr>
<tr><td>Comparison of challenges identified in theory and practice</td><td></td><td></td><td>5.5</td><td>37 – 48</td></tr>
</table>

Figure 29. Overview of tables for answering RQ 2

5.2 Overview of company technologies

In the following sub-chapter, two tables are presented, which give an overview of the used technologies implemented at the interviewed companies. The second table summarizes the considerations of the interviewed companies regarding the analyzed technologies, whether these companies will implement these technologies in the future or not.

For this thesis, 9 companies have been interviewed, which already implemented and use specific kinds of technical solutions for automation for the movement and tracking of goods. Therefore, to be able to classify the further findings of this analysis, it is interesting to get an overview of the already implemented technologies at the interviewed companies. With this summary, the current status of the implementation and consideration level in practice can be given for each of these technologies. This means, in case a technology is mainly used from all interviewed companies, this technology must have advantages in comparison to other technologies, which are not implemented at all companies.

It has to be mentioned, that the chosen companies are only chosen by convenience sampling and therefore the results of the interviews cannot be generalized for the whole economic. The statements of the companies regarding the used and considered technologies depend strongly on their company situation, which means e.g. that the financial resources of the company, the physical company environment or simply the handled products have a big influence on the decision of the used technologies. Nevertheless, this analysis and its findings can be used as a rough guide for the current status quo of the implementation degree of specific technologies in practice.

Starting with the already implemented and used technical solutions for automation for the movement and tracking of goods, the following table gives an overview of the implemented technologies at the interview companies divided into the movement of goods and into the tracking of goods. The numbers used in that table represents the number of the interviewed companies, defined in the empirical chapter.

The movement of goods		
AGVs	Automated forklifts	Automated conveyor systems
3, 6, 7, 8	7	1, 2, 4, 7, 8, 9
The tracking of goods		
Barcodes	QR-Codes	RFID technology
1, 2, 3, 4, 5, 6, 7, 8, 9	1, 4, 6, 9	1, 8, 9

Figure 30. Summary of implemented technologies

Regarding the movement of goods, it can be seen that Automated conveyor systems are mainly used at the interviewed companies, which is mostly caused by the high performance of these systems, when it comes to the transportation of products. Also AGVs are currently used in 4 out of 9 companies, which visualize the importance of this technology for companies. As it is stated from many companies, which use AGVs in their warehouses, AGVs have the big advantage that they are not restricted to their path in the warehouse or rather can easily be adapted to changed circumstances in comparison to Automated conveyor systems. Therefore, AGVs increase the flexibility of the automated moving of goods within a warehouse.

This table visualizes, that Automated conveyor systems are the most popular technical solutions for the moving of goods within a warehouse, closely followed by AGVs. Automated forklifts are rarely used in practice currently, which is caused by the increased complexity of these systems even in comparison to AGVs. As most companies stated, this increased complexity is mainly caused by the extension of the movement direction, which means that Automated forklifts also are capable of the vertical movement, which increases the complexity enormously in comparison to the horizontal movement with AGVs.

The last point regarding the movement of goods, which has to be mentioned in this table, is the combined usage of technologies within a company. As it can be seen, Company 7 and 8 use AGVs and also Automated conveyor system, which is caused by the different advantages of these systems. As these companies stated, the primary use of Automated conveyor systems is the movement of a big amount of goods over a longer distance. In comparison to that, the purpose of the usage of AGVs in these companies is the movement of fewer goods on a more flexible way. This means that AGVs are rather used for a bunch of goods with a varying destination or for internal express shipping. The purpose of these companies with using AGVs is to be able to transport goods more flexible than it is possible with Automated conveyor systems.

When it comes to the tracking of goods, it can be stated that Barcodes are still the most common way of tracking goods within a warehouse. The main reason, why Barcodes are still used from 100% of the interview companies, is the widespread of this type of code in all business industries and therefore the needed capability of all companies to be able to handle these kinds of codes. Additionally, another big advantage of Barcodes is that they are cheap, simple and usage friendly.

Nevertheless, as it can be seen in the Figure 30, companies also use QR-Codes in their businesses, mainly caused by the improved storage capacity of these codes. As they stated, it is necessary to use QR-Code in case the storage capacity of information on the Barcodes is not enough anymore. Therefore, QR-Codes are mainly used, when a lot of information has to be stored on the label and also the cheap generation of these codes is a big advantage.

The RFID technology is not used in most of the companies, mainly caused by the immense costs in this technology like the investment in the readers, tags or antennas. Nevertheless, 3 companies use RFID in their warehouse caused by the big advantage of live-tracking, which increases the traceability in the warehouse, and the transmission of information via radio waves. As these companies stated, the usage of RFID mainly makes sense for high-value products.

The following table presents the considerations of the interviewed companies regarding the future implementation of technical solutions for automation.

The movement of goods			
	AGVs	Automated forklifts	Automated conveyor systems
Considered and will implement it	4, 5, 9	6	
Considered and will not implement it	1, 2	1, 2, 3, 4, 5, 8, 9	3, 5, 6
The tracking of goods			
Status of consideration	Barcodes	QR-Codes	RFID technology
Considered and will implement it			
Considered and will not implement it		2, 3, 5, 7, 8	2, 3, 4, 5, 6, 7

Figure 31. Considerations about technologies

As it can be seen in this Figure 31, all companies, except of Company 7, which uses all three different kinds of technical solutions for the movement of goods, have considered AGVs, Automated forklifts or Automated conveyor systems for their warehouses.

Based on that result, it can be seen that Automated conveyor systems will not be implemented in the companies, which did not already implement it. As these companies stated, this is mainly caused by the maturity of this technology, which is available for a longer time already. Companies that already considered about Automated conveyor systems in detail and implemented that technology already, in case they were persuaded that this technology is useful in their warehouses.

Regarding Automated forklifts, most companies considered about that technology and decided not to implement it in the near future, beside of Company 6. As they stated, this is mainly caused by the increased complexity of this technology. Another aspect that these companies stated in relation to the implementation of Automated forklifts was the lack of available and appropriate technology and suppliers, which would fit their needs.

AGVs will be implemented in 3 of 5 companies in the near future, as the companies stated. The development of that technology is in the meantime well-advanced that it fits the needs of the interviewed companies. The main reason why this technology is not implemented already in their warehouses, are the huge implementation costs of this technology, as these companies stated.

According to the tracking technologies, all companies already decided not to implement the technology, if they did not do it in the past. As mentioned before, Barcodes are used in 100% of the interviewed companies. The companies, which do not use QR-Code currently, decided not to implement those in the near future mainly caused by the less added-value in comparison to Barcodes, as they stated. The main reason against the implementation of RFID technology in the warehouses is simply the huge investment costs in this technology, which would have to be justified by the added-value of this technology. The companies, which decided not to implement RFID in their warehouses, mentioned that the capability of an increased traceability via live-tracking and the transmission of information via radio waves do not justify the investment costs in comparison to e.g. Barcodes.

5.3 Summary of empirical perceived challenges

The following sub-chapter summarizes the empirical perceived challenges gathered from the taken interviews. The chapter is divided into the movement of goods and into the tracking of goods. In addition to the summary of the challenges, the importance of the challenges for the companies is highlighted by the bold font of the company number within a challenge cell.

It has to be highlighted, that a comparison among technologies regarding their challenges will not be done caused by the different company situations, which has a biased influence on the challenges. This means that companies have implemented e.g. one technology and considered another one, but stopped after the planning phase caused by insurmountable problems or challenges. Therefore, this company has not perceived any specific challenges in further planning or implementation stages for the cancelled technology, caused by the stopped planning and implementation. Hence, a comparison among the different technologies would be biased and will not be done.

Nevertheless, a comparison within the different technologies between the challenges can and will be done based on the common considerations regarding one specific technology at the companies. Even though, a company did not implement a technology and therefore have not have detailed challenges, it can be seen that the challenges, which the company had before the cancellation, have been so serious that the company decided to cancel the implementation of that technology. This allows the comparison within a technology and supports the reliability of this study.

5.3.1 **The movement of goods**

The following table presents the summary of the challenges perceived from the empirical data for the technical solutions for automation for the movement of goods. If a company mentioned or had a specific challenge, the company number is stated in the corresponding cell. If this challenge is perceived as very important for that company, the company number is highlighted in bold font.

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	**1**, **2**, **3**, **4**, **5**, **6**, **7**, **8, 9**	**1**, **2**, **3**, **4**, **5**, **6**, **7, 9**	**1**, **2**, **3**, **4**, **5**, **6**, **7**, **8, 9**
Physical integration in the warehouse	1, **2**, **3**, 4, 7, **9**	1, **2**, **3**, **5**, 7, **9**	**2**, **3**, 4, **5**, 6, 7, **9**
Added-value in comparison to the investment	**1**, **2**, 3, 4, **9**	**1**, **2**, 3, **9**	**2**, 3
Investment justification in relation to the size of the warehouse	1, 2, **5**	1, 2, **5**	2, **5**
Integration complexity - planning and organization	3, 4, 5, 6, 7	6, 7	1, 2, 4, 5, 7, 9
IT integration in the system landscape	3, **4**, 5, **6**, **7**, **8**, 9	**4**, **6**, **7**, **8**, 9	**1**, 2, **4**, **7**, 9
Flexibility in the future	**3**, 5, 6	6	**3**, 5, 6

Flexibility in operations	3, **4**, 5, **7**	**4**, **7**	2, **4**, **7**
Safety issues in mixed operation	**6**, 8	**6**	2, 4
Implementation time	3, 5, 6, 9		9
Efficiency issues	1, 2, 3, **4**, 7, 8, **9**	1, 2, 3, **4**, 7, **9**	2, 3, 7, **9**
Running costs	4, **6**, 8	4, **6**	
Number of automated units used within a specific area	6, **8**	6	
Communication among the devices	8		
Orientation at the company site	6	6	

Figure 32. Summary of empirical challenges for the movement of goods

As it can be seen in this table, the interviewed companies have already perceived or are aware of the challenges for AGVs, caused by the importance and timeliness of that technology in the context of the movement of goods within a warehouse. There are challenges, which are identified in nearly all companies, like the Implementation costs, the IT integration in the existing systems or the Efficiency issues for the use of AGVs. It has to be mentioned that not all of the interviewed companies have implemented AGVs yet. Therefore, the challenges, which are perceived by all companies, are mainly in the beginning of the invention phase of that technology. Companies that faced advanced challenges, which they were not able to overcome yet, stopped the implementation of that technology and hence did not face challenges, which arise mostly in the further implementation process like the Communication among the devices. This fact is one reason, why only a minor group of the interviewed companies faced challenges like the Orientation at the company site. Another reason, why only a few companies faced challenges like that, is the foundation of different AGV characteristics. This means that there are e.g. different ways of trying to solve the orientation at the company site challenge, but not all solutions work in a perfect way, which is then still challenging for these companies.

Regarding Automated forklifts, it has to be mentioned that this technology is way more advanced in comparison to AGVs caused by the extension of the vertical movement. This higher degree of complexity is one of the main reasons, why so many companies stopped implementing this technology after considering the Implementation costs, the physical and technical integration in the warehouse and the Efficiency issues with that technology. This is also the reason, why challenges like the Implementation time are not yet perceived by companies, caused by the lack of companies that implemented that technology.

The third technology mentioned is the Automated conveyor system, which is implemented by a huge amount of companies. As it can be seen in this table, the amount of challenges identified for Automated conveyor systems is not that much in comparison to the other technologies. This is mainly caused by the maturity of this technology and the lack of unexpected challenges. This means, as many companies stated, the development of Automated conveyor systems for the movement of goods is progressed so far that there are nearly no unexpected problems or challenges, which have to be faced. Of course, there are challenges like the Implementation costs and the Physical integration in the warehouse, but these challenges are well expected from the companies when implementing Automated conveyor systems.

5.3.2 The tracking of goods

The following table presents the summary of the challenges perceived from the empirical data for the technical solutions for automation for the tracking of goods. If a company mentioned or had a specific challenge, the company number is stated in the corresponding cell. Also if this challenge is perceived as very important for that company, the company number is highlighted in bold font.

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs	**4**, 6		**1**, 2, 3, **4**, 5, 6, 7, 9
Switching cost for technology	2, 3, 5, **6**, 7, 9	2, 3, 5, **6**, 7, 9	
Generation of added-value in comparison to the investment			1, **2**, **3**, **4**, **5**, **6**, **7**, 8, 9
Added-value in comparison to other technologies		**2**, **3**, 5, 7, **9**	
Limited storage capacity	1, 4, 6		
Visibility problems	1, 5, 6, 7	1, 6	
Vulnerable for damages	1, 4, 5, **6**, 7, 9		
Illegibility	5, 6, **7**, 9	6	1, 4, 6
Wi-Fi connection for mobile devices	**1**, 5	**1**	**1**

IT integration in the existing systems	**4**		**4**, 8
Human involvement needed for the scanning	8, 4, 6	4, 6	
Requirement of live-tracking	6, 8	6	
Privacy and security			6

Figure 33. Summary of empirical challenges for the tracking of goods

Barcodes are used in all interviewed companies, as it is the most common used tracking method or technology used in business. Therefore, the challenges for the usage of Barcodes are well examined by companies. There are no challenges like the Generation of added-value in comparison to other technologies, which is caused by the maturity of this already used technology. Companies use Barcodes for many years and so do not consider any more about generated added-value of that technology, because it was and still is the most efficient way of tracking goods for most of the companies. Nevertheless, Barcodes have also a lot of weaknesses, which are well identified by most of the companies like the Vulnerability for damages, Visibility problems or Illegibility challenges. The challenge of Switching costs for the technology is perceived by many companies, as they wanted and still want to switch from Barcodes to e.g. QR-Code. This switching causes immense costs, for instance, for the change of the used equipment and also for the exchange of all used Barcodes on each of the products, which takes a lot of time and effort.

Regarding QR-Codes, two challenges have to be highlighted, which are identified at most of the companies. For QR-Codes, the Added-value in comparison to other technologies and the Switching cost for technology like from Barcodes to QR-Codes is for many companies challenging. Even though, these companies would like to change their way of tracking products, a huge investment and time effort has to be spend to totally switch from e.g. Barcodes to QR-Codes, see change of scanners, readers and label printers. This investment in the background has to be justified by the added-value, which can be generated with the usage of QR-Codes instead of Barcodes. Of course, there is an added-value, like the extended storage space for information on the label, but this added-value is for the interviewed companies not enough to justify the change from Barcodes to QR-Codes. Nevertheless, the benefits of QR-Codes like the resistance against damages or the lack of illegibility problems can be seen in the table as well, by the lack of company numbers in the relevant cell.

For the last tracking technology mentioned here, the RFID technology, the Implementation costs and therefore the Generation of the added-value in comparison to the investment are the most important challenges. Nonetheless, the benefits of RFID, like the capability of live-tracking, the lack of visibility problems or the lack of vulnerability for damages, are enormous in comparison to Barcodes and QR-Codes. But the needed money for the implementation of RFID for e.g. the

RFID tags, the installation of readers and the acquisition of antennas, is a big obstacle to justify the implementation and usage of RFID in warehouses.

5.4 Importance of the empirical perceived challenges

This chapter highlights the most important empirical perceived challenges for each of the mentioned technologies. The importance of the challenges is based on the amount of companies, "voted" for that challenge, and on their emphasis of the challenge.

To be able to compare these challenges regarding their importance, a scoring and weighting system has to be introduced. With the help of this scoring system, simple company challenges or rather not highlighted challenges, and emphasized company challenges, see bold numbers, can be compared regarding their importance.

The subjective scoring systems is described in the following: a challenge gets 1 point for a simple "vote" and it gets 2 points for an emphasized "vote" in bold font. An exemplary calculation is presented in the following for a challenge in the area of AGVs:

Challenge	Points	Total score
Flexibility in operations	3, **4**, 5, **7**	6

Figure 34. Exemplary challenge scoring calculation

The total score of 6 is determined with the following calculation: $1 + 2 + 1 + 2 = 6$. After generating the total score of all challenges for each technology, a decreasing point list of all challenges will be generated. This means, that the challenge with the highest amount of points, is the most challenging aspect for the interviewed companies. For the complete unsorted scoring-lists of the challenges for the movement and the tracking of goods, please see Appendix 3.

The following two sub-chapters highlight the most important challenges for each of the mentioned technologies for the movement and the tracking of goods based on the gathered points in the point system.

5.4.1 **The movement of goods**

The following table visualizes the most important challenges for the movement of goods based on the findings of the empirical data.

Challenges for the movement of goods					
AGVs		Automated forklifts		Automated conveyor systems	
Challenge	Score	Challenge	Score	Challenge	Score
Implementation costs	18	Implementation costs	16	Implementation costs	18
IT integration in the system	11	Physical integration in	10	Physical integration in	11

landscape		the warehouse		the warehouse	
Physical integration in the warehouse	9	IT integration in the system landscape	9	IT integration in the system landscape	8
Efficiency issues	9	Efficiency issues	8	Integration complexity - planning and organization	6
Added-value in comparison to the investment	8	Added-value in comparison to the investment	7	Flexibility in operations	5

Figure 35. Most important empirical challenges for the movement of goods

As seen in the Figure 35 the most important challenge for all the automation solutions is the same. The Implementation costs are the most challenging aspect according to the companies in this study. All of them consider this as the main challenge that needs to be considered a lot. Both, AGVs and Automated conveyor systems reach, the maximum score of 18, which mean that all companies agreed that this is the most important challenge for them. Automated forklifts have 16 points and this is still a lot higher than the second most important challenge for this technology.

As it can be seen in this table, the Physical integration in the warehouse and the IT integration in the system landscape are, beside of the Implementation costs, the most important challenges for the implementation of all different technologies.

The number of points decreases until the end of the table, but all these challenges are still considered important by several companies. The lowest score of the "top five" challenges that companies considered, is 8 and 7 points for the Added-value in comparison to the investment for AGVs and Automated forklifts and 5 points for Flexibility in operations for Automated conveyor systems.

5.4.2 The tracking of goods

The following table visualizes the most important challenges for the tracking of goods based on the findings of the empirical data.

Challenges for the tracking of goods					
Barcodes		QR-Codes		RFID technology	
Challenge	Score	Challenge	Score	Challenge	Score
Switching cost for technology	7	Added-value in comparison to other technologies	8	Generation of added-value in comparison to the investment	15
Vulnerable for damages	7	Switching cost for technology	7	Implementation costs	10

Illegibility	5	Visibility problems	2	Illegibility	3
Visibility problems	4	Wi-Fi connection for mobile devices	2	IT integration in the existing systems	3
Implementation costs	3	Human involvement needed for the scanning	2	Wi-Fi connection for mobile devices	2

Figure 36. Most important empirical challenges for the tracking of goods

In Figure 36, the RFID technology really stands out in what companies consider to be the most important. The challenge of the Generation of added-value in comparison to the investment for RFID technology gets 15 points and Implementation costs get 10 points. Both challenges are perceived as really important challenges for the implementation of that technology caused by the huge costs for the equipment to use RFID within the warehouse. The importance of these challenges can be seen in the comparison to the gathered points of the other challenges, which is outstanding in this table.

For Barcodes the highest score is 7 for Switching cost that is considered the most important challenge and for QR-Codes it is the Added-value in comparison to other technologies, which is still caused by the existence of satisfaction with Barcodes at most companies. The fact that the most important challenges for Barcodes and QR-Codes only have 7 and 8 points highlights the facts, that challenges for these two technologies do not seem to be of high importance. This might be caused by the similarity of these technologies and the widespread distribution of these technologies among companies, which leads to the overcome of difficult and important challenges.

The scoring for Barcodes and QR-Codes is very similar except for the fifth important challenge which is Implementation cost with 3 points for Barcodes and Human involvement needed for the scanning with 2 points for the QR-Codes. The challenges differs between the different solutions where Barcodes have Vulnerable for damages with 7 points and this challenge does not appear in any of the other solutions.

5.5 Comparison of challenges

This chapter examines the similarities and differences of the theoretical and empirical perceived challenges for the movement and tracking of goods. Additionally, a comparison is drawn between the most important challenges of the two data sources.

5.5.1 The movement of goods

The following tables highlight the similar and different challenges identified in theory and in practice for the movement of goods, which includes AGVs, Automated forklifts and Automated conveyor systems. This includes a short summary of the challenges, the reason of their existence, the foundation of their sources and an importance comparison of the challenges between the two sources.

5.5.1.1 AGVs

The following two tables present the similarities and differences of the perceived challenges in theory and in practice for AGVs.

Similarities

AGVs		
Challenge	Identification in Theory	Identification in Practice
Implementation costs	x	x
Physical integration in the warehouse	x	x
IT integration in the system landscape	x	x
Flexibility in the future	x	x
Safety issues in mixed operations	x	x
Implementation time	x	x
Efficiency issues	x	x
Number of automated units within a specific area	x	x
Communication among devices	x	x

Figure 37. Similarities for AGVs

Implementation costs: One of the most important challenges for the implementation of AGVs in a warehouse is the Implementation costs. These costs are mainly caused by the huge amount of money, which has to be spend for the devices and for the acquisition of knowledge to use the vehicles in the warehouse. The challenge of the high implementation costs is identified in theory (Oleari, et al., 2014) and in practice by all companies, which endorse existence of this challenge for the implementation of AGVs in a warehouse.

Physical integration in the warehouse: This challenge is seen in several of the companies. The challenge derives from not having enough space at the existing warehouse to implement AGVs, which is caused by necessary requirement for enough space for the moving of this device. This physical integration is seen in practice in the same way as the theory that Oleari, et al. (2014) describe as Integration in existing warehouse.

IT integration in the system landscape: This is considered a challenge according to the companies. In the theory this challenge is described by Wurman (D'Andrea and Mountz, 2008). The challenge is to ensure that the implemented technology is well connected to the already used systems. Many of the companies got for example new WMS with the implementation.

Flexibility in the future: Three of the companies experience Flexibility in the future as a challenge for AGVs. Westfaliausa (n.d.) and Jiamruangjarus and Naenna (2016) both mention flexibility in the future as a challenge and explain that goods can be different in the future. This is how the companies also see it. If their product lines change this will be a challenge.

Safety issues in mixed operations: Both, the companies and theory, experience this as a challenge. The challenge expressed by the companies is very similar to what Oleari, et al. (2014) and Jacobus (Beach and Rowe, 2015) explain as Safety issues when interacting with humans. When technology and humans are working together in mixed operations the safety needs to be taken to account.

Implementation time: The time for implementation, as Oleari, et al. (2014) and Jacobus (Beach and Rowe, 2015) write about, is challenging for many of the companies. This can be due to that many companies need help from other companies implementing a solution and they underestimate their performance with implementation.

Efficiency issues: Many of the companies have had problems with efficiency when implementing AGVs. This confirms what Oleari, et al. (2014) describe in theory. The challenge often comes from the complexity and the lack of capability of handling the system in a good way in the beginning of the implementation.

Number of automated units within a specific area: Oleari, et al. (2014) means that the number of units can be challenging to companies due to the lesser space for the units. This is confirmed by the companies using AGVs. Some of them have problems with bottlenecks where the units need more space to pass through.

Communication among the devices: One company that uses AGV systems, experience the communication between the devices, which is caused by the connectivity of these vehicles and also the increased costs to ensure this connectivity, which is necessary to ensure a smooth flow of the systems. This could also be identified in theory, as it is stated by Cardarelli, et al. (2017).

Differences

AGVs		
Challenge	Identification in Theory	Identification in Practice
Added-value in comparison to the investment		x
Investment justification in relation to the size of the warehouse		x
Integration complexity – planning and organization		x
Flexibility in operations		x
Knowledge and maintenance of the system	x	
Running cost		x
Orientation at the company site		x

Figure 38. Differences for AGVs

Added-value in comparison to the investment: Many of the companies found it challenging to justify the investment of AGVs with benefits that made the warehouse more effective. This could only be identified in practice.

Investment justification in relation to the size of the warehouse: In contrast to the theory, many of the companies had problems to justify the big investment of an AGV system for a small warehouse. Many of them needed a bigger warehouse before investing.

Integration complexity - planning and organization: Many companies found the planning and integration of AGVs challenging. There was no theory mentioning this, which can be caused by the reason that many of the theories look at already implemented or planned AGVs.

Flexibility in operations: Many of the companies saw the challenge in losing flexibility when implementing AGVs. Due to the often complex system the small changes were harder than before. In theory there seems to be a lack of this experienced challenge.

Knowledge and maintenance of the system: The companies do not mention this as a challenge mostly due to that many of the companies that use the AGV solution, get help with the implementation, the maintenance and quick fixes for the system from third party suppliers. The theory is mentioned by Oleari, et al. (2014), Jacobus (Beach and Rowe, 2015) and Jiamruangjarus and Naenna (2016), where they explain that the companies need this expertise.

Running costs: No theory could be found about the running cost of the AGV systems. It might be that this is included in the implementation costs but as many of the companies expresses this as running costs make the authors feel that this is a challenge that do not match the theory.

Orientation at the company site: A few of the companies had experienced challenges with the orientation of the AGVs at the company site. In theory they mentioned this problem, but more in the context that this problem is already solved.

Importance Comparison
As it can be seen in Figure 35, the Implementation costs and the IT integration in the system landscape are the most important challenges for the implementation and usage of AGVs identified in practice. In comparison to that, Figure 7 highlighted the Implementation costs and the Safety issues when interacting with humans as the most important challenges for the implementation and usage of AGVs identified in theory. Therefore, it has to be stated that the Implementation costs are without doubt the most important challenge identified in both areas. Nevertheless, the theoretical perceived challenge of the safety aspect is not identified as an important challenge in practice, mainly caused by the technical development, which has the safety aspect as the number 1 priority. In contrast, the IT integration in the system landscape and the Physical integration in the warehouse are identified as very important challenges for the implementation and usage of AGVs in practice. Unlike in theory, these challenges are not perceived as challenges of high importance.

Therefore, it has to be stated that for AGVs the challenge of the safety issues with the interacting with humans seems to be overcome in practice. Though, practice perceives right now other challenges when it comes to the technical and physical integration of these systems.

5.5.1.2 Automated forklifts
The following two tables present the similarities and differences of the perceived challenges in theory and in practice for Automated forklifts.

Similarities

Automated forklifts		
Challenge	Identification in Theory	Identification in Practice
Implementation costs	x	x
IT integration in the system landscape	x	x

Safety issues in mixed operations	x	x
Number of automated units within a specific area	x	x

Figure 39. Similarities for Automated forklifts

Implementation costs: Most of the companies experienced the implementation costs for Automated forklifts as a big challenge. In theory, Jacobus (Beach and Rowe, 2015) explain that the Implementation costs of Automated forklifts are one aspect that makes companies look for other solutions instead.

IT integration in the system landscape: Wurman (D'Andrea and Mountz, 2008) describe technological compability regarding tracking technologies as a challenge for companies. In practice, many companies had experienced challenges with implementing new systems and integrating them with the old ones.

Safety issues in mixed operations: Oleari, et al. (2014) and Jacobus (Beach and Rowe, 2015) describe safety issues, when interacting with humans as a challenge. This is very similar to what companies have experienced in practice. When mixing technology and humans, companies need to think about how they interact and what dangers there can be.

Number of automated units within a specific area: A few companies had experienced challenges with the number of automated units for Automated forklifts, which is described by Oleari, et al. (2014) in theory and caused by overlapping sensor ranges of the vehicles.

Differences

Automated forklifts		
Challenge	Identification in Theory	Identification in Practice
Physical integration in the warehouse		x
Added-value in comparison to the investment		x
Investment justification in relation to the size of the warehouse		x
Integration complexity – planning and organization		x
Flexibility in the future		x
Flexibility in operations		x

Efficiency issues		x
Running costs		x
Orientation at the company site		x
Knowledge and maintenance of the system	x	
Time for implementation	x	

Figure 40. Differences for Automated forklifts

Physical integration in the warehouse: In theory, the challenge of the Physical integration in the warehouse for Automated forklifts could not be perceived. In contrast to that, in practice many of the companies experience this as a challenge, because often the whole warehouse layout needed to be changed.

Added-value in comparison to the investment: Many of the companies found it challenging to justify the investment of Automated forklifts with benefits that made the warehouse more effective. No theories could be found about this, when doing the literature review.

Investment justification in relation to the size of the warehouse: In theory, no evidence was found for this. However, many of the companies had problems to justify the big investment of an Automated forklifts for a small warehouse. Many of them needed a bigger warehouse before investing.

Integration complexity – planning and organization: Many companies found the planning and integration of Automated forklifts challenging caused by the extended direction of the vertical movement. There were no theories mentioning this.

Flexibility in the future: No theories could be found about flexibility in the future for Automated forklifts. This might be because they often work similar to how the manual warehouses are operating and it does not change. In practice companies consider this as a challenge, because their product line might change and then there would be other systems that could been better.

Flexibility in operation: This was considered as a challenge for some of the companies in practice in contrast to theory. They explained that it was easier to flexible when the company operates manually.

Efficiency issues: Some of the companies had efficiency issues with Automated forklifts. Often it was in the implementation phase or due to that the solution did not work perfectly yet. In theory there were no authors mentioning this.

Running costs: There could no theories be found about running costs for Automated forklifts. This might be because the implementation costs are often considered at first-hand. In practice companies did consider this as a challenge, caused by the needed adaptations in operations.

Orientation at the company site: A few of the companies had experienced challenges with the orientation of the Automated forklifts at the company site. In theory they mentioned this problem, but more in the context that this problem is already solved.

Knowledge and maintenance of the system: The companies do not mention this as a challenge mostly due to that many of the companies that use Automated forklifts get help from third party suppliers. For instance, Oleari, et al. (2014) or Jiamruangjarus and Naenna (2016) mentioned this challenge for the Automated forklifts in literature.

Time for implementation: Jacobus (Beach and Rowe, 2015) and Oleari, et al. (2014) mention this as a challenge in theory for Automated forklifts. None of the companies interviewed perceived this as a challenge.

Importance Comparison
The Implementation costs are the most important challenges, when it comes to the implementation of Automated forklifts in warehouses, as it is identified in practice. Also the physical and technical integration play a big role, when it comes to challenges in this area (see Figure 35). In comparison to that, theory has identified the Implementation costs and the Number of units in a specific area as challenging for the implementation and usage of Automated forklifts in warehouses (see Figure 7). As it is explained for AGVs, the implementation costs are the most important challenges identified in theory and in practice, which emphasize the timeliness and importance of this challenge. Nevertheless, the technical and physical integration is perceived as really challenging for companies in practice in contrast to the theory, which sees the number of units used in a specific area as challenging for the implementation and usage of Automated forklifts as challenging.

To summarize this part, it can be stated that the Implementation costs are the most important challenge for the implementation and usage of Automated forklifts in warehouses. The Number of units is not perceived as challenging for companies in practice, in contrast to the technical and physical integration in warehouses, which is seen as challenges with high importance for companies.

5.5.1.3 Automated conveyor systems
The following two tables present the similarities and differences of the perceived challenges in theory and in practice for Automated forklifts.

Similarities

Automated conveyor systems		
Challenge	Identification in Theory	Identification in Practice
Implementation costs	x	x

Physical integration in the warehouse	x	x
IT integration in the system landscape	x	x
Flexibility in the future	x	x
Safety issues in mixed operations	x	x
Efficiency issues	x	x
Implementation time	x	x

Figure 41. Similarities for Automated conveyor systems

Implementation costs: Most of the companies experienced the implementation costs as a big challenge for implementing Automated conveyor systems. Jiamruangjarus and Naenna (2016) explain that this is something that many companies find challenging.

Physical integration in the warehouse: Oleari, et al. (2014) and Gu, (Goetschalckx and McGinnis, 2010) express that the integration in an existing warehouse might be challenging for companies due to limited space. Many companies agreed to that, it was hard to fit the solution for the warehouse and not the other way around.

IT integration in the system landscape: Oleari, et al. (2014), Jacobus (Beach and Rowe, 2015) and Jiamruangjarus and Naenna (2016) all mention the problems that come with implementing and integrating new IT systems with old ones. Many of the companies have also found this to be a challenge.

Flexibility in the future: Westfaliausa (n.d.) explains that an Automated conveyor system often needs to be very much adapted for the company requirements. If their product line would change also the Automated conveyor system needs changes. Many companies saw this as a challenge for the future and were aware that if something changes it was not going to be a simple task to fix it.

Safety issues in mixed operations: Safety issues in mixed operations, as Oleari, et al. (2014) and Jacobus (Beach and Rowe, 2015) describe, derives from getting the Automated conveyor system to work with humans. With a system like this there will be places where humans are not allowed due to safety reasons. Many companies also experience this as a challenge and something that they needed to consider.

Efficiency issues: Jiamruangjarus and Naenna (2016) explained that there are theoretical challenges with implementing an Automated conveyor system due to the problem of gaining higher efficiency. Many of the companies experienced the same but mostly in the beginning before making the Automated conveyor system work properly.

Differences

Automated conveyor systems		
Challenge	Identification in Theory	Identification in Practice
Added-value in comparison to the investment		x
Investment justification in relation to the size of the warehouse		x
Integration complexity – planning and organization		x
Flexibility in operations		x
Knowledge and maintenance of the system	x	

Figure 42. Differences for Automated conveyor systems

Added-value in comparison to the investment: Some of the companies experienced this as a challenge. The benefits of implementing the Automated conveyor system was in those cases not enough in comparison to the investment. Theory does not perceive this as a challenge.

Investment justification in relation to the size of the warehouse: Many companies saw the fact that the warehouse did not handle enough goods and therefore waited to implement this solution until there was evidence of how much profit they could get. In the theory there is nothing that mentions the amount of goods or the size of the warehouse as a challenge.

Integration complexity – planning and organization: In theory there were no authors mentioning the complexity that comes with planning and organizing the implementation of Automated conveyor systems. Many of the companies saw this as a challenge since there were so many pieces that needed to fit together.

Flexibility in operations: Many of the companies thought of this as a challenge due to the decrease of flexibility. These systems are complex and if someone just picks up goods at the wrong place the system had errors. In theory nothing about the flexibility in operations could be found.

Knowledge and maintenance of the system: In theory, Oleari, et al. (2014), Jacobus (Beach and Rowe, 2015) and Jiamruangjarus and Naenna (2016) described the knowledge and maintenance as a problem for the Automated conveyor systems. In practice companies does not see this as a challenge since they are often buying the whole package with education and maintenance about the Automated conveyor system from the company providing it.

Importance Comparison
The same, as it is mentioned for AGVs and Automated forklifts, is true for Automated conveyor systems, that the Implementation costs and the technical and physical integration of this technology in the warehouses is perceived as the most important challenges for the implementation and usage of Automated conveyor systems in practice (see Figure 35). In comparison to that, the Implementation costs, the Time for implementation and the Flexibility in the future aspects are identified as the most important challenges in theory (see Figure 7).

Hence, the Implementation cost are also for the Automated conveyor systems the most important challenges identified in theory and in practice, which emphasizes on the importance of this challenge even more. The technical and physical integration, which is of high importance for the companies in practice, could not be identified as important in theory. The aspects of Time for implementation and Flexibility in the future, as it is stated in theory as important challenges, are not identified as challenging for companies in practice.

5.5.2 The tracking of goods
The following tables highlight the similar and different challenges identified in theory and in practice for the tracking of goods, which includes Barcodes, QR-Codes and RFID technology. This includes a short summary of that challenges, the reason of their existence, the foundation of their sources and an importance comparison of the challenges between the two sources.

5.5.2.1 Barcodes
The following two tables present the similarities and differences of the perceived challenges in theory and in practice for Barcodes.

Similarities

Barcodes		
Challenge	Identification in Theory	Identification in Practice
Implementation costs	x	x
Limited storage capacity	x	x
Visibility problems	x	x
Vulnerable for damages	x	x
Illegibility	x	x
Human involvement needed for the scanning	x	x

Requirement of live-tracking	x	x

Figure 43. Similarities for Barcodes

Implementation costs: One of the challenges for the implementation and the usage of Barcodes are the costs for the Barcode equipment. This can include costs for the Barcode scanners, readers, label printers and label rolls. The challenge of implementation costs have been identified in theory, as High acquisition and running costs by Lotlikar, et al. (2013) and AHG (2017), and also from the empirical data (Company 4 and 6). Therefore, it can be stated, that the implementation costs for the usage of Barcodes in a warehouse should not be underestimated as a challenge for Barcodes.

Limited storage capacity: Another challenge identified in theory for the usage of Barcodes is the limited storage capacity of these codes. The limited storage capacity is caused by the low amount of storage positions on the Barcode, as it is stated in theory by Lotlikar, et.al. (2013) and Explainthatstuff! (2017). This challenge is also perceived by three companies (Company 1, 4 and 6), which highlighted in the interviews the limited capability of the Barcodes.

Visibility problems: To be able to generate the information of Barcodes, a reader has to scan the Barcode and transfers the information to the information system of the warehouse. Therefore, the Barcode has to be visible for the scanner, which can be in some situations challenging for companies. Pihir (Phir and Vidacic, 2011) explained that this challenge especially arise for automated scanning processes, where the direction of the Barcode has to be standardized for the scanning process. The importance of that challenge was emphasized by the interviewed companies, as 4 of them as mentioned the visibility of Barcodes as a challenge for their running business (Company 1, 5, 6 and 7).

Vulnerable for damages: Caused by the low amount of storage positions on Barcodes, the integrity of the Barcode positions has to be ensured. Hence, little damages of the Barcodes can cause the loss of the whole Barcode. This challenge was identified in theory (AHG, 2017) and also in practice (Company 1, 4, 5, 6, 7 and 9), which highlights the existence of this challenge.

Illegibility: The illegibility of Barcodes is the next challenge, which appears in theory and in practice at the same time. Beside of the mentioned damages, other aspects like the printing quality can affect the illegibility of Barcodes. This was, inter alia, mentioned by Lotlikar, et al. (2013) and also by the a few companies (Company 5, 6, 7 and 9), which highlights the timeliness of that challenge.

Human involvement needed for the scanning: Another challenge for the implementation or rather the usage of Barcodes, is the needed human involvement for the scanning process. As it is explained in Pihir (Phir and Vidacic, 2011), the human involvement is needed for the attaching of the Barcodes on the products, but also for the scanning of these codes in not fully automated scanning lines, to ensure a smooth run of scanning. This challenge also appears similar in practice, as

Company 4, 6 and 8 mentioned the needed human involvement for their Barcode scanning process.

Requirement of live-tracking: In comparison to the RFID technology, it is not possible to track the movement of goods live with the usage of Barcodes, since Barcodes are scanned at a single point of time to get the information from them. In case, a gapless tracking of goods would like to be done, the Barcodes would have to be scanned non-stop, which is economical senseless. According to Jia, et al. (2012) and Wasp (2017), it can be challenging for companies to use Barcodes, if they want to have live-tracking in their facility. Company 6 and 8 affirmed this as a challenge from the practical point of view.

Differences

Barcodes		
Challenge	Identification in Theory	Identification in Practice
Switching cost for technology		x
Wi-Fi connection for mobile devices		x
IT integration in the existing systems		x

Figure 44. Differences for Barcodes

Switching cost for technology: The challenge of switching cost for the technology is one of three challenges, which are only identified in practice. As 5 companies stated, based on the widespread distribution and usage of Barcodes and therefore the usage of the Barcode equipment, it is challenging for companies to switch to another technology easily and quickly (Company 2, 3, 5, 6, 7 and 9). An example for the switching costs can be the modification of all scanners and readers within a facility, which can be really costly.

Wi-Fi connection for mobile devices: Another challenge, which one was identified from the empirical data, is the Wi-Fi connection for mobile devices. As Company 1 and 5 mentioned during their interviews, the permanent and reliable providing of Wi-Fi for the mobile scanning devices is challenging for these companies. As they mentioned, the lack of a permanent Wi-Fi connection can lead to systems problems and inoperable scanning processes.

IT integration in the existing systems: The last challenge, which was only identified in practice by the interview with Company 4, is the IT integration in the existing systems. As Company 4 mentioned, the technical integration in the other systems used in the warehouse, is for that company challenging caused by the poor quality of the IT interface between the Barcode systems and the WMS.

Importance Comparison
As it could be identified in practice, the Switching costs for Barcodes to another technology and the Vulnerability for damages are the most important challenges (see Figure 36). In comparison to that, the Illegibility, the High acquisition costs and the Visibility problems could be identified as the most important challenges in theory (see Figure 9). Nevertheless, these three theoretical perceived challenges are also identified in practice as the third, fourth and fifth most important challenges for the implementation and usage of Barcodes within a warehouse.

Therefore, the Illegibility, the Visibility and the Acquisition or rather Implementation costs are identified in both areas as important challenges, which emphasizes the importance of these challenges, as they are identified in theory and in practice. Though, the most important challenges identified in practice, like the Switching costs and the Vulnerability aspect, could not be identified in theory.

5.5.2.2 QR-Codes
The following two tables present the similarities and differences of the perceived challenges in theory and in practice for QR-Codes.

Similarities

QR-Codes		
Challenge	Identification in Theory	Identification in Practice
Visibility problems	x	x
Illegibility	x	x
Human involvement needed for the scanning	x	x
Requirement of live-tracking	x	x

Figure 45. Similarities for QR-Codes

Visibility problems: One challenge, which is identified similar in theory and by the empirical data, are the visibility problems for QR-Codes. Since the information of QR-Codes is transferred via the scanning of the codes with readers, a requirement for this scanning process is the visibility of the label for the reader. This challenge for QR-Codes was identified by Pihir (Phir and Vidacic, 2011) and Visaisouk (2013) in literature, but also from two of the interviewed companies (Company 1 and 6).

Illegibility: Another challenges perceived from theory and practice, is the illegibility of QR-Codes, which can be negatively affected by e.g. a poor printing quality of a too high degree of customized label, as it Lotlikar, et al. (2013) highlighted. This challenge is also identified by the empirical data (Company 6)

Human involvement needed for the scanning: As it is already explained for Barcodes, the needed human involvement for the scanning process can also be a challenge for QR-Codes, caused by aspects like the attaching of the code or the assurance of a smooth scanning process. Beside of the theoretical perception by Pihir (Phir and Vidacic, 2011), this challenge was also identified by the Companies 4 and 6.

Requirement of live-tracking: Also as Barcodes, QR-Codes are not capable of providing live-tracking for goods, since QR-Codes have to be read by a scanner at one point of time. This capability could be provided by a permanent scanning of the QR-Code, which would be economically senseless caused by the infinite number of scanning processes. The lack of the capability of live-tracking was mentioned by Jia, et al. (2012) and Wasp (2017) in theory, but also by 2 of the interviewed companies (Company 6 and 8).

Differences

QR-Codes		
Challenge	Identification in Theory	Identification in Practice
Switching cost for technology		x
Added-value in comparison to other technologies		x
Wi-Fi connection for mobile devices		x
Slow scanning speed	x	

Figure 46. Differences for QR-Codes

Switching cost for technology: One of the challenges, which are not identified similar in theory and in practice, are the switching costs for the technology for the QR-Codes. This is caused by the argumentation of the companies (Company 2, 3, 5, 6, 7 and 9), that the switching from e.g. Barcodes to QR-Code is quite expensive and time intensive. Companies would like to switch from Barcodes to QR-Codes, to use the benefits of these codes, but based on the switching effort for all products in their warehouse, it does not make enough sense for them.

Added-value in comparison to other technologies: The challenge of the added-value in comparison to other technologies is only identified from the empirical data (Company 2, 3, 5, 7 and 9). As these companies stated, they do not have big problems regarding the limitations and problems of Barcodes. This lack of motivation causes the challenge of the added-value in comparison to e.g. Barcodes, even though these companies would like to use the benefits of QR-Codes

Wi-Fi connection for mobile devices: Another challenge of the usage of QR-Codes in a warehouse can be the lack of a reliable Wi-Fi connection for mobile devices for the scanning processes. As it is stated from Company 1, one challenge in their warehouse is the permanent providing of Wi-Fi for the mobile scanning devices for e.g. QR-Code, which leads to inoperable scanning transactions.

Slow scanning speed: The challenge of a slow scanning speed for the scanning of QR-Codes could be only identified by theory (Visaisouk, 2013), who mentioned that the scanning speed can be negatively affected caused the greater amount of information, which has to be transferred with QR-Codes. In comparison to that, practice does not perceive this challenge based on high-tech scanners, which are able to scan Barcodes and QR-Codes in the same amount of time.

Importance Comparison
As it is visualized in Figure 36, the Added-value in comparison to other technologies and the Switching costs are identified as the most important challenges perceived in practice. In comparison to that, Figure 9 highlights the Illegibility and Visibility aspect as the most important challenges for the implementation and usage of QR-Codes within warehouses identified in theory. The Visibility challenge of QR-Code could also be identified in practice, but only as a minor challenge regarding the gathered scoring.

Hence, it can be stated, that for the implementation and usage of QR-Code the perceived challenges in theory and in practice differ quite a lot. The Added-value in comparison to other technologies and the Switching costs could not be identified in theory in comparison to practice, which highlights a gap in the perception of the challenges for the implementation and usage of QR-Code in warehouses in theory.

5.5.2.3 RFID technology
The following two tables present the similarities and differences of the perceived challenges in theory and in practice for RFID technology.

Similarities

RFID technology		
Challenge	Identification in Theory	Identification in Practice
Implementation costs	x	x
Illegibility	x	x
IT integration in the existing systems	x	x
Privacy and security	x	x

Figure 47. Similarities for RFID technology

Implementation costs: One of the most important challenges, which is identified in theory and in practice, are the implementation costs for the usage of the RFID technology in a warehouse. These costs can include the acquisition of RFID tags, readers, scanners and antennas. Based on the importance of this challenges, when it comes to the implementation of RFID in a warehouse, theory (Kumar, Kadow and Lamkin, 2011; Lim, Bahr and Leung, 2013; Bahr and Lim, 2009) and practice (Company 1, 2, 3, 4, 5, 6, 7, 8 and 9) highlighted the importance of that challenge.

Illegibility: Another aspect that appears similar in theory and in practice, is the illegibility challenge of the RFID technology. As both source explained, RFID can be negatively influenced by the overlapping of RFID tags or interferences of antennas. Beside of Lim (Bahr and Leung, 2013), Companies 1, 4 and 6 highlighted the timeliness of that challenge.

IT integration in the existing systems: The main advantage of RFID technology for the tracking of items within a warehouse is the possibility of live-tracking and scanning without direct visuality. To be able to use the advantages of RFID, the technical integration in the existing systems has to be ensured, which can be a challenge for companies, as it is stated in theory (Bahr and Lim, 2009) and in practice (Company 4 and 8).

Privacy and security: The last challenge for the implementation and usage of RFID technology in a warehouse identified in theory and practice, is the privacy and security aspect of information transmission. Based on the transmission of information via radio waves, it is possible that unknown recipients are able to read the information of the tags. This is stated in theory by Lim (Bahr and Leung, 2013) and also by Bahr and Lim (2009) and also in practice by Company 6.

Differences

RFID technology		
Challenge	Identification in Theory	Identification in Practice
Generation of added-value in comparison to the investment		x
Wi-Fi connection for mobile devices		x
Standardization in technology	x	

Figure 48. Differences for RFID technology

Generation of added-value in comparison to the investment: One of the most important challenges, which is only identified in practice from all companies, is the generation of added-value in comparison to the investment. The reason of this challenge is the comparison of the huge investment to the added-value of that technology. The investment in the needed equipment for the usage of RFID outweighs mostly the benefits of the RFID technology.

Wi-Fi connection for mobile devices: Another challenge, which is only perceived in practice, is the Wi-Fi connection for mobile devices. As already stated for the Barcodes and QR-Codes, the lack of reliable Wi-Fi connection to the mobile readers can be a challenge for companies, which might lead to the inoperability of the scanning process (Company 1).

Standardization in technology: The challenge of standardization in the technology for RFID can only be identified in theory (Lim, Bahr and Leung, 2013; Bahr and Lim, 2009). This challenge is caused by the lack of standardization at e.g. the used frequency within the RFID technology. Nevertheless, as it is perceived in practice, this challenge does not exist for the interviewed companies. That is probably caused by the regional characteristics, in which these companies mainly operate. Since the interviewed companies mostly operate within Europe, the standardization of e.g. the used frequency of the RFID technology is normally given.

Importance Comparison
The challenge of the Generation of added-value in comparison to the investment and the Implementation costs are the most important challenges at a large distance when it comes to the implementation of RFID in practice (see Figure 36). In comparison to that, the theoretical perceived challenges of the Illegibility, the Acquisition or rather Implementation costs and the Privacy and security aspects are identified as the most important ones (see Figure 9). The Privacy and security and the Illegibility challenges of the RFID technology are also identified in practice, but not as one of the most important challenges. Otherwise, the challenge of the Generation of added-value in comparison to the investment is not even perceived in theory at all.

Therefore, it has to stated, that the challenge of the Implementation costs for the RFID technology is one of the most important challenges identified in both areas. The Generation of added-value in comparison to the investment could only be identified in practice, which constitutes a gap in theory regarding the perception of challenges for the implementation and usage of RFID technology in warehouses.

5.6 Summary and discussion of results

As it can be seen, the interviewed companies are aware of the challenges and benefits of the mentioned technologies, which could be presented by the number of companies, which already implemented these technologies. E.g. AGVs are already used by 44% (4 of 9) of the companies and will be implemented by 60% (3 of 5) of the other companies, which did not implement AGVs yet. It must be mentioned that also Automated conveyor systems are already implemented by 67% (6 of 9) of the interviewed companies. Regarding the tracking of goods, 100% use Barcodes and 44% (4 of 9) use QR-Codes. These results can be seen as a valid foundation of the awareness of these companies, when it comes to the perception of challenges for the technologies of the movement and tracking of goods within a warehouse.

The analysis has carved out, that there are similarities between the challenges for the movement and tracking of goods identified in theory and in practice, but there are also quite a lot differences. This means that theory reflects the challenges of the implementation and usage of the movement and tracking technologies within a warehouse, but not in a complete way.

Starting with the challenges for the movement of goods within a warehouse, it can be stated that there could be challenges identified, which occur for all three mentioned technologies in theory and in practice. For instance, the Implementation costs as a challenge for AGVs, Automated forklifts and Automated conveyor systems are identified in literature and in the empirical data, which highlights the importance of this challenge and is one of the similarities between the perception of theory and practice. Another similarity between theory and practice is the IT integration in the system landscape, which is challenging for all technical solutions for automation in this thesis. The challenge of Safety issues in mixed operations could also be identified as a similarity between theory and practice.

The fact that these three challenge examples could be identified in theory and in practice highlights the awareness and timeliness of these challenges. It also emphasizes on the importance, that these challenges have to be overcome by theory and also by practice, when implementing technical solutions for automation for the movement and tracking of goods.

When it comes to the differences of the challenges identified in theory and in practice for the movement of goods, there are also a few challenges, which differ for all of the mentioned technologies. As an example, the Added-value in comparison to the investment could be perceived in practice, but not in theory, which is mainly concentrating on other aspects like the Implementation costs. Also the Investment justification in relation to the size of the warehouse could be only identified in practice and not in theory. Another example is also the Integration complexity – planning and organization, which could be perceived for all three technologies only in practice and not in theory.

This highlights the fact that there are a lot of challenges, which could be identified in practice and not in theory, mainly caused by the different focus of practice and theory. As it is stated in the empirical data, companies face a lot of challenges before the technology can be implemented, like the consideration of the added-value or the investment justification. In contrast to that, theory mainly focuses on the challenges after these considerations are already done.

The same can be stated for the challenges identified for the tracking of goods within a warehouse. There are similarities of these challenges, which are identified for more than one technology, like the challenge of Illegibility. Another example of a challenge, which could be identified in theory and practice similar, are the Implementation costs for the RFID technology and Barcodes, and also the Visibility problems for QR-Codes and Barcodes. These exemplary challenges could be identified in theory and in practice, which highlights the importance, the timeliness and the awareness of these challenges in both foundation areas.

Nevertheless, there are also a few challenges, which differ between theory and practice, like the challenge of the Wi-Fi connection for mobile devices, which could be identified for all three mentioned tracking technologies in practice. Another difference in the perception of challenges is the Switching costs for technology, which could be identified in practice for Barcodes and QR-Codes. The last example, which is mentioned here for the differences between theory and practice, is the

Generation of added-value in comparison to the investment for the RFID technology.

The fact that there are quite a lot of challenges, which are identified in practice and not in theory, highlights the gap of the theoretical perception of challenges for the tracking of goods within a warehouse.

When it comes to the reason of these challenges, it is difficult to answer that in a unified way, caused by the variation of the reason for a challenge among the different companies. For instance, the reason of the existence of challenges like the Implementation costs is easily explained by the huge costs for the equipment. But for challenges like Integration complexity – planning and organization, the reason of existence differ from company to company caused by the variation of the company circumstances. Therefore, a detailed and customized explanation of the reason of existence of the challenges is given during the thesis for the theoretical perceived challenges and for each of the interviewed companies separately.

To summarize the findings of the analysis, it can be stated that there are a lot similarities and differences between the identified challenges in theory and in practice. By having a more differentiated analysis of the finding, it can be seen that the similarities and differences can be detected for specific areas. This means e.g. for the movement of goods, the similarities between the perception of the challenges could be identified for general challenges like the Implementation costs, the IT integration in the system landscape and the Safety issues in mixed operations. The awareness of these general challenges is in theory and in practice caused by the maturity and importance of these challenges, when it comes to the implementation of technical solutions for automation for the movement of goods. Differences for the movement of goods could be identified mainly for challenges, which are at the first phase of the implementation process, like the Added-value consideration in comparison to the investment or the Integration complexity – planning and organization, which are important challenges for the companies in practice. In contrast to that, theory is focusing on challenges, which arise after the beginning phase of the implementation, so when the decision for a technology has already been taken.

For the challenges for the tracking of goods, similarities could be detected also for general challenges, like the Illegibility or the Visibility problems for the QR-Codes and Barcodes. These general challenges for the tracking technologies could be identified in theory and in practice, which is caused by the period of presence of these technologies. The differences in the identified challenges for the tracking of goods, like the Wi-Fi connection for mobile devices or the Switching costs for technologies, mainly concentrate on specific practical problems within the usage of one or more technologies.

6 Conclusion and recommendations

To conclude this paper, the research questions will be answered. The conclusion starts with a short summary, then the RQ1 and RQ2 is answered. In the end the authors reflect about the work and suggest further research questions or rather research areas that can be analyzed.

Many companies have implemented automation in their warehouses. It is due to the standardized and repetitive work as Hamberg and Verriet (2012) mention, but also the potential to reduce costs as Gunasekaran (Patel and Tirtiroglu, 2001) with others write. The conclusion of this paper is that there is a lot of different challenges arising both before, during and after the implementation of technologies. Some of which is already brought up in theory and some that today only appears in practice.

Regarding the answering of the raised research questions, it can be stated:

RQ 1: What technical solutions for automation of the movement and tracking of goods are currently applied in warehouse operations?

To answer this research question in an appropriate way, literature and empirical data was conducted, with the result of AGVs, Automated forklifts and Automated conveyor systems for the movement of goods. For the tracking of goods, Barcodes, QR-Codes and RFID technology is applied in warehouses. To emphasize on the finding of these technologies, the percentage of companies that already implemented these technologies, can be seen in following table.

The movement of goods		
AGVs	Automated forklifts	Automated conveyor systems
44%	11%	67%
The tracking of goods		
Barcodes	QR-Codes	RFID technology
100%	44%	33%

Figure 49. Percentage of implemented technologies

For movement of goods it can be clearly seen that AGVs and Automated conveyor systems are a lot more applied than Automated forklifts. As seen in Figure 49, only one company of the 9 interviewed uses Automated forklifts. The Automated conveyor systems are used at 66% (6 of 9) of the companies and AGVs at 44% (4 of 9). Depending on what type of company it is and where they use the solution, it seems like the reason for why not more companies use the Automated forklifts is the complexity when involving vertical movement to the solution.

For the tracking of goods Barcodes are used at all the companies. QR-Codes are used at 4 and RFID technology at 3 of them. This implies that an old technology like Barcodes is still the most popular one and the easiest to use. QR-Codes and RFID technology is used when the tracking of goods needs to be more advanced. It also seems like RFID technology is used for more expensive and rare goods.

RQ 2: What are the differences and similarities between the challenges with the implementation of these technologies identified in theory and experienced in practice and why do these challenges exist?

When looking at challenges from both, the theoretical and practical view, there are similarities and differences that appear for the movement technologies. Examples of similarities among challenges for all of the mentioned technologies are the Implementation costs, the IT integration in the system landscape and Safety issues in mixed operations. This highlights the importance of these challenges, since they are already considered in both theory and in practice. Examples of differences in the perception of challenges could be identified for the Added-value in comparison to the investment, the Investment justification in relation to the size of the warehouse and the Integration complexity - planning and organization. It seems like theory often only perceives challenges after the implementation, but in reality companies face challenges already before the implementation process. These examples of differences for all of the movement technologies are challenges that emerge already, when the company starts considering automation in the warehouse.

In the tracking of goods, there are as well similarities and differences between the identified challenges in theory and practice. As examples of similarities for challenges the Implementation costs and Generation of added value for RFID technology, Vulnerability for damages in Barcodes and Visibility problems for both Barcodes and QR-Codes can be mentioned. This means that the theory already have found these challenges to be important. Examples of differences between theory and practice is the Wi-Fi connection for mobile devices for all the technologies, Switching costs for Barcodes and QR-Codes and the Generation of added value in comparison to the investment for RFID technologies. This means that there seems to be a gap in theory and that there is nothing written about how and why the companies perceive these challenges. Theory is not so much focused on the challenges for the usage of the technologies for the tracking of goods.

Therefore it can be concluded that the perceived challenges for movement of goods between theory and practice differs and that theory is more directed to see challenges after implementation. In the tracking of goods, the perceived challenges in practice are more about the usage of the technologies, compared to the technical orientation of the challenges in theory.

Regarding the reason of the existence of the examined challenges, it has to be stated, that the reasons differ and vary among each technology and each company. Therefore, the individual explanation of the justification of the challenges is given during the thesis.

Reflections about the essay

The perceived challenges differs among companies due to many reasons like company size, warehouse size, number of warehouses, age of the company, what industry the company is based in and how these companies look at technical solutions. To ensure trustworthiness, several considerations were made. Even though, the perception of challenges differs in some ways, the interviewed companies encountered the same challenges as others will do in the future. This causes the results to be transferable to other companies. To ensure the credibility of this study, 9 companies in 10 interviews have been asked about their company situation, which ensures rich and credible data. The dependability is also taken into account via the gapless documentation of the data gathering process, as it can be seen in the empirical chapter and in the Appendix 2 of this thesis. Regarding the conformability, the authors have tried their best to be objective in every situation of the thesis through the discussion among, the reciprocal control and the good faith of the two researchers.

When it comes to reliability, Bryman and Bell (2015) explain that it is impossible to do an exact replica of a qualitative research. The authors are aware that the same results would be hard to get in a new study with other companies, but the thesis is still valid due to the lack of theoretical writings about some of the practical perceived challenges. To support the characteristic of reliability of this study, the Interview Guide and the Interview Questions are attached in the Appendix 1.

The validity of this study, which consists of the internal and external validity, is tried to ensure during the whole thesis. Internal validity is ensured through the semi-structured interviews, including the supply of an Interview Guide for the respondents, the recording, the transcription and the post-preparation of the interviews. The external validity is concerned with the generalizability of the study. The authors are aware that in some cases, these differences and similarities of the perceived challenges cannot be generalized for other companies caused by the e.g. different economical company circumstances. There might be also differences on what people see as a challenge and this is something that the authors were aware off. Nevertheless, the perceived finding of this study can be used as an orientation for further studies in this area.

Theoretical and practical contribution

This thesis examined the differences and similarities of challenges for the implementation and usage of technical solutions for automation in warehouses between theory and practice. This means that the theoretical contribution contains of revealing the gaps in theory about the practical perceived challenges. The challenges that the companies added, which could not be found in theory should be further examined like any challenges before the implementation of technical solutions for the movement of goods. The answers about perceived challenges also highlights, what has been the most important challenges. The practical contribution of this thesis is, that the perceived challenge lists can work as a guideline for companies wanting to implement automation for the movement and tracking of goods in warehouses. What challenges have similar companies experienced and what can be learned from that? There may be challenges perceived in this thesis that other companies have not thought about, before planning and starting the implementation of technical solutions for automation.

Further recommendations

There is a permanent need of further research in this area of studies, caused by the constant development and implementation of new technologies and so the generation of new challenges. There could also be challenges arising, when using the different movement and tracking technologies e.g. in combination, as it was stated in Bahr and Lim (2009) with the usage of RFID tags on Automated forklifts, which generates e.g. synergies. Also the area of responsibility of one of these technologies could be extended, which would have an influence on the identification of challenges and therefore would need further research. One example can be here the tracking of perishable goods, which is very innovative with the usage of RFID technology (RFID Journal, 2018). With developments like this, new challenges for technologies arise and further research in this area is needed.

Nevertheless, it has to be mentioned at this stage, that automation in general also decreases flexibility. Therefore, further research could be done to examine the effect of flexibility of these challenges in a supply chain or in a warehouse.

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7.3 Interviews

Company 1 – Supplier in the automotive industry, 2018. Director of warehouse logistics. [phone] 30.04.2018, duration: 27:33 minutes.

Company 2 – Distributor of office material, 2018. Warehouse logistics manager for northern Europe warehouses. [phone] 02.05.2018, duration: 20:50 minutes.

Company 3 – Online Retailer for clothing and sport article, 2018. Logistics manager of warehousing. [phone] 03.05.2018, duration: 24:20 minutes.

Company 4 – Logistics service provider, 2018. Engineering consultant for corporate contract logistics of the company group. [phone] 04.05.2018, duration: 39:20 minutes.

Company 5 – Logistics service provider, 2018. Logistics manager for one warehouse in a specific region. [phone] 07.05.2018, duration: 18:15 minutes.

Company 6 – Manufacturer for electronic parts, 2018. Head of logistics management and data systems. [phone], 07.05.2018, duration: 51:03 minutes.

Company 7 – Retailer within food and beverages, 2018. Supply chain and Logistics manager. [phone], 07.05.2018, duration: 24:50 minutes.

Company 8 – Manufacturer of professional office chairs, 2018. Part 1: Director of Operations. [phone], 07.05.2018, duration: 33:57 minutes.

Company 8 – Manufacturer for professional office chairs, 2018. Part 2: Technical Director. [phone], 07.05.2018, duration: 08:43 minutes.

Company 9 – Product wholesaler, 2018. Director of logistics and warehousing. [phone], 15.05.2018, duration: 24:40 minutes.

8 Appendix

8.1 Appendix 1 – Interview Guide and Interview Questions

Presentation of the thesis and of the area of interest:
We are interested in the challenges of the implementation of technical solutions for automation in warehouse operations with a focus on the technologies for the movement and tracking of goods. This means, we are interested, if [your Company …] has already or is planning to do or will implement automation technologies in your warehouse for the tracking and the movement of goods. As well, we are interested, if you already faced challenges with this or are considering that you will face challenges. Thereby, we would be interested, if you consider how you can overcome these challenges and why they exist in your opinion.

We structured that interview regarding a timeline. Therefore, we would like to start to talk about the past of your technological warehouse operations. Afterwards, we would like to talk about the current situation of the process of the implementation of technical solutions of automation for the tracking and movement of goods within warehouses. Then, we would like to talk about future plans of warehouse automation at [your Company …]. In the end, we would like to talk about different concepts of technical solutions for warehouse operations, about which we read in theory, and about which we are interested in your opinion.

Note, how we define automation and technologies in our research:
- “Automation refers to the process of automatically”, handling goods, “through the use of robots, control systems and other appliances with minimal direct human operation” (Pettinger, 2018, p.1).
- Technology can be briefly defined, as “products and processes used to simplify our daily lives” (Ramey, 2013, p.1). Addionally, “technology is defined as consisting of both hardware and software (the knowledge required to produce and use technological hardware)” (Grübler, 2003, p.19).

Start of the questionnaire/interview questions
Past situation
- What technologies have you already implemented and used in your warehouse operations for the tracking and movement of goods?
- What challenges did you face by the implementation of those technologies?
- Did you overcome already challenges by the implementation of that?
- Were there also challenges, which you expected to face, but did not face in the implementation process?
- For the perceived challenges, how did they overcome these challenges?
- Are there still challenges from the implementation of past technologies, which you still have to overcome or are still struggling with?
- Why do you think these challenges exist at [your Company]?

Current situation

- Are you currently planning or implementing technologies in your warehouses for the movement and tracking of goods? If yes, which technologies?
- What challenges do you already perceive and try to overcome?
- Why do you think these challenges exist, what is the source of these challenges?
- How do you plan for short-term and long-term to overcome these challenges?

Future situation

- Are there technologies for the movement and tracking of goods, which you plan to implement in the future?
- If yes, did you consider challenges you will face, or can imagine you will probably face?
- Why do you think, that you will face those challenges?
- How do they think, you will overcome those challenges?

Open questions (based on the theoretical insights)

- What do you think about … as a technology for warehouse automation?
- Have you considered automated guided vehicles? What do you think about it?
- Have you considered Automated forklifts? What do you think about it?
- Have you considered Automated conveyor systems? What do you think about it?

Tracking of goods (Barcode, QR-Code and RFID technology)

- What technology are you using now?
- Have you considered others? Why have you not implemented it?
- Do you think some technologies fit your products better?
- How does your WMS look like? How does it work?

Type of goods and automation system

- What goods are you handling? Size, weight, standardized, number of products/packages that goes through the warehouse etc.
- Did they adopt their automation system to these products?
- What happens if their products change, is the automation flexible?
- Number of employees in total and at the warehouse?
- How many storage places do you have in your average warehouse?
- What turnover does [your Company …] has?

8.2 Appendix 2 – Most important results of company interviews

In this chapter, the most important findings of the company interviews are presented. The structure is divided into general aspects, findings about the movement of goods and statements about the tracking of goods stated by the respondent.

For completeness reasons, it has to be mentioned that these are only the most important aspects, from the subjective perspective of the authors, of the interviews. Therefore, this list does not contain all statements of the interviews. On request, a full transcription of each interview can be submitted.

8.2.1 Company 1 – Supplier in automotive industry

- General aspects
    - the warehouses are mainly running manually; there are only two warehouses, which are highly automated
    - all systems in the company's group are maintained from external suppliers, which means that their employees can repair minor things on their own, but a competent and fast service hotline is needed and provided
- The movement of goods
    - Used technologies: Automated Conveyor systems
        - responsible for the movement and the storage of products
        - the Automated conveyor systems are located at the ceiling of the warehouses and are connected to the WMS
        - one of the reasons why Automated conveyor systems were chosen is that Company 1 wanted to use the height of their warehouses
        - the Automated conveyor system interacts with the shop floor system to communicate, which item has to be transported and stored or retrieved
        - beside of the huge investment in this technology, it was also challenging to organize the implementation and integration of the Automated conveyor system in their system landscape
        - a modern system landscape, including easily reachable IT connection points for external systems, is necessary for a smooth running and an easy maintenance of the system
        - beside of the Automated conveyor system, goods are transported from A to B manually
        - Company 1 used in the past in one of their sites AGVs for the usage of Goods-to-person, but it was tested and the result was that the saved time and the reduced errors were

too low to justify the huge investment. So there were too high investment costs and maintenance effort and as well a lack of enough efficiency increase

- Additional notes regarding the movement of goods
    - Automated forklifts and AGVs in general are not used caused by the high investment costs
    - the size of the warehouses (between 1.000 and 6.000 storage places) is not so big that it would justify the huge investment and immense planning effort in technologies like AGVs or Automated forklifts
    - as an alternative to AGVs and Automated forklifts, a smart warehouse design can increase the efficiency in the transportation as well, without investing so much

- The tracking of goods
    - Used technologies: Barcodes and QR-Codes, test RFID
        - Company 1 uses both types of codes, Barcodes and QR-Codes
        - Barcodes represent a 6-digits number, which is needed for the transportation of goods
        - QR-Codes additionally contain two other numbers, which are needed for the inbound, the picking and the production
        - Barcodes and QR-Codes are still the most efficient and cheapest way of tracking goods
        - the scanning of QR-Codes takes a little bit longer than the scanning of Barcodes, but as company 1 scans not so much items, this is only a minor aspect
        - most of the scanning is done manually with mobile devices, so there are nearly no visibility issues. Only for the Automated conveyor systems human involvement is needed to ensure the visibility of the label
        - caused by the short time of the product in the warehouse, there are nearly no damage problems of the label. But in case, the usage of QR-Codes, which are very resistant caused by their huge storage capacity, reduces the risk of a total damage of the label
    - Additional notes regarding the tracking of goods
        - in some areas of the warehouse RF is used
        - Company 1 tests for every new project, if the use of RFID would generate added-value in relation to the investment

costs. Until now they are not using RFID for their normal product categories

        - no consistent Wi-Fi supply through the whole warehouse, which decreases the scanning reliability and speed of the scanning for Barcode scanning (at non fixed stations, for the mobile devices) and RF scanning
        - It also appears regarding RF, that the staff is switching antennas a lot, when they move in the warehouse. This causes sometimes connection errors and system crashes
        - Company 1 only uses RFID, when customers require these tags for their inbound process. For the internal processes, Company 1 does not use RFID, even though tests are permanently done to check if the added-value would justify the investment
        - the saved scanning time and reduced scanning errors still do not bring enough added-value to justify the investment

(Company 1, 2018)

8.2.2 Company 2 – Distributor of office material

- General aspects
    - the warehouse is almost entirely run with an Automated conveyor system
- Movement of goods
    - Used technologies: Automated conveyor systems
        - responsible for the movement and the storage of products
        - the Automated conveyor systems are located all over the warehouse on both the ground and ceiling
        - is connected to the WMS
        - the reason for implementing an Automated conveyor system was to gain efficiency.
        - merged several warehouses together and use only this one instead of the previous 7
        - when incoming goods are put into the system it is done manually
        - the goods are transported to specific storage places
    - Additional notes regarding the movement of goods
        - Automated forklifts, AGVs and/or an bigger warehouse was considered but did not qualify as efficient and cost effective

        - did business cases to calculate possible solutions and what the benefits and disadvantages with each system
        - thought much about their products. Since they've had the same products for a long time they thought it will stay the same in the future
        - For heavier and bulky items manual transportation with forklifts are used
- Tracking of goods
    - Used technologies: Barcodes
        - Company 2 uses Barcodes, they both create own Barcodes for incoming goods that does not already existing ones
        - scanning of incoming goods is done manually
        - scanning of products in the Automated conveyor system is done automatically
        - scanning of goods in the picking area is done automatically and confirmed by the picker
        - considered both RFID and QR-Codes before implementing the Automated conveyor system but did not see why this would be more useful for them. "It's enough storage space on the Barcodes"
        - do not see any challenges with damaged Barcodes or labels
        - do not have any visibility issues due to the manual scanning by pickers and that packages travel with the "same side up" in the Automated conveyor system

(Company 2, 2018)

8.2.3 **Company 3 – Online retailer for clothing and sport articles**

- General aspects
    - the warehouses are running mainly manually but 50% use AGVs in a closed box system.
    - Next year they hope that 95% is automated
- The movement of goods
    - Used technologies: Autonomous guided vehicles
        - responsible for the movement and the storage of products
        - a box system with room for 60.000 boxes store products
        - AGVs replenish the boxes with incoming goods
        - AGVs collect boxes and brings to picking stations

        - had many problems with implementation due to longer implementation time than expected and effectivity issues
        - built a completely new warehouse instead of their existing fully manually one
        - still have almost 50% of goods moved manually
        - expect the AGV system to increase and within a year be capable of handling 95% of the goods
        - 5% of their items are too big to handle with the AGV system and needs to be handled manually even in the future
    - Additional notes regarding the movement of goods
        - Compared to other solutions like Automated conveyor systems, Automated forklifts and other AGV systems but calculated this one to be the best solution
        - Increased automation to gain higher efficiency
        - This automation solution was the best fit because of standardized products, packages and small deliveries
        - Would not fit good for bigger units
- The tracking of goods
    - Used technologies: Barcodes
        - all of their products have Barcodes from the beginning
        - incoming goods is scanned manually
        - products in the boxes have their own Barcode and the box have a Barcode
        - the boxes are scanned automatically within the AGV system
        - picker does not scan anything, just confirm the pick with a button
        - considered RFID and QR-Codes but could not find any meaning with replacing Barcodes and use these methods instead
        - do not see any problems with reading time or damaged labels
        - no visibility issues in the AGV system due to that the box travels with the same side up always
        - no visibility issues with the incoming goods since it’s counted, sorted and repacked anyway

    - Addition notes regarding the tracking of goods
        - used Barcodes in the old warehouse as well
        - think that the Barcodes serves their purpose of tracking goods in their system really well but still considered RFID and QR-Codes
        - compared to other similar types of warehouses and found out before implementation that they also use Barcodes

(Company 3, 2018)

8.2.4 Company 4 – Logistics service provider

- General aspects
    - main parts of the warehouses are manually run
    - as a high-technology system, this company uses the Aviator system from the company Westfalia (see Westfaliausa, n.d.), which is a corridor free crane system responsible for the storage and retrieval of products in the high-bay warehouse
- The movement of goods
    - Used technologies: Automated conveyor systems
        - the Automated conveyor system works in the loading and unloading process of the companies warehouses mainly in the context of a Milk run (truck carousels) with customers
        - the Automated conveyor system is able to unload a truck within 5 minutes and to transport the goods into the warehouse or the other way round
        - this system increases the efficiency enormously caused by the need of less trucks for the transport volume
        - the construction of the system was extremely challenging, especially when the system is integrated subsequently
        - by the integration of the system in an existing warehouse, the running business was limited, so parts of the warehouse had to be closed
        - the implementation of the system caused extreme costs
        - to implement that system, a huge organizational and planning effort was done (see e.g. the synchronization between the customer and the company for the system)
        - there are nearly no maintenance and repair problems caused by the maturity of the system, which means that errors are well known

        - challenging for the usage of the system is the safety and security aspect, caused by the power of the system at work
    - Additional notes regarding the movement of goods
        - the Aviator system can be also seen as a goods-transportation system, which is attached to the top of the shelves and moves on tracks, including a lifting device connected with steel cables
        - manually access to the shelves is still possible caused by a safety shut-off mechanism
        - challenging for this system was the subsequent integration in an existing warehouse
        - the IT integration and especially the IT interface integration in the existing system landscape was challenging (WMS)
        - it has to be taken into account that the connection of the system to other systems has to be well done, to avoid the decrease of efficiency when the system is implemented
        - challenging is the maintenance of these system, as it is elaborating and costly caused by the rarity of them
        - the most important aspect is the decrease of flexibility of the way the company can work, but this count for all kind of technologies.
        - the company is considering to use AGVs, but caused by the huge investment did not implement them yet
        - challenging for the implementation of systems, like AGVs, is the IT integration and the standardization of business processes
        - to operate in so called mixed operations is currently challenging, without decreasing the efficiency of these vehicles caused by permanent safety stops
        - challenging right now are the considerations of the implementation of these devices in an existing warehouse
- The tracking of goods
    - Used technologies: Barcodes and QR-Codes, rarely RFID tags
        - Barcodes are used for our internal processes and QR-Codes are mainly required from the customers
        - today, there are nearly no differences in the scanning time of QR-Codes and Barcodes anymore
        - Barcodes are challenging because of their limited storage space

  - for the purpose of the company Barcodes totally fit, because in case that company attaches another Barcode with other information on the product
  - for the use of all kind of tracking technologies, the IT interchange with the customer is important and challenging, because without the data exchange, the usage of Barcodes is useless
  - the scanning process is mainly done manually, but for the Automated conveyor systems human involvement is still needed to ensure the visibility of the labels
  - caused by the highly vulnerable Barcodes, damages have a big effect on the Barcodes and therefore it happens that goods are standing in the companies inbound area as errors
- Additional notes regarding the movement of goods
  - the investment in the RFID technology is huge in comparison to the added-value
  - especially in the companies industry it makes nearly no sense to use RFID tags on products, because of the quick leave of the products the value of the tags would be lost
  - for the internal processes, this company only uses RFID for the tracking of their own swap bodies
  - a big challenge with that is the reliability and accuracy of the tags, which has currently a failure rate of 2%
  - this is causes by interferences with the tags environment and by the interferences of the antennas as a part of illegibility

(Company 4, 2018)

8.2.5 **Company 5 – Logistics service provider**

- General aspects
  - The warehouse is still working entirely manually
- The movement of goods
  - Used technologies: None at the moment
    - have decided to use implement an autostore system with AGVs
    - have not decided about the size of the box system
    - are aware that some of their products won’t fit in the boxes
    - AGVs will collect boxes and bring it to picking stations
    - picking will still be done manually

        - will still partly us manual warehouse because all products won't fit in the boxes
        - focused on learning from others that have implemented the same system
    - Additional notes regarding the movement of goods
        - did not want to change the warehouse landscape with other more demanding systems
        - have around 13.000 pallet places in the warehouse
        - discussions about pros and cons with several different automation systems was done
- The tracking of goods
    - Used technologies: Barcodes
        - the Barcodes are scanned manually by employees
        - when implementing the autostore system incoming goods will be scanned manually, automatically in the AGV system and manually in the picking and outgoing of goods
        - does not feel that there is a lack of storage capacity on the Barcodes
        - have had troubles with reading due to visibility, damages and printing
        - consider Barcodes as the most appropriate solution for their business
        - was looking in on RFID but ignored because the huge investment and lack of added value
        - do not see a need for RFID tags in the new system
        - 5% of the products arriving to the warehouse today does not have any Barcode and is marked with one at the warehouse
        - have had problems with damaged Barcodes and scanners that stopped working
    - Additional notes regarding the tracking of goods
        - Company 5 does not see RFID in a near future
        - look on what others used with the same automation systems in other warehouses and they still use Barcodes
        - say that the storage capacity may not be enough in the future if something changes and it needs to be investigated more with the new automation system

(Company 5, 2018)

8.2.6 **Company 6 – Manufacturer for electronic parts**

- General aspects
    - as technical solutions for automation, that company uses radiography machines for scanning items and 3D-printing
    - the company is tenant in an industry park, which means that also other companies use the same location and corridors as this company does
- The movement of goods
    - Used technologies: AGVs, planned to implement Automated forklifts
        - AGVs are used in the warehouse for the transportation of smaller boxes for internal express shipping
        - that company plans to implement Automated forklifts for the transportation of pallets in the Inbound area from August on
        - caused by the extreme costs of this technology, Company 6 is still looking for areas of application of that technology to decrease the amortization time
        - AGVs have an implemented map of the location in their systems and have a Wi-Fi connection to locate themselves, but there are still orientation problems
        - the AGVs have flexibility problems, which means that they struggle a lot with changing conditions in the warehouse
        - the implementation time of that technology is much more longer than expected caused by the location problems of the vehicles
        - that company stated that the more infrastructural flexibility is needed, the more challenging is the implementation and maintenance of the system
        - as they stated, a minor challenge will be in the future the usage of too many automated vehicles in a specific area, like the usage of Automated forklifts in the main corridor
        - a big challenge is, how the vehicles will act in the case of a fire alarm, which means, when two vehicles meet each other exactly at the time of a fire alarm in the a corridor, how they will react or if they just block the corridor
        - caused by the usage of two different types of codes (Barcodes, QR-Codes) it is challenging to ensure that the

vehicles (AGVs and Automated forklifts) are able to read both types of code

- Additional notes regarding the movement of goods
  - with the usage of Automated conveyor systems and their requirements, is challenging for that company to make any building changes caused by the reason that they need the approval of the park owner
  - caused by the huge amount of existing systems, such an implementation of a new system is really challenging with regards to the IT integration

- The tracking of goods
  - Used technologies: Barcodes, QR-Codes and in some parts RFID tags
    - this company switches right now from Barcodes to QR-Codes caused by the limited storage space on the Barcodes
    - this company does not have so many problems with illegibility, even though its challenging for them to keep a good quality of the label, caused by the high quality of their printers
    - they had huge investment costs in the printers to ensure a good quality of the labels
    - caused by the automatically scanning of the labels by the AGVs, human involvement is still needed to ensure that the label is always at the same position and is readable for the vehicles
  - Additional notes regarding the tracking of goods
    - caused by the huge amount of items in the warehouse (around 55.000) the switching process from Barcodes to QR-Codes takes a while
    - the company planned to implement RFID for all of their products to be able to track them live
    - caused by the huge investment, especially in the reading technology at the gates, they decided not to use for their main parts of the products
    - RFID is currently only used at one production island, which is manufacturing a high runner product
    - RFID technology is used there to ensure that this island is not running out of stock

   - the illegibility of the tags was challenging in the past caused by interferences of the antennas, the tags or their surrounding
   - the privacy aspect of RFID tags is a challenge for the company caused by the presence of a competitor in the same industry park

(Company 6, 2018)

8.2.7 **Company 7 – Retailer within food and beverages**

- General aspects
  - the warehouses are almost entirely automated; only a small part is still manually
- The movement of goods
  - Used technologies: Automated conveyor systems, AGVs and Automated forklifts
    - the Automated conveyor systems are responsible for the movement in and out from the warehouse to the trucks
    - the AGVs brings pallets to and from the Automated conveyor system
    - the Automated forklifts (or cranes) stacks pallets on top of each other and bring them down to the AGVs when delivered
    - the Automated forklifts interact with the shop floor system to communicate, which item has to be transported down and later delivered
    - the AGVs interact with the Automated forklifts but also the incoming trucks to be able to deliver pallets to the Automated conveyor system
    - the Automated conveyor system brings pallets directly to an open truck where the driver uses a forklift to load the truck
    - the warehouse was before building a new one completely manually
    - the reason for automation was the standardized goods in big volumes and the need of higher efficiency
    - the warehouse is running in a cold chain where the temperature is below 20 degrees Celsius all the time
  - Additional notes regarding the movement of goods
    - are renting the warehouse by a 3PL company that delivered this solution

        - the size of the warehouse that can be used is around 80 000 pallet places
        - the automation solution is a combination of several but discussions about what was the best fit for each part was done
- The tracking of goods
    - Used technologies: Barcodes
        - the Barcodes are scanned automatically by readers
        - had Barcodes in the old warehouse
        - does not feel that there is a lack of storage capacity on the Barcodes
        - have had troubles with reading due to visibility, damages and printing
        - consider Barcodes as the most appropriate solution for their business
        - considered RFID but ignored because the huge investment and lack of added value
        - no customers (resellers) have the need for RFID tags
        - had raw material in the warehouse before and then had troubles with damaged Barcodes due to moist
        - pallets that does not go through the automatic scanning for incoming goods needs a new Barcode put on manually
    - Additional notes regarding the tracking of goods
        - Company 7 does not see RFID in a near future
        - have urged suppliers to change their printing technique to enable better reading in their warehouse
        - placement of the Barcode is really important on the pallets

(Company 7, 2018)

8.2.8 Company 8 – Manufacturer of professional office chairs

- General aspects
    - this company has an automated high-bay warehouse, where the products are transported on request via cable railway, which operates like an Automated conveyor system
    - an AS/RS system is used, which operates in the different corridors of the warehouse
- The movement of goods

- Used technologies: AGVs and also cable railway, working as an Automated conveyor system
  - this company uses two AGVs in the production process caused by the specific requirements
  - there are two sectors in the production, one for the first step in the final production and the other sector for the second step
  - the sectors consist of different working stations, which are specified on different kind of chairs
  - the induction-loop free AGVs transport on a distance of around 30-40 meters the half-finished chair to the right working station in the second sector
  - before a lot of repetitive carrying had to be done and that company wanted to relieve their staff of the carrying task
  - as a part of the Technology 4.0 initiative, it was the first step in the human/machine collaboration in that company
  - by the implementation of the AGVs, the communication among them and with our system landscape was challenging
  - they have to operate in a specific area, which has a bottleneck. So there was a big challenge, when the AGVs meet at this bottleneck caused by overlapping scanning areas
  - during the solving process of the bottleneck problem, the company changed the scanning area of the AGVs, so that they do not stop anymore, when they scan each other. This was challenging again, because the change of the scanning area of the AGVs is also a safety problem for the interaction between human and machine
  - there also have been huge investment costs, which were part supported by the government
  - there are still huge costs for the adaptation of the programming of the AGVs
- Additional notes regarding the movement of goods
  - caused by the long distance between the warehouse and the production building marked-out routes are used, which also cross a public street
  - the transportation system uses baskets, where the products are put inside

            - the technological interface of the systems was challenging for the transportation system, also caused by the age (20 years old)
            - except of a few age caused repairs, the system is working perfectly. Also caused by the age, the maintenance of the system is very elaborating

- The tracking of goods
    - Used technologies: Barcodes, for the internal processes also RFID
        - in the inbound process, on every product a Barcode is attached
        - this product will be "married" (wording of Company 8) with its Barcode to one of the baskets, therefore scanning of that Barcode is only needed once at the marriage
        - caused by the one-time scanning of the new generated Barcode, there are no damages or illegibility challenges
        - but it is still human involvement needed to ensure that the Barcode can be read
        - the storage space of Barcodes is enough for the company
    - Additional notes regarding the tracking of goods
        - RFID tags are used for the tracking of the internal used basket in the transportation system
        - based on the usage of the baskets, which only move in line, there is no illegibility problem with the reading of the tags caused by e.g. overlapping of tags or antennas
        - the only minor challenge, which had to be overcome in the past, was the technical integration of the RFID technology in the system landscape of the company

(Company 8, Part 1, 2018; Company 8, Part 2, 2018)

8.2.9 **Company 9 – Product wholesaler**

- General aspects
    - the warehouse is only partly automated where only transportation, storing and sorting in some ways are automated
- The movement of goods
    - Used technologies: Automated Conveyor systems
        - the Automated conveyor systems are responsible for the movement and storage of goods
        - uses Automated conveyor systems to transport and store goods

- wanted a goods-to-people solution to gain efficiency and reduce time waste
- the incoming goods are manually scanned and put on the Automated conveyor system that brings it to small bins
- when the goods is needed the Automated conveyor system brings it to a picker that picks the goods and puts it into boxes
- the boxes is sorted with the Automated conveyor system and divided into plastic pallets

  - Additional notes regarding the movement of goods
    - have 90.000 different articles at their warehouse, many of them is too bulky to use on the Automatic conveyor system and is still handled manually
    - the size of the warehouse is 235.000 [m^2]

- The tracking of goods
  - Used technologies: Barcodes, QR-Codes and RFID technology
    - incoming goods is scanned manually
    - goods on the Automated conveyor system is scanned automatically
    - Barcodes are used for all their products, they print Barcodes for all their delivery boxes
    - QR-Codes is used on all customer orders to enrich the customer offering by getting the bill of shipping when scanning it
    - RFID technology is used on the plastic pallets that gets delivered by truck to different repackaging stations
    - RFID technology was implemented to lower the failed delivery rate, which it did
    - have experienced different challenges like damaged labels and bad printing
  - Additional notes regarding the tracking of goods
    - Company 9 does not feel any pressure from customers to implement RFID on their packages
    - can see a possibility to change from Barcodes to QR-Codes if more customers request it

(Company 9, 2018)

8.3 Appendix 3 – Scoring-lists of challenges

Note: In case of an equal score, a subjective chronological order is defined for the equal challenges. The first number in each cell represents the reached amount of points and the second number the relative position within the technology.

8.3.1 **Challenges for the movement of goods – unsorted**

Challenges	AGVs	Automated forklifts	Automated conveyor system
Implementation costs	Points:18; Place within technology: 1	16; 1	18: 1
Physical integration in the warehouse	9; 3	10; 2	11; 2
Added-value in comparison to the investment	8; 5	7; 5	3; 8
Investment justification in relation to the size of the warehouse	4; 8	4; 6	3; 9
Integration complexity - planning and organization	5; 7	2; 9	6; 4
IT integration in the system landscape	11; 2	9; 3	8; 3
Flexibility in the future	4; 9	1; 11	4; 7
Flexibility in operations	6; 6	4; 7	5; 5
Safety issues in mixed operation	3; 12	2; 10	2; 10
Implementation time	4; 10	-	1; 11
Efficiency issues	9; 4	8; 4	5; 6
Running costs	4; 11	3; 8	-
Number of automated units used within a specific area	3; 13	1; 12	-

Communication among the devices	1; 14	-	-
Orientation at the company site	1; 15	1; 13	-

Figure 50. Scoring-list for the movement of goods

8.3.2 Challenges for the tracking of goods – unsorted

Challenges	Barcodes	QR-Codes	RFID technology
Implementation costs	3; 5	-	10; 2
Switching cost for technology	7; 1	7; 2	-
Generation of added-value in comparison to the investment	-	-	15; 1
Added-value in comparison to other technologies	-	8; 1	-
Limited storage capacity	3; 6	-	-
Visibility problems	4; 4	2; 3	-
Vulnerable for damages	7; 2	-	-
Illegibility	5; 3	1; 6	3; 3
Wi-Fi connection for mobile devices	3; 7	2; 4	2; 5
IT integration in the existing systems	2; 9	-	3; 4
Human involvement needed for the scanning	3; 8	2; 5	-
Requirement of live-tracking	2; 10	1; 7	-
Privacy and security	-	-	1; 6

Figure 51. Scoring-list for the tracking of goods